Progress In Electromagnetics Research B, Vol. 97, 91–114, 2022

A Review on Materials and Reconfigurable Antenna Techniques for Wireless Communications: 5G and IoT Applications

Rayirathil K. Athira Mohan and Kanagasabapathi G. Padmasine*

Abstract—Compact wireless devices have been proposed as a result of the introduction of wireless communication systems, allowing more space to be used for other electronic components. A reconfigurable antenna is critical in today's cutting-edge wireless technologies. Reconfigurable antennas can perform a variety of tasks depending on their operating frequency, radiation pattern, and polarization. Dynamic tuning can be done by altering mechanical, electrical, physical, or optical switches to run a certain switching mechanism. This can be accomplished using a single reconfigurable antenna that allows the user to customize a range of performance attributes such as resonant frequency, polarization, and radiation pattern to meet their specific requirements. This paper looks into different types of reconfigurable antenna switching mechanisms, different types of effective implementation techniques, different types of reconfigurable antennas, and some recently proposed reconfigurable antenna designs for the Fifth Generation (5G) and IoT applications in various wireless communication systems.

1. INTRODUCTION

Antennas are an integral feature of every wireless communication system (regardless of whether they are at the transmitting or receiving end). They are used to generate (transmit) or acquire signals in the form of electromagnetic (EM) waves and have time invariant characteristics [1]. Antenna engineers have developed multiple kinds of antennas for a variety of diverse applications, including short/long-range communication, sensing, imaging, navigation, mobile devices, biomedical applications, etc., as the wireless communication industry has advanced and established over the last few decades. Various types of antennas, such as monopole antennas or dipole antennas, log periodic, patching, horns, reflectors, lenses or dielectric, and waveguide-based antennas, have been investigated here [2] depending on their design, basis of analysis, and feeding mechanism. Although each of these antenna groups has its own set of benefits and drawbacks, these characteristics aid in determining their suitability for various applications.

In today's culture, a wide range of wireless connectivity is becoming increasingly relying on and supported by life activities. Fixed frequency, radiation, and polarization characterize the majority of antennas used in today's communication systems or wireless platforms. Combining multiple Fixed Performance Antennas (FPAs) in a particular device to support numerous communication protocols, on the other hand, could result in a plethora of issues, including increased system size, control complexity, and efficiency loss, to mention a few. On the one hand, providing a diverse set of services promotes productivity and communication; on the other hand, incorporating multiple FPAs with varying features and guaranteeing sufficient isolation between them (for expected performance levels) becomes a major undertaking. Furthermore, due to a lack of variation and selectivity in signal reception, static working antennas are prone to interference. Because of their fixed attributes, fixed performance antennas

Received 20 September 2022, Accepted 19 October 2022, Scheduled 12 November 2022
* Corresponding author: Kanagasabapathi Girirajan Padmasine (padmasine@buc.edu.in).
The authors are with the Department of Electronics and Instrumentation, Bharathiar University, Coimbatore, Tamil Nadu, India.

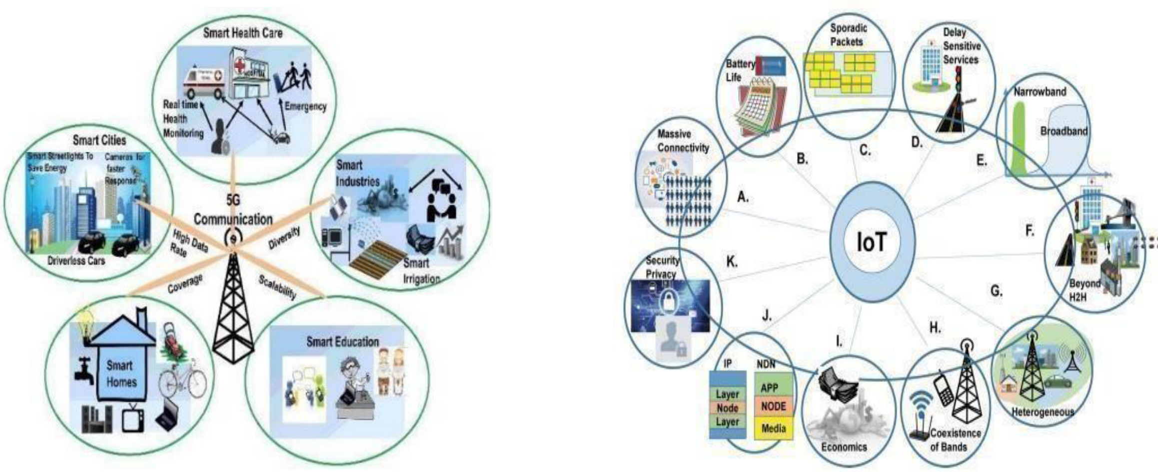
limit the overall results of the trans-receiver system. Multifunctional and intelligent antennas that can adapt to changing system needs and modify their features accordingly are required by modern electrical and wireless communication technologies [3]. In addition, offering additional services without expanding the number of parts, system complexity, or circuit size of the device is becoming increasingly difficult due to rapid changes in the perception of wireless-based services in many industries. Future communication trends will redefine connection and bring new technologies in order to handle enormous data needs, high-speed connectivity, unified communications, and data services. It is critical to create and produce antennas that are both flexible and controlled, given the demands of today's and tomorrow's wireless systems. Due to their dynamic ability to adapt to changing conditions, antennas with reconfigurable properties become an effective and practical alternative [4]. They can help to overcome the limitations imposed by a multitude of single-function or fixed-function antennas, as well as provide functionality and efficiency to the system. Individual feeding to distinctive characteristics, partial or full physical movements, reconfigurable feeding networks and impedance matching circuits, and many other facets of antenna reconfigurability were all evaluated in various ways as the design process advanced. Mechanical movements, external feeding/matching circuits, and other controlling systems all affect antenna performance, and antenna compactness decreases as a result. The antennas can be rearranged as well. To work correctly, controllable microwave circuits must be appropriately integrated and matched. In this scenario, the most useful and realistic choice is a self-configurable antenna that is not reliant on any external or complicated feed systems. It has a wide range of applications as a single or array member, and it is not reliant on the feeding network. When the antenna is complex-structured and requires a high number of components of control circuitry, the goal of consistent reconfigurability is impeded. The effectiveness of the reconfigurable features is reduced as the antenna size and profile are increased. As a result, recent research has focused on coming up with new ideas and design approaches for multi-functional, high-performance reconfigurable antennas. When design complexity is decreased, system integrity is increased; antenna operation control is simplified; and losses are reduced. This review includes the development of a variety of innovative, simple-to-control, compressed, and low-profile reconfigurable antennas (for single and multiple reconfigurable operations) with simpler reconfiguration methods and consistent reconfigurable performances in order to achieve these goals [5].

1.1. Outline of the Reconfigurable Antenna Systems

A "Reconfigurable Antenna" is one that may alter its performance characteristics by physically or electronically adjusting its structure, according to the IEEE Standard Definitions of Antenna Terms released in 2014. The antenna's basic working mechanism frequently combines with the reconfiguration technique, which alters the antenna's surface current or electric field distribution to provide changeable output characteristics [6]. As a result, antenna configurations that have external reconfiguration circuits and/or feeding/matching networks but no internal reconfiguration mechanism are not termed reconfigurable antennas. External phase shifters, for example, influence a phased array antenna's performance from the outside, but they have no effect on the antenna's core operation.

1.2. Introduction

For many years, there existed a rich and varied history of reconfigurable antenna upgrade and design. Changes in the radiation properties and/or antenna impedance are caused by the electromagnetic fields of the antenna aperture, allowing for antenna reconfiguration. A lot of factors contribute to these changes. The reconfiguration excludes any extra device or component that does not interact directly with the radiating mechanism. As a result, in exchange for increased complexity, this antenna provides a performance trade-off. Antennas that may be reconfigured exist in a variety of shapes and sizes. The operation can be carried out utilizing current design concepts by using well-defined antennas as the basic design for the desired activity. Based on their characteristics, reconfigurable antennas can be categorized into three groups. These are (a) The reconfigurable antenna features, (b) The reconfiguration proximity, and (c) The reconfiguration continuity. Reconfigurable antennas are usually classified into first of these categories, which comprises programmable radiation and impedance. A reconfigurable antenna can be used for a number of different applications. In reaction to changes in system variables, this is used to vary the radiation pattern, polarization, or frequency. Additional patterns on various polarizations and frequencies, which are required in current communication systems, may be emitted by this device. All of these demands, combined with the need to improve functionality while maintaining a small footprint, put a greater strain on today's technology. As a result, reconfigurable antennas can solve all of these problems. There is a slew of advantages in using reconfigurable antennas. Although reconfigurable antennas may be a viable solution for future wireless and space applications, increasing tenability to an antenna's performance in a specific system comes at a price. There are four primary types of reconfiguration processes that are typically used to configure an antenna. These can produce additional patterns with varying frequencies, which can be used to address a number of problems. This generation of telecommunications networks, referred as 5G, is in high demand by the end of 2021 and will continue to grow globally. Communication technology has been improved in recent years, allowing more on-demand services to be delivered to the general public. The need for several wireless services on a single handheld device has grown in tandem with the internet of things, leading to an increase in the maximum number of linked devices. The new 5G radio access networks are expected to enable a large number of concurrent connections because they cover a wide range of frequencies. In order to promote 5G services, the Federal Communications Commission (FCC) separated the major spectrum into low bandwidth (600, 800, and 900 MHz bands), medium bandwidth (2.4, 3.5, and 3.7–4.2 GHz bands), and high frequency Millimeter-Wave bands (28, 38, and 60 GHz). The goal of 5G is to build a massive Internet of Things (IoT) substructure that can handle billions of linked devices while retaining critical speed, latency, and cost parameters [7] (Figure 1). The 5G mobile communication system will have a huge impact on digital technology since it will carry data via millimeter waves, which will be speedier, easier to manage, and more efficient than present communication methods [8]. The collective use of mobile data is expected to witness a huge increase in data traffic in the coming years as a result of a connected world full of smart devices.



(a) (b)

Figure 1. (a) View of 5G beam forming environment. (b) Different requirement for arrangement of IoT.

Global mobile data traffic grew 71 percent in 2014 and is expected to expand at a compound annual growth rate of 77 percent till 2022. As a result, mobile communication systems in the fifth generation (5G) are expected to have a high data rate of 10 Gb/s. In addition, the Internet of Things (IoT), the next major advancement in wireless communication, is already beginning. The IoT is a network that connects a variety of devices to a wireless network, such as RFID tags, cell phones, and other devices. Each device is uniquely identifiable and capable of communicating with other devices. Without the need for human intervention, these technologies can communicate and collaborate to execute tasks. As a result, network and data traffic have grown in importance, with human traffic making up a modest fraction of overall traffic. The millimeter is a measuring unit. With wavelengths ranging from 1 to 10 mm, the 30 to 300 GHz (GHz) wave spectrum has a vast theoretical bandwidth, enabling larger data rates and throughput [9]. Sophisticated frequencies are expected to help 5G and IoT devices with a range of channel features, including various features and applications. As a result, 5G improves our ability to communicate and anticipate problems. To connect to numerous networks, modern radios must communicate with a number of radio systems, necessitating the usage of multiple single-band or multi-band antennas. To allow diverse communication protocols, numerous antennas with fixed characteristics are now connected into one device. Each protocol might have its own radio and antenna, taking up a lot of space in a compact device. Variable antennas and similar devices are advantageous in this circumstance because a single antenna can replace multiple single-function antennas while also serving a range of needs. It is often utilized in multi-channel communication systems to replace traditional broadband antennas, which typically use broadband antennas that span all frequency bands. As a result, utilizing a tunable antenna is a viable option and practical solution, as it considerably reduces the system size while also allowing for portability and downsizing [10]. This is a prerequisite for any wireless application. This article focuses on reconfigurable antennas for 5G and IoT applications, as well as some of the unique designs, latest developments, and future prospects.

2. DIFFERENT RECONFIGURATION TECHNIQUES

For the competent switching of reconfigurable antennas, many active application approaches are used. Various real application strategies have been presented to be employed in different wireless systems to identify the reconfigurable antennas, and some of them are Satellite, Multiple Input Multiple Output (MIMO), Biomedical and Cognitive radio communications, which are classified as follows:

- Changes to the electrical system.
- Reconfiguration of the optical system.
- Reconfiguration of mechanical systems.
- Tunable Materials for Switching.

Electrical reconfiguration is one of the most prevalent techniques. Varactors, PIN diodes, Photodiodes, and Radio Frequency Microelectromechanical Systems (RF-MEMS) switches are among the active elements that this approach deals with. PIN diodes provide enough performance at a moderate cost. Another method, optical reconfiguration, is based on photoconductive materials. Changing the elements, Mechanical Reconfiguration refers to reconfigurable antennas that are triggered by changing the antenna arrangement and controlled mechanically. Aside from these methods, smart adjustable materials in the antenna configuration can be used to reconfigure an antenna. By disrupting current distribution or modifying current flow, switching circuits have been proposed to create a reconfigurable antenna. It explains how to modify an RF setup's electrical and radiation settings [11]. The following are a few examples of various types of reconfigurable antennas and their uses.

2.1. Electrical Reconfiguration

In this type of reconfiguration strategy, PIN diodes, varactor diodes, and RF-MEMS are used in electrically reconfigurable antennas for surface current redistributions by adjusting the antenna radiating structures or radiating edges in terms of frequency, polarization, and radiation pattern. Both discrete and continuous tuning approaches are used in the electrical system. The implementation is straight forward and takes various things into account in the subject of research. These antenna components require a DC source and biasing circuit to function properly. As a result, this antenna is powered by a DC electrical source and employs electronic switching components that decrease the process and performance of the antenna.

2.2. Optical Reconfiguration

In the design of reconfigurable antennas, photonic vision has been used as a switching mechanism. In the optical reconfiguration process, photoconductive switches made of semi-conductive material are widely used. Photoelectric switches are utilized instead of electric switches in optical reconfiguration because they provide less interference, better isolation, and faster switching speeds. This allows optical control of antenna operational bandwidths and radiation patterns. The capacity of electrons to shift from the valence to the conduction band when they are ignited by a certain wavelength of light is the basis for the creation of a visual control switch. In other words, the optical switch is triggered when a laser diode emits the light of a specified wavelength.

The main advantage of optically driven switches is that they do not require a metallic biasing wire, which might interfere with radiation patterns. As shown above, the frequency reconfiguration was then validated using an optically controlled switch [12].

2.3. Mechanical Reconfiguration

To manually adjust any electromagnetic property, actuators or motors can be used instead of switches. Mechanical reconfiguration is a strategy in this industry. In this arrangement, the main radiator of the antenna can be mechanically changed to produce appropriate characteristics. Active elements and biasing structures must be added to the mix. Physical antenna adjustments are a novel approach to antenna reconfiguration compared to using a switching mechanism. The speed is slower than any switching component when using this alternate design, and yet it is adequate for most applications. This technology is significant since it does not require any switching mechanisms, biasing lines, or optical fiber/laser diode integration. On the other hand, the physical limitations of the equipment to be physically modified limit this technique. Using a physically controlled technique, the antenna in question operates as a frequency reconfigurable antenna. More power can be managed when the rotating motor requires a high voltage. The antenna's tuning speed is slow, and its reconfigurability is limited [13].

2.4. Switching Using Tunable Materials

A DC bias electric field determines the dielectric constant of tunable materials. Because of this property, ferroelectrics have a lot of potential. Although tenability is marginally diminished, this trait is subdued in the par electric phase due to loss concerns. Another possibility is to use material properties like graphene plasmonics and liquid crystals in the antenna design. By applying various voltage levels to specific materials, they can modify their chemical potential. When a DC bias voltage is supplied to a liquid crystal, it switches from perpendicular to parallel orientation, as shown in the diagram below. When perpendicular and parallel orientations are used, the dielectric characteristics of the BL038 liquid crystal fluctuate. As a result, changing the DC voltage modified the liquid crystals' permittivity, which may be used in a frequency tuning antenna. The disadvantage of these methods is that each patch requires a complex feeding network [14].

3. SWITCHING METHODS

Switching circuits were used to terminate or adjust the current distribution in terms of creating a reconfigurable antenna. It is also recognized as a way for manipulating the electrical and radioactive properties of an RF structure. Converting a reconfigurable structure to an RF source is difficult for electromechanical switches. Signal coupling can be caused via high-frequency mechanical contact gaps, which can be used to make capacitors. While keeping a significant distance from the capacitor can assist prevent capacitor development, it also increases the capacitor's size. Some RF equipment tasks, notably in the gigahertz range, necessitate the use of a switching mechanism. A semiconductor RF switch is an integrated circuit that overcomes or attenuates certain frequency bands in either an on or off mode. During development, the most important factors are the design, underlying technology, layout, and performance to specification. Each switching technology has its own set of performance requirements, including bandwidth, insertion loss, isolation, switching speed, and power handling. The ideas given here can be used to control switching devices in a continuous or discrete way [15].

3.1. Varactor Diode

The varactor diode can fine-tune the antenna's resonance frequency due to its continuous range of capacitance values. This switch is a bi-static switch in general, which implies that it cannot switch constantly. Varactor has shown to be a useful tool for scanning with a null pattern and a continuous frequency. A varactor is a device with a changeable voltage and a low junction capacitance. The capacitance changes when the diode is given a varied bias voltage. When the voltage is increased, the capacitance of a varactor drops. On the other hand, varactor has a low linearity. This can be done with the reconfiguration antenna, a patch, or the feed line.

The capacitance of the varactor changes when the voltage levels of the varactor fluctuate, causing antenna performance to be modified. A bias voltage ranging from 0 to 30 volts constantly modifies the diode's capacitance, allowing for continuous tuning. The operating frequency of a varactor diode is inversely related to its capacitance, which is inversely proportional to the voltage applied. Fast frequency adjusting is possible with the diode varactor. The directional function of a varactor diode is superior to that of a PIN diode. To give the required reconfiguration power, a varactor diode with adjustable power CY is put in the microstrip line [16].

3.2. PIN Diode

In a variety of wireless systems, PIN diodes can be employed as switching components. It has the ability to manage a large amount of power at a minimal cost. Because it has a quick tuning speed, can withstand a lot of power, is highly appreciated, and is also relatively inexpensive, the PIN diode is an excellent choice for reconfiguration approaches. This is a discrete PIN diode with forward and reverse bias which allows RF energy to pass through a structure while blocking the flow. An inner layer is sandwiched between a positive and a negative type semiconductor layer in a PIN diode. By modifying the distribution of surface currents, the on or off mode operation of the given diode alters the structure of the radiation patch [17]. Another area where there is interest in technology is the design of more competent support circuits, which is essential to establish inaccessibility performance standards. Surface PIN diodes, also called SPIN diodes, are a form of PIN diode that is used in switching applications. The PIN diode switching element, which adjusts bias current and changes the effective length, enables the reversible antenna design. Most reconfigurable antenna research over the last decade has focused on the use of PIN diodes to create a patterns and frequency diversity. PIN diodes have been extensively employed in a variety of devices due to their higher response, low resistance at high frequencies, and low sensitivity to electrostatic discharge damage. A PIN diode has heavily doped p-type and n-type regions split by a wide, lightly doped intrinsic region. When a PIN diode is forward biased, it has a very low resistance at high frequencies, which is when the switch is ON, but when it is reversely biased, it has an open circuit or is turned off. The PIN diode has the advantage of being able to withstand large currents while using much less control power [18].

3.3. FET RF Switches

The maximum switching power of this SPST monolithic RF switch is +47 dBm or higher. The III-Nitride HFET achieves yet another high switching power. The FET switch is simple to utilize in reconfigurable antennas since it comes in an IC package. For the energy harvesting system, a programmable dual-layer ultra-wideband (UWB) antenna with a Gallium Arsenide (GaAs) Field Effect Transducer (FET) switch is shown. When a 5.6 GHz signal intrudes, the UWB antenna acquires bandwidth, and when the interferer is removed, it returns to normal UWB operation. In order to switch, the FET switch is only supplied by the recovered energy absorbed by the noisy signals. The front layer of the UWB antenna is a microstrip single pole with an elliptic slit. Within such a region, a linear quarter wavelength functions as a resonator, which can be linked and disengaged using a reduced power FET switch. The RF ground is shared with the UWB antenna via an exceptionally compact energy conversion system consisting of a twisted F planar antenna, a very compact voltage-doubled rectifier, and a passive DC-DC gain converter. Above the 3.3 V threshold, which is the minimum voltage required to activate the FET switch, the voltage is rectified by the step-up converter. When the power received at the rectifier's input is more than −12 dBm, the notch band of the UWB antenna can be dynamically changed without an external DC supply.

3.4. RF-MEMS

RF-MEMS are already available on the market and function well. An RF-MEMS switch is one of the most useful components in this field for reducing the number of RF systems among all MEMS components. Switching performance and features that need to be enhanced include acceptable RF performance, good reliability, low trigger voltage, short switching time, multiband topology, integration, and being packaged on chip. The antenna is reconfigured using a small electromechanical radio frequency device based on a four-pole monopole switch that passes through the slots of the radiation patch. This common RF switch creates a short or an open circuit in an RF transmission line using mechanical movement. Depending on the actuation mechanism, electrostatic, magnetostatic, piezoelectric, or thermal designs can be used to generate the forces required for mechanical movement. RF-MEMS components have been employed as switches to change the radiation pattern, polarization, and engage in multi-frequency applications. To explore the effectiveness and effects of real MEMS switches during operation, an operational multiple antenna frequency with pattern and polarizing diversity system featuring MEMS switches is given. Two of the most difficult aspects of MEMS switches are the contact station and the switch's problematic protective packaging [19] given in Figure 2. It is a photolithographic approach for electronic integrated circuits which is improved. It consists of two conducting strips linked at a small location, with the space between the two conducting layers forming a substantial capacitance. This switch can be created in a variety of ways. It is possible to use any form of production technology. Compared to PIN and FET switches, these switches offer low power consumption, good isolation, low insertion loss, and low cost, but they also have limited speed, poor power management, high driving voltage, poor reliability, and compactness. The following considerations influence whether or not an RF switch is suitable for a certain application: The frequency of operation for all RF switches is 50 or 75 MHz.

- Supply voltage fluctuations have an effect.
- Changes in the operating temperature have an effect.
- The frequency ranges of the switch's action.
- Protection against power fluctuations by handling power levels during on/off operation. The amount of time it takes the switching output to stabilize.

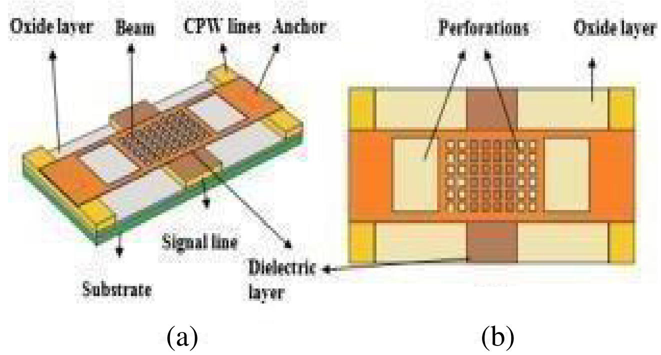


Figure 2. Suggested RF-MEMS.

3.5. Power Consumption and Drive

Switch power consumption and switch control management is basically a parametric research which is carried out to understand the impact of numerous structures on antenna performance, and the parameters are adjusted using the EM Simulator HFSS.

- The RF-MEMS switch has the widest frequency range. Because of their reduced power loss, they are also suited for low-power applications.
- Because the PIN diode compensates for ohmic loss, its gain is lowered, particularly at low frequencies.

- Because it is available in an IC package, the RF-FET switch is appropriate for low frequency applications and is simple to use.
- Hybrid switches combine the benefits of numerous independent switches in a single package.
- Varactor diodes have a quick frequency adjusting capability, allowing them to be used in applications with variable resonant frequencies.

4. WORKING PRINCIPLE OF RECONFIGURATION WITH SINGLE RECONFIGURE FEATURES

The antennas reconfigurability refers to its ability to change its operational properties by means of electrical, mechanical, electromechanical, or other techniques. It is a difficult task for the designer to achieve reconfigurability in desired features without interfering with other constraints. Reconfigurable antennas reduce complexity and power consumption by using a low-cost, energy-efficient antenna construction. The antenna can be reconfigured in a variety of ways, as shown below.

4.1. Frequency Reconfiguration

These types of antennas are designed to allow the resonance frequency of the antenna to be tailored to a certain frequency band. Depending on the switching circuit used, it can operate in a wide range of frequency bands with appropriate resonance frequencies. For different 5G applications, a novel selectively frequency reconfigurable antenna with proximity-coupling feeding is investigated in this work in Figure 3. It consists of multiple substrates connected by a thick air gap. Four PIN diode switches positioned on both substrates can modify the excitation of the given patch and the distance of feed-lines, resulting in two unique operational frequency bands. According to experiments, the constructed antenna can flip between two operating modes in different level bands. The radiation patterns and gain achieved in both states are identical, and the differential mode reflection coefficient modelling and measurement findings are very similar. The proposed antenna is well suited for different applications operating at frequencies below 6 GHz [20].

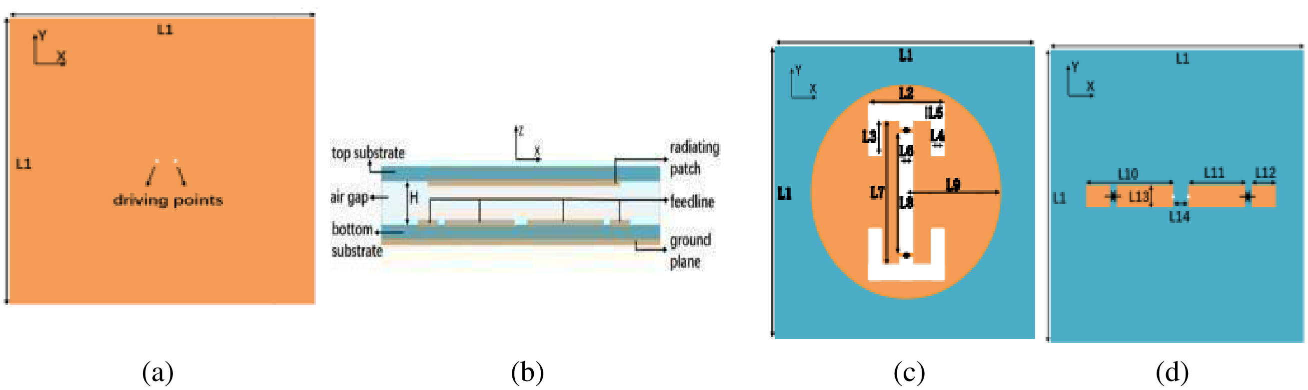


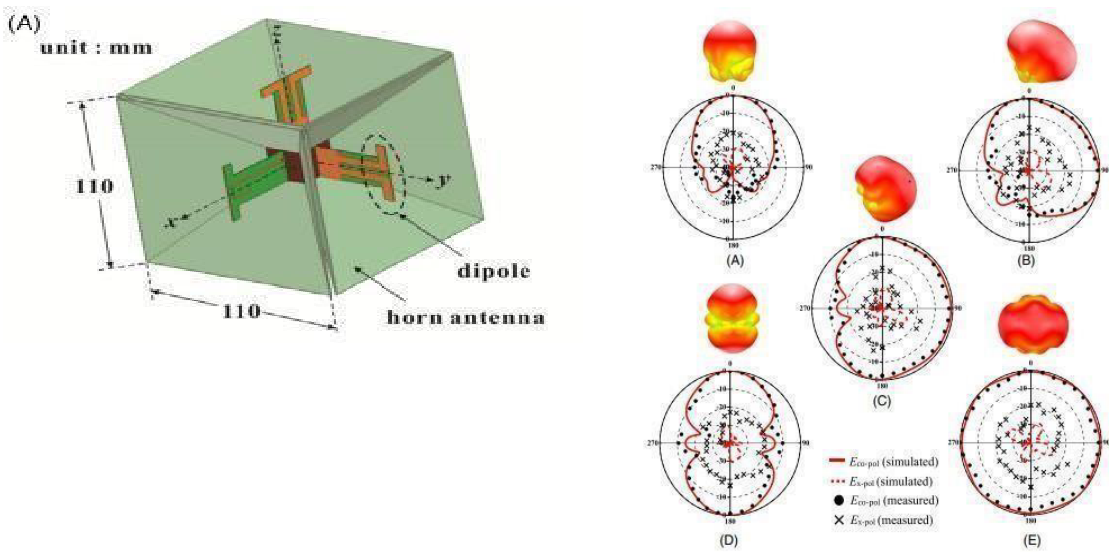
Figure 3. The configuration of the suggested antenna. (a) Geometry of the given patch. (b) Feedline geometry. (c) Ground level. (d) Side view.

4.2. Reconfiguration of Polarization

In wireless applications, polarization reconfigurable antennas are being developed for frequency reuse with minimal fading. They may employ several switching mechanisms to function in many polarization modes, such as vertical, horizontal, circular, and other polarization modes. This work describes a new circular polarization-based polarization reconfigurable antenna that can switch among linear, left circular, and right circular polarization modes. The radiator element operates at 2.45 GHz and is a flattened square with two distinct aperture coupling feeds that can work in two orthogonal circular polarization (CP) modes with minimal interference. The two microstrip lines can be used to make left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) modes respectively. Meanwhile, linear polarization (LP) mode can be created in the first stage by simultaneously activating two microstrips with equal amplitudes, with the polarization plane concerned within any necessary azimuth direction. The replicated and distinguished antenna gain of the suggested antenna at 2.45 GHz is around 6.8 dBi, and the impedance matching bandwidth is fully covered for both polarization states. The outcomes of the tests indicate that the proposed antenna is effective [21].

4.3. Pattern Reconfiguration

The emission patterns of pattern reconfigurable antennas can be changed to improve the antenna's directivity and gain in the desired direction. An antenna's beam shape can be modified to cover various sweep areas with various angles of radiation to be covered. These antennas are very directional and may be the most effective. This system includes an excited cubic array with a switchable feed network, a microcontroller unit, and a mobile application. The operating status of each of the cubic array's five radiated elements is controlled by a switchable feed network. According to modeling results, the antenna incorporated into the feed network can offer five highly directional scan beams, 11 unidirectional patterns with large beam width, two bidirectional patterns, and a unidirectional pattern. To quickly switch between these radiation patterns, the Microcontroller Unit (MCU) is used. Regulate the DC voltage of the PIN diode in the feed network. The MCU in issue also has a Wi-Fi module, which allows it to communicate with a mobile device over a wireless local area network. As a result, the pattern can be changed using a remote control. The architecture of the system is explored in detail. The outcomes are quantified, and details on the system architecture are also presented in Figure 4 [22].



(a) (b)

Figure 4. (a) Geometry of the cubic array. (b) Radiation patterns of the array at various modes in x-y plane.

4.4. Bandwidth Reconfiguration

The act of shifting an antenna's bandwidth from narrow to wide, depending on the needs of the end-user, is denoted as "Bandwidth Reconfiguration". This antenna can be made by tuning the transmission zeroes or adding matching networks. To ensure high selectivity and interference suppression, transmission zeroes with a specified frequency are used. It is possible to reconfigure the antenna by making changes to its structure in Figure 5.

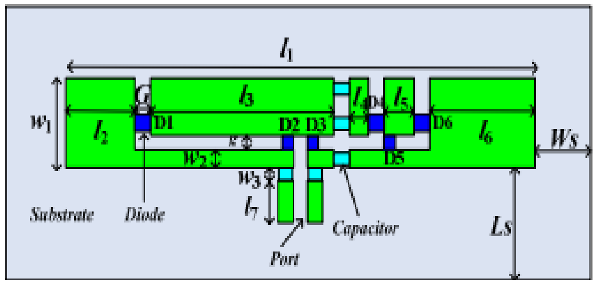


Figure 5. Proposed antenna.

In this case, the antenna should have proper impedance matching, radiation patterns, and gain. This offers a lot of advantages, and the antenna is more efficient than other antennas. A new bandwidth-configurable planar printed dipole antenna is offered in this paper. The suggested matching, a step-shaped gap is used, and the feed input is a coplanar strip line. The impedance bandwidth varies from one to another. Radiation patterns that were consistent were also obtained.

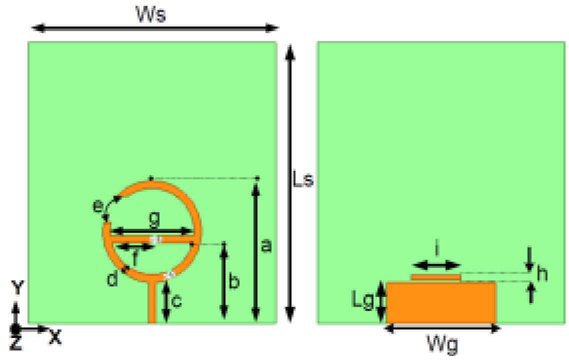
5. TYPES OF ANTENNAS WITH MULTIPLE RECONFIGURE FEATURES

On multiple antennas, two or more antenna attributes can be modified individually. The concept of multiple reconfigurability is used in a lot of novel antenna applications, especially for contemporary communication equipment. Single-configurability is also employed, but multiple-configurability is significantly more complicated and sophisticated. Multiple antenna settings are linked together, making it impossible to change them all at once. Various scientific efforts to build compound reconfigurable antennas have been recognized, though. Multiple and solitary reconfigurability approaches are frequently coupled in a single multi-reconfigurable antenna, necessitating meticulous design and control procedures. Many important articles on multi-reconfigurability antennas have been published, with frequency and pattern reconfigurability, frequency agility, polarization diversity, and pattern and polarization reconfigurability all being considered.

- Reconfiguration of frequency and bandwidth.
- Frequency and polarization reconfiguration.
- Frequency and radiation pattern reconfiguration.
- Polarization and radiation pattern reconfiguration.
- Frequency, radiation pattern, and polarization are all rearranged.

5.1. Frequency and Bandwidth Reconfiguration

Multiple antenna design concepts are employed to use the multimode functionality. To shift from narrow to wideband functioning, antenna design approaches are utilized as a function for filter methods on the antenna feed-line. The design can be used to add parasitic and slit structures to a ground plane, as well as slots and active elements. This is accomplished using a reconfigurable octagonal antenna with UWB to narrowband (NB) and Bi bands. The chosen antenna will be used to switch among UWB, NB, and Bi-band modes, as well as the other way around. The first antenna can be covered by UWB, then NB or Bi-band mode can be added to the octagonal antenna by adding two resonators. Two RF PIN diodes work together to execute multi-configuration operations. A circular loop pattern is used to create the patch. PIN diodes are inserted to the patch, and the loop's basic structure is changed. The antenna operates in a dual-band configuration at 3.42 and 8.02 GHz in the "OFF" state of the diodes, while in the "ON" state of the diodes, the antenna changes to 2.21, 4.85, and 10.19 GHz tri-band operating in addition, and the antenna's bandwidth has been increased from 7.71 to 8.48 GHz when the diodes are "ON", and from 7.54 to 12 GHz when the diodes are "OFF". To implement and produce the appropriate antenna architecture, an FR4 epoxy substrate is used. The observed gain of the PIN diodes is 3.07 dBi,



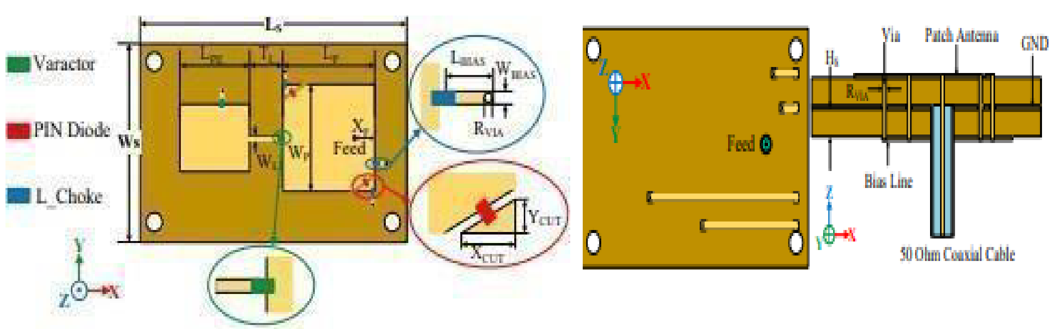
(a) (b)

Figure 6. The designed antenna's complete layout, (a) radiating patch, and (b) altered ground.

2.8 dBi, and 2.93 dBi at 2.2, 4.86, and 10.2 GHz, respectively, in the "ON" state, whereas the gain is 3.03 dBi at 3.43 GHz and 3.38 dBi at 8.03 GHz in the "OFF" state [23] in Figure 6.

5.2. Frequency and Polarization Reconfiguration

The frequency and polarization state are combined in a single structure. This combination is commonly employed in multi-channel communication systems to provide high channel capacity and security. Frequency reconfigurability allows for an increase in channel capacity by utilizing previously unused channels, while polarization reconfigurability is utilized to solve a variety of spectrum issues with also increasing channel capacity. This paper proposes a patch antenna with a modest gain fluctuation. Eight separate operational frequency bands can be created by properly switching shorting pins and the three polarization states in Figure 7. The consistent gain performance was obtained by exploiting the loss character of PIN diodes for the appropriately switched condition in different states and from a wide reconfigurable frequency as well as all states. The element gain is good, and the switching frequency range is large. This paper presents a design for a reconfigurable microstrip antenna for wireless applications. PIN diodes are utilized to switch between linear and circular bias, while varactor diodes work to adjust the operating frequency continuously. Both the states of the PIN diodes and the bias voltage of the varactor diodes, which ranges from 0.8 V to 10 V, affect the antenna's performance. A number of wireless ISM band applications could benefit from the suggested polarization/frequency antenna [24].



(a) (b)

Figure 7. Geometry of the offered antenna. (a) Uppermost view of the radiator. (b) Lowermost and the side view.

5.3. Frequency and Radiation Pattern Reconfiguration

Either the frequency or the radiation pattern is modified in this type of reconfiguration. This combination can increase link dependability and channel capacity in wireless communications. By modifying the signals, pattern reconfigurability helps the system avoid noisy conditions and save energy, while frequency reconfigurability allows the system to automatically transfer the spectrum and reduce the number of antennas required. Pattern reconfigurability can be added to this combination of designs by shortening the patch, varying the ground size, changing between various antenna outlines, or introducing a switchable slit in the ground plane. This research proposes a compact and flexible reconfigurable antenna in terms of frequency and radiation pattern. The antenna is built out of a triangular monopole with a semicircular patch. On opposite ends of the top patch, two L-shaped stubs are placed. In the L-shape stub, two PIN diodes are employed. From a frequency to another, different states of the PIN diode aid antenna resonance. When both diodes are on/off, the antenna will emit in a unidirectional way.

5.4. Reconfiguration of Radiation Pattern and Polarization

Among other things, a polarization reconfigurable antenna and a radiation pattern can increase communication system capacity, improve radiation coverage, and boost signal power. The ability to adjust the antenna pattern to meet your needs without increasing the radiator volume is known as pattern reconfigurability. For the 2.45 GHz–2.65 GHz band, a reconfigurable antenna design with a switchable radiation pattern and polarization diversity was introduced. Three round substrate discs and four plastic screws are included.

It has three circular substrates: a radiator, feeding, and switching, as well as an annual slot structure carved into the circular patch radiator. This device has a single contribution and four productivity ports, with L-shaped feeding probes in the center layer. The antenna in issue can produce switchable broadside and conical circular polarized radiation beams. A reconfigurable antenna's capacity to modify its radiation pattern and polarization is investigated. A core dielectric resonant antenna (DRA) and two parasitic dielectric resonator antennas made of a low-dielectric-loss liquid solution make up the antenna. The parasitic DRA may be modified using a liquid stream to produce alternative models. When just the central DRA emits, multidirectional modelling is conceivable; however, parasitic DRA can be employed to construct a one-way model. In addition, parasitic ARDs, which can be generated through fluid flow, can be used to change the polarization of unidirectional radiating antennas. This method can generate three types of radiation: omnidirectional, x-, and y-polarized radiation.

5.5. Frequency, Radiation Pattern and Polarization Reconfiguration

Only one solution for autonomous three-parameter reconfiguration is proposed in this antenna reconfiguration. Some designs are only capable of limited adjustment, while others are unable to provide many settings at the same time. A patch antenna radiator and a parasitic pixel surface with pixels and PIN diodes are used in the following design. A switched grid pixel surface allows the antenna to be changed in three different configurations at the same time. To tailor the frequency between 2.4 GHz and 3 GHz, the switches were set up in a variety of ways. The pattern can be steered between different degrees, and the antenna's polarization can be altered between LP and LHCP/RHCP. The architecture is extensible to a wide range of wireless communication platforms.

6. MULTIBAND ANTENNA DESIGN TECHNIQUES

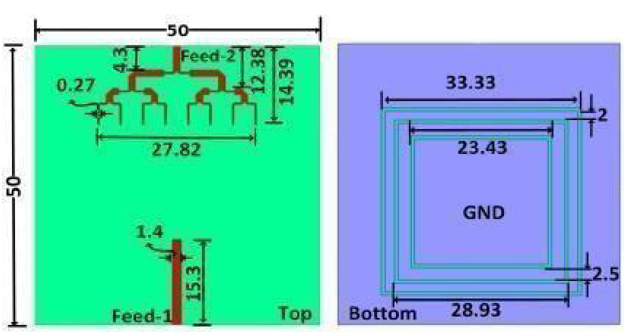
Multiband antenna design approaches transform a basic antenna into one that can operate across multiple frequency bands. Multiband antennas are preferred over separate antennas for a variety of applications. Various design ideas for multipurpose multiband antennas have lately been presented as follows. This method offers some advantages over a single reconfiguration method, but it requires the designer to deal with modelling mechanisms, performance loss, and compliance with several modes of operation. Mixed reconfigurable antennas include frequency-polarization antennas, polarization-pattern antennas, and frequency pattern reconfigurable antennas, according to the researchers. A variety of communication systems, including cognitive radio, software defined radio, and other procedure systems, have used reconfigurable antennas with frequency polarization.

6.1. Use of Parasitic Elements

Parasitic components can be employed to provide virtual antenna rotation. It has an impact on current transmission and distribution since their resonating operates at separate low frequencies without affecting antenna size. As a result of perturbation and antenna coupling, this approach can combine inverted L and T shaped parasitic components, which will resonate. A wideband polarized dipole antenna for LTE/5G base stations is made up of loop dipoles, cross feeds, parasitic elements, and metallic cylinders. As a result, the test results show that the bandwidth, consistent gain, and good port isolation are all met. On a horizontal plane, a rectangle box reflector was employed to generate good cross-polarization discrimination and a constant radiation pattern. Due to its basic construction, the antenna can also be used as a partial reference for the design of the LTE/5G base station antenna.

6.2. Use of Cutting Slots

When slots are dispersed, they cause a brief period of discontinuity, producing a shift in their present travel along the ground path or inside its radiating component, permitting the formation of varied shaped slots. The wideband, compact size qualities are improved by slotting technique strategies. Cutting slots in various shapes, such as U, T, I, L, rectangle, V, fork-shaped, etc., causes current flow and distribution to alter, resulting in a dual band or multiband antenna. To construct trapezoidal and rectangular slots, slotting can be employed on the patch and the ground, respectively. Although much research has been done on frequency reconfiguration, the process of extending the number of bands is still a hot research issue. This article shows a 5G millimeter wave and sub-6 GHz compatible concentric square-based slot antenna for Internet of Things (IoT) devices. The given antenna design has a resonance frequency of 28 GHz and operates in the Octa-band at frequencies less than 6 GHz. A radiating aperture that functions in the bands used for 5G application is included in the suggested design. The antenna was made up of three concentric square slots with a diameter carved from the ground flat. The antenna is controlled via a microstrip line in the sub-6 GHz frequency range, and the 18-power divider is used to excite connected flat millimeter wave antenna arrays in the band. The millimeter wave frequency range is 27.4–28.4 GHz, with a minimum bandwidth of 1 GHz. The recommended antenna covers the vast majority of IoT frequencies, making it an excellent contender for future 5G IoT devices in Figure 8 [25].



(a) (b)

Figure 8. Proposed IoT antenna. (a) Top. (b) Bottom view.

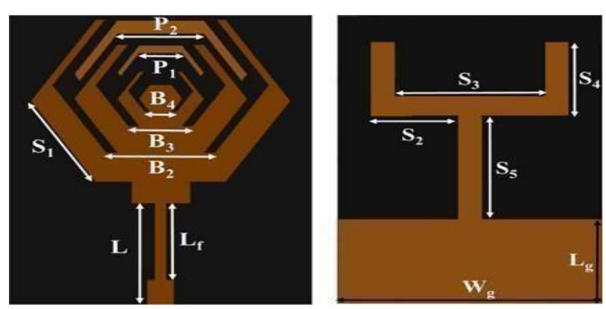


Figure 9. Proposed antenna with radiator.

6.3. Use of Fractal

Fractal geometry is used by antenna designers to achieve log periodical multiband behavior. A fractal item will appear similar to or identical to the original shape as fractal antennae radiate and zoom in on it. The self-likeness property asserts that some elements of the primary structure have the same structure as the main structure but on a smaller scale. The use of such an antenna could improve modern wireless communication systems. Self-similarity principles extend the radiating path perimeter or lengthen the antenna as much as possible, resulting in a tiny antenna size. Another option is to use self-similarity in the geometry to create multiband or resonance antennas that cover a wide range of frequencies. Some examples of fractal-based geometries are as follows:

- Multiband hybrid meander Koch fractal antenna.
- Hilbert Curve and Contor Set.
- A fractal tree is used as an antenna.

In a system with many bands, the parasitic elements of a fractal antenna result in an increase in gain. It is best to use interlocking hexagon loop radiators with a top opening. Three hexagonal opening rings with a hexagonal radiator are powered by microstrips in the center. Parasitic features in the design boost the antenna gain. Due to the load of two parasitic components in the antenna opening, gain performance is improved at each of the resonance frequencies of 2, 3.7, and 4.92 GHz. In the frequency bands 1.97–2.2 GHz, 3.5–3.92 GHz, and 4.7-GHz, the suggested antenna given in Figure 9 has an impedance of less than -10 dB for LTE, 5G, and WLAN applications. In the E-plane and H-plane, an omnidirectional radiation pattern is observed at three resonant frequencies. The antennas are made of an FR4 sheet and have overall dimensions of $37\,\text{mm} \times 28\,\text{mm} \times 1.6\,\text{mm}$. The simulated and measured properties have a strong relationship.

7. FEEDING TECHNIQUES

The amount of power transmitted by feedline to the radiation patch determines the feeding technique. Feeding strategies concentrate as much as possible on antenna input impedance matching. Various feeding techniques have lately been proposed. Feeding strategies can be divided into two categories. One is concerned with contacting, while the other is concerned with not contacting.

When the radiation patch is contacted, the feed is delivered straight to it through a microstrip line. Power is delivered through electromagnetic coupling between the radiation patch and the feedline in non-contacting. Some of the sub-feeding techniques are as follows.

7.1. Feeding Approaches Using Aperture-Coupled Apertures

These are employed to induce coupling effects, and on the ground plane, a window of various shapes is created. A slot in the ground connects the feeding line to the patch. The ground separates the patch from the microstrip feed line in this type of feed technology. To optimize the outcome for broader bandwidths and lower return losses, the patch and feed line are linked through a slot or aperture in the ground plane, with changes in coupling dependent on the aperture size, i.e., length and width. Aperture coupled feeding has several advantages, including no physical contact between the feed and radiator, enlarged bandwidths, and improved isolation between antennas and the feed network. Furthermore, by utilizing substrates of varied thickness and permittivity, aperture-coupled feeding allows for independent antenna and feed network optimization. A circularly polarized hook-shaped aperture coupled antenna is described for 5G applications in Figures 10 and 11. A radiant copper plate is on top, a thick foam substance in the middle, an FR4 material with the shaped holes in the ground plane on the bottom, and an angle feed line on top. The feed mechanism improves the characteristics of the recommended work by using a curved microstrip coupling with four slots to offer four consecutive sources of the same phase for the excitation of the patch antenna. The suggested design met the target and attained 4.08 dBic at the 3.47 GHz frequency, with a bandwidth of 29 percent, an axis ratio bandwidth of 13.48 percent, and a CP level of 20 dB. In terms of azimuth, elevation patterns, and surface current distribution in the intended frequency range, the suggested antenna is well matched to the 5G radio spectrum.

7.2. Inset Feed Techniques

It is also used to match the feed line and patch impedances. There are almost no matching items required. The conducting strip is smaller than the patch in this sort of microstrip line feeding technology,

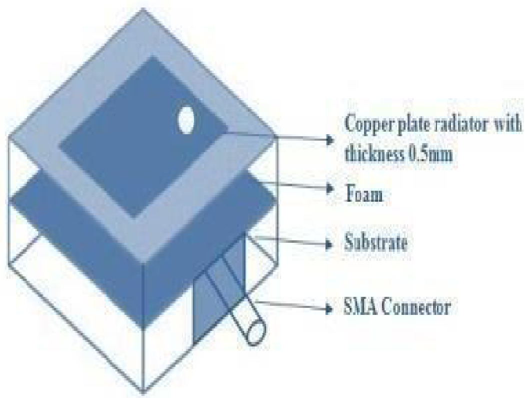


Figure 10. Circularly polarized antenna.

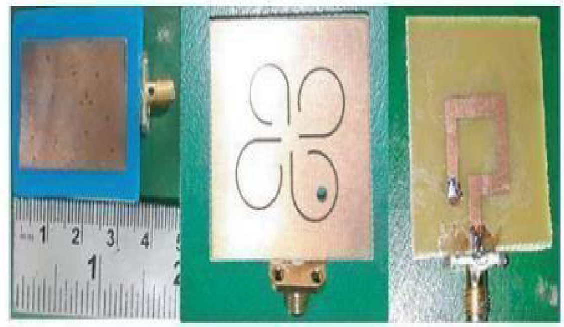
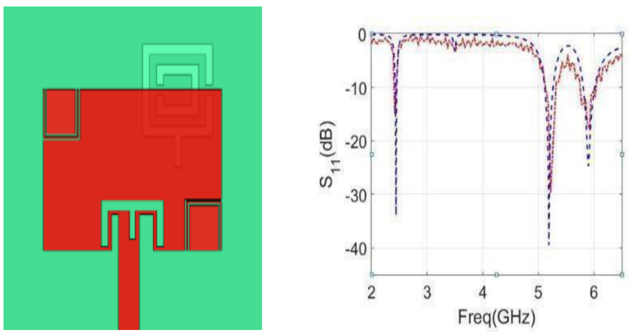


Figure 11. Fabricated antenna of top view, aperture and feed line structure.

resulting in a planar shape for the feed. Without the use of any further matching devices, the inset cut in the patch is utilized to balance the feed line impedance to the patch input impedance. This might be aided by getting the inset cut position and proportions appropriate. A new multi-band microstrip patch antenna design is proposed, which combines slots in the patch with defective ground structures in the ground. The dual resonance response obtained by carving Defected Ground Structure (DGS) patterns onto the ground of a conventional patch operates at 5.2 GHz, a common frequency for Internet of Things applications. This work has yielded a distinct new result. The antenna has three resonance bands: 2.42 GHz, 6 GHz, and 5.92 GHz. To optimize the antenna's performance at various resonance levels, various types of slots are used. To increase impedance matching, the antenna employs an insert feed approach. A Rogers RO3003 substrate with a relative dielectric constant of 3, attenuation tangent of 0.0013, and thickness of 1.5 mm is used to make the antenna. HFSS software is used to model the proposed antenna. At resonance frequencies, good simulation and testing consistency enhance the antenna's ability to boost benefits for IoT applications.

7.3. Proximity Coupled Feed Techniques

The feed line is located between two substrates, and the radiation patch is mounted on top of the upper substrate in this process. The electromagnetic coupling strategy is another name for this type of feed technique. Due to the massive increase in the thickness of the microstrip patch antenna, this feed approach decreases misleading feed radiation while providing exceptionally high bandwidth. To strengthen individual performance, this system has two main distinct dielectric mediums, one for the patch and the other for the feed line. A rectangular patch is on top of the upper layer which is corner-truncated and has a rectangular slit in the center. The bottom of this layer's side metal has been fully etched out. Proximity coupling is achieved by placing a meandering microstrip feedline on top of the bottom substrate layer. The lower side of this substrate has a slotted ground structure. The upper layer is somewhat shorter than the bottom layer to allow for the connection of the inner conductor of an SMA connector to the microstrip feed. In this method, an electromagnetic interface is used between the feed line and radiating patches, which are created on separate materials. The feed line is put between the two dielectric substrates, and the radiating patch is placed on top of the upper dielectric substrate. Compared to other coupling approaches, this coupling offers the greater bandwidth, is relatively easy to predict, and has low spurious radiation. In order to optimize individual performance, this feeding strategy also allows for the use of two alternate dielectric media, one for the feed line and the other for the patch. Controlling the width-to-line ratio of the patch and the length of the feed line can help with matching because of the two dielectric layers that must be aligned properly, and this feeding system has a significant disadvantage in terms of fabrication. In addition, the antenna's total thickness grows. Using corner connect/disconnect techniques and additional connect/disconnect patches, a reconfigurable microstrip patch antenna is constructed to perform bias switching in three frequency bands. Five PIN diodes are used to receive three switchable operating bands with a central frequency of 5.2 GHz (first band), 5.4 GHz (second band), and 6.4 GHz (third band). In three switchable frequency bands, the suggested structure may switch among left circular polarization (LHCP), right circular polarization (RHCP), and linear polarization (LP). This also gives an overview of the circuit's behavior in terms of resonant frequency, which can be beneficial for translating the structure to different frequency ranges for various purposes. The proposed design's polarization and frequency diversity can increase the resilience of modern wireless networks in Figures 12 and 13.



(a) (b)

Figure 12. (a) Schematic diagram of the antenna. (b) Measured and simulated S-parameters.

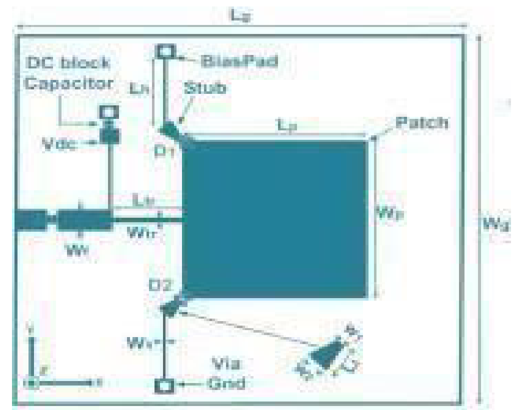
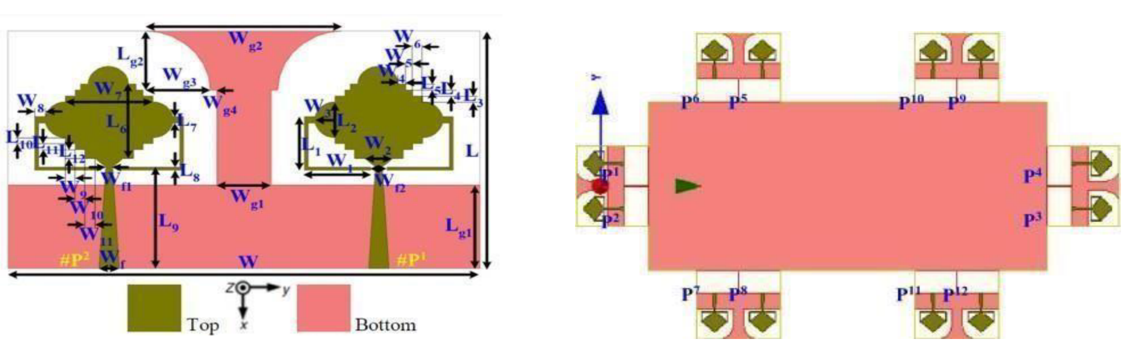


Figure 13. Proposed reconfigurable antenna.

7.4. Tapered Feed Line

Another application for it is impedance matching. A small two-element MIMO antenna system with superior impedance matching and isolation is provided for potential 5G applications below 6 GHz. Two similar tapering microstrip lines provide modified rhombus radiation elements that are oriented in the same direction on a single rectangular floor with a compact background region. To boost impedance bandwidth and isolation, a revised T-shaped floor ground stub is put between two radiating elements. A split U-shaped stub is also connected to the center of each radiating element to provide the 3.6 GHz resonance frequency. The suggested antenna has a 10 dB operating range between 3.34 and 3.87 GHz and over 20 dB insulation between two components (530 MHz). In addition, for practical application, a simulation analysis is carried out to see how the enclosure and extended plane affect the two MIMO antenna factors. Using the proposed two-element MIMO antenna, the notion of realizing 12 element MIMO is also investigated and are given in Figure 14.



(a) (b)

Figure 14. (a) Final pattern of the MIMO antenna with optimized parameters. (b) 12 Element MIMO antenna.

8. SOME RECONFIGURABILITY DESIGNING METHODS

Tunable antennas, also known as frequency reconfigurable antennas, allow for smooth transitions between discrete operating bands or operating bands. Several researchers have created reconfigurable structures for a limited set of applications, such as basic communication systems and space technology. To achieve frequency reconfigurability, the lumped element components (i.e., RLC) are utilized as switching elements inside the radiating structure of the proposed antenna. The following is a summary of studies on multiple frequency antenna design concepts conducted by various researchers.

8.1. EBG Cell Based Reconfigurable Antenna

As an antenna, a matrix made up of electromagnetic band gap unit cells of various sizes can be used. Direct activation of electromagnetic band gap (EBG) cells with an impedance transformer in a specified pattern can be performed to reconfigure an EBG cell-based antenna. PIN can also be used as a switching element. EBG cell-based reconfigurable antenna for both surface wave and normal mode radiation with dual resonance feature in frequency and polarization hedged on silicon material. A lotus-shaped patch with a low profile is recommended for a printed circuit antenna. A patch, a volumetric surface with a thin copper coating, and a Roger RT/duroid 5880 material for high gain bandwidth applications such as microwave imaging systems are the multiple sections of the antenna. To construct a fractal design, the patch's structure is modelled using triangle flaws. The ground plane, on the other hand, failed because of the creation of the EBG. Other frequency modes are below -10 dB at 4.2 and 6 GHz, whereas the initial resonance mode is around 3 GHz in Figure 15. The antenna's dimensions are reduced to $32\,\text{mm} \times 28\,\text{mm} \times 0.5\,\text{mm}$ by using shortening plates on the substrate's edges.

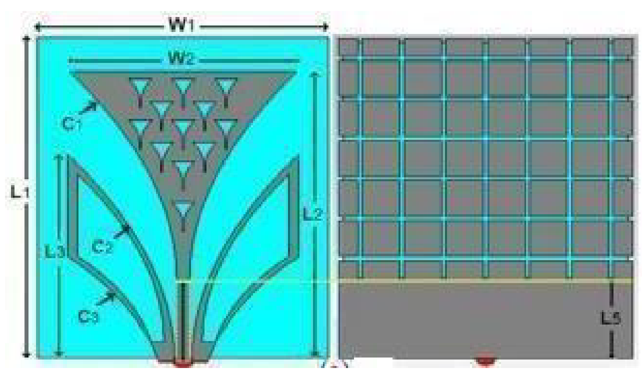


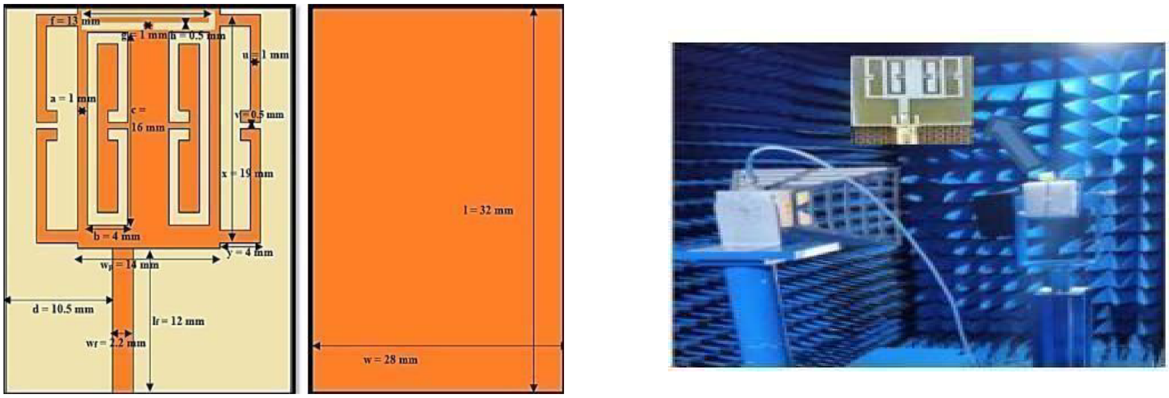
Figure 15. EBG structured antenna.

8.2. MTM Reconfigurable Unit Cell Antenna

It is a bandwidth augmentation technology that uses a composite right/left transmission line metamaterial (CRLH-MTM) to create a small resonant antenna. The series L and parallel C make up CRLH-TL. For UWB and multiband applications for metamaterial (MTM), many researchers have introduced split ring resonator (SRR) and CSRR based antennas on metamaterial and FR4 substrate. To acquire resonance frequency in the WLAN, WiMAX, and wave switching frequency, metamaterial-inspired SRR and CSRR are combined within the radiating element [26].

8.2.1. CSRR Approach Structural Realignment

These methods shift the current direction and give a new resonance frequency for the pass filter by utilizing negative permittivity features. This is an antenna with an offset microstrip feeding. FR4 is used to make the structure. Multi-band functionality is achieved by etching two extra split-loop resonators (CSRR) and a C-shaped slot onto the suggested construction. On the surrounding faces of the radiation element, two SRRs are printed. Parametric analysis is used to establish the location of the feed, as well as other important elements. The permeability of the SRR and the ability of the CSRR are calculated and displayed. The given patch antenna is simple to build, has a consistent radiation pattern, works in a variety of bands, and has a reasonable gain in Figure 16.



(a) (b)

Figure 16. (a) Geometry of the offered antenna. (b) Measurement setup.

8.2.2. Electric Field Coupled Resonator (EFCR)

The metamaterial created using these processes has a negative permittivity and does not cross polarize. For frequency, a metamaterial antenna based on an electric field coupled resonator was developed. The term "reconfigurable antenna" is used. It comes with a coplanar waveguide (CPW) direct power supply, a monopole measuring 11 mm × 14 mm, and an electric inductive-capacitive (ELC) resonator. Two PIN diodes inserted in the gaps on both sides of the ELC resonator can be used to switch on or off the unit cell. The simulation results demonstrate that the suggested antenna can switch among four modes for five distinct frequencies: 2.0 GHz, 2.10 GHz, 2.14 GHz, 2.54 GHz, and 2.92 GHz in Figure 17.

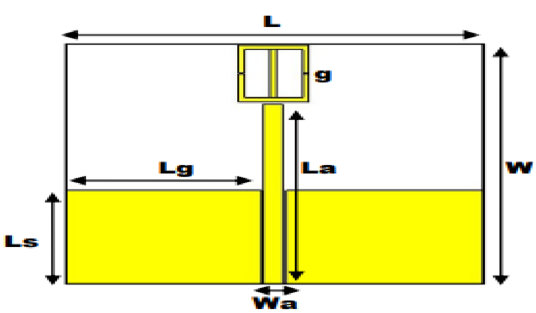


Figure 17. Proposed antenna geometry.

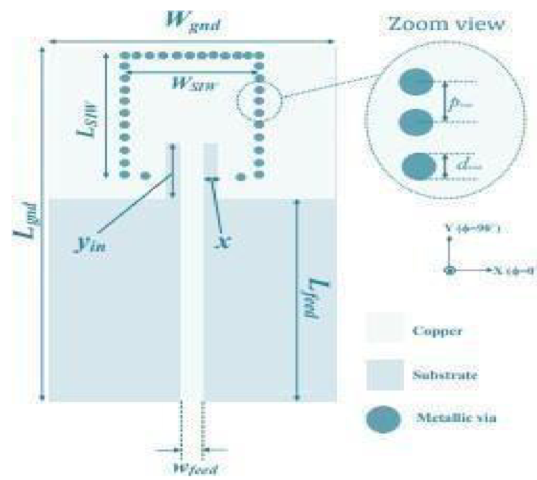


Figure 18. Geometric configuration of the proposed antenna.

8.2.3. Substrate Integrated Waveguide Technology (SIWT)

These procedures produce metamaterial with a negative permittivity that does not cross polarize. A metamaterial antenna based on an electric field coupled resonator has been created for frequency. It is referred to as "reconfigurable antenna". It includes a CPW direct power supply, an 11 mm × 14 mm monopole, and an ELC resonator. The unit cell can be switched on or off using two PIN diodes positioned in the intervals on both sides of the ELC resonator in Figure 18. The simulation results show that the proposed antenna can switch among four different modes for five dissimilar frequencies: 2.0 GHz, 2.10 GHz, 2.14 GHz, 2.54 GHz, and 2.92 GHz.

8.3. Defective Ground Plane

This process can be used to etch slots of various widths and sizes into the ground plane. Because of the slots, the remaining ground plane will have a low inductance, wasting energy. The defective ground layer and feed line layers have a low capacitance when being combined with other parts. A high center frequency and broad bandwidth were attained as a result of the low capacitance and inductance values. In the WLAN and WiMAX frequency bands, it is utilized to determine the frequency of resonance.

8.4. Shorting Loaded Techniques

The unit cell can be controlled with on or off using two PIN diodes positioned in the gaps on both sides of the ELC resonator. Using this technology, researchers created a tri-band antenna with three feeding points and three shorting sets. The top layer's feeding point is connected to the ground layer's feeding network, and the bottom layer's shorting set is connected to the top layer's shorting pin, using the rotation process. The resonance frequency for the next frequency band will be altered by each of the patterns. Because of the tiny space required to decrease the structure, this design method enables more flexibility and compactness.

8.5. Defected Ground Structure (DGS)

Cutting a form out of the substrate's lowest ground layer is one way to do so. It expands the quantity of accessible bandwidth.

8.5.1. Technique of the Coplanar Waveguide (CPW)

The antenna is made up of many metallic elements and is supplied by a 50 coplanar waveguide (CPW) line. The resonant frequency lowers as the slot dimensions increase.

8.5.2. Proximity-Coupled Method

To do this, a meandering microstrip feed-line is placed on top of the bottom substrate surface in paper.

8.5.3. L-Probe Technique with Slots

As a multiband antenna, this probe supplying MSA with numerous U-slots is employed in this manner.

9. SUBSTRATES

A number of factors influence antenna performance, including insufficient gain, low efficiency, and significant return loss. The use of the correct antenna substrate material can mitigate these antenna performance degradation issues. Antenna characteristics and performance are influenced by a material's dielectric constant and loss tangent. The authors show a variety of RF structures for various applications, with materials chosen based on the structure's specifications. The substrate is currently made up of a range of natural and man-made materials. The dielectric constant of the substrate material should be between 2.2 and 12.

9.1. Metamaterial Substrate Material

Electromagnetic structures have negative permittivity, permeability, and refractive index. By altering the permittivity and permeability characteristics of a metamaterial substrate, it can be used in a multiband antenna. The MTM's average cell size is p/4. Metamaterials such as CRLH, SRR, CSRR, triangular SRR, pentagonal SRR, and others are available.

- Negative and zero order modes are included in composite right left-handed (CRLH) antennas. The CRLH unit cell aids in the design of small antennas with good emission patterns across a wide range of frequencies.
- Circular Ring Resonator (CRR) based metamaterial provides a variety of microwave components by transferring negative permittivity characteristics through a pass filter.
- Metamaterials based on the ELC have a negative permittivity and no cross polarization. This material can be used in a variety of high-frequency applications.
- Magnetic resonant dipoles are split ring resonator metamaterials.
- A complementary split ring resonator is an electrical dipole that works by stimulating an axial electrical field.

For miniaturization of a circularly polarized microchip antenna, artificial two-dimensional metamaterial substrates with high constitutive parameters have been proposed. In a circularly polarized antenna, the electric and magnetic field directions shift, necessitating the use of a single two-dimensional meta material cell. The supplied metamaterial substrate supports lower substrate permeability and permittivity for circularly polarized patch antennas, and it includes low-level decoupled resonant circuits that allow dielectric under the substrate. This results in the material with equal permittivity and permeability, negating the negative impact of raising the bandwidth allowed. The structure is also implemented using printed circuit board technology. At the given frequency, the antenna area is about 75% less than a typical microstrip antenna. Compared to a high-allowable antenna substrate, the required antenna bandwidth is enhanced.

9.2. FR-4 Substrate

Glass epoxy is a versatile composite material that is also known as high-pressure thermo set plastic laminate grade combined material. Because of its excellent mechanical strength, it is one of the most commonly used electrical insulating substrate materials. Researchers use FR-4 substrate material to construct multiband and reconfigurable antennas because its relative permittivity is usually 4.4. A compact UWB electronically reconfigurable multiple band omnidirectional to directed radiation pattern was demonstrated in a microstrip planar printed rectangular monopole antenna. A radiator, reflector, and two symmetrical grounds are all incorporated on the same layer of rectangular monopole antenna (PRMA). Radiation patterns and frequency speeds range from omnidirectional to directed. Two surface mounted device (SMD) PIN diodes were used to generate the directional effect. The C-frequency band's spectrum produces 180° phase-shifted directed radiation patterns. A prototype antenna is created utilizing a UV laser cutting tool and a printed circuit board etching method. Due to the employment of two SMD PIN diodes in the switching circuits, there are three basic forms of operation. High-speed wireless sensor networks in sectors such as automotive and gas, chemical reactors, and pharmaceuticals can benefit from the antenna properties detailed here. It is also great for IoT and 5G sub-6 GHz applications.

9.3. Bakelite (Polyoxybenzylmethylenglycolanhydride)

It is the first synthesized phenol formaldehyde (PF) resin type. Because of its non-conductivity and heat resistance, it is extensively employed in electrical insulators. Bakelite was a ground breaking material. It is a thermosetting phenol formaldehyde resin created through an elimination reaction between phenol and formaldehyde. Its most common application is as a mechanically robust electrical insulator. Bakelite is a common material with a loss tangent of 0.04 and a relative dielectric constant of 4.79. The multiband switching frequency of this material-based antenna is the best. The performance of a UWB antenna is examined using a variety of substrate materials. The antenna's properties are influenced by the substrate's dielectric constant, loss tangent, and other parameters. The three substrates utilized to create the proposed antenna are FR4-epoxy, Roger, and Bakelite, all of which are 1.6 mm thick. The simulated antenna has a multiband capability and an operational bandwidth of 2.2 to 10.3 GHz, with a maximum gain of 5.64 dB. By changing the relative permittivity with substrate material, bakelite has been proved to be the best substrate for a given microstrip patch antenna. The antenna can be used in the WiMAX IEEE802.16 (3.30–3.80 GHz) and UWB frequency ranges, especially for X-band downlink satellite systems (7.1–7.9 GHz), C-band (4–8 GHz) satellite communication applications, and medical applications to detect malignancies and tumors where the safe frequency range for human tissues is 4 GHz–9.5 GHz.

9.4. Polyester

Polyester is utilized, which has a loss tangent of 0.09 and a relative dielectric constant of 1.39. Everything will be 5G wireless in the near future, including wearable devices, which have recently gained popularity. In consumer electronics, mobile antennas are becoming more common. Mobile devices must provide a wide bandwidth and high data rate with more consistency in order to reach 5G. A reconfigurable mobile antenna on a cloth material is seen in this image. The suggested design is frequency reconfigurable and capable of operating in the 5G Mid band (3–5.5 GHz). The proposed antenna could be worn as part of a military uniform or other apparel and communicate via Wi-Fi, WLAN, satellite, 5G mobile, and cognitive radio. The antenna's shape is determined by combining all of the above-mentioned reconfiguration features into a single antenna, and parametric analysis is done to find the best possible prototype. When polyester is employed as a substrate, good results can be achieved.

9.5. RT Duroid

Chemical resistance, ease of production, and environmental friendliness are all features of this material. Duroid absorbs very little moisture and loses very little electricity. A typical RT Duroid is used with a relative dielectric constant of $r = 2.2$ and a loss tangent of 0.0004. Researchers use this material to develop multiband antennas and programmable antennas for a variety of wireless applications. A new frequency reconfigurable antenna based on a substrate integrated waveguide (SIW) is developed for S-band and C-band applications. A SIW resonant cavity with a rectangular slot and a long slot is carved into the antenna's upper surface. An addition post is used to modify the resonance frequency of a unique low frequency mode without affecting impedance matching or diminishing gain in the high frequency mode. Several PIN diodes are symmetrically positioned along the rectangular ring slot to connect the patch to the top surface. The operation of the PIN diodes is tested using a simpler bias configuration. The suggested antenna has been prototyped, and measurements reveal that it has a low-frequency bandwidth of 18 MHz and a high-frequency bandwidth of 322 MHz.

9.6. RO4003

Because of its outstanding high-frequency performance and cost-effective manufacturing technology, it is chosen for antenna design. This paper discusses the development of a new multiple monopole antenna with multiple band operation and unidirectional emission arrangements at two activity frequencies. IEEE 802.11a and IEEE 802.11b wireless network communication protocols have official operational ranges that exceed authorized bands. The effects of geometrical parameters on return loss and radiation behavior are briefly discussed. The suggested antenna is made of a thick material with a $40\,\mathrm{mm} \times 40\,\mathrm{mm}$ overall board size.

9.7. Roger 4350

The largest value of return loss is produced by this material, which has a relative permittivity of 3.66. Researchers are also looking into flexible Kapton-polyimide material, silicon, and foam-based substrates as possible substrate materials. According to the examination of various materials used as substrates for the manufacture of RF devices, dielectric losses are regulated by a variety of variables, including circuit configuration, dielectric constant, frequency, and loss tangent, among others.

10. APPLICATIONS

In the current generation, wireless communication has advanced to a very high application level, with the ability to adapt to changing environments. For both terrestrial and space applications, cognitive radio systems, satellite communications, military applications, MIMO systems, and biomedical applications are some of the examples [27].

10.1. Reconfigurable Antennas for Satellite Applications

In response to the demand for wireless and space applications, reconfigurable antennas for satellite applications have been developed. This method reconfigures the antenna radiation pattern to aid coverage zones and sustain high data speeds across many frequency bands. An antenna structure is used as an example for this satellite application. The usage of deployable antennas that alter shape from small to massive structures has enabled space reconfiguration. The antenna can be changed to take multiple frequency bands as the satellite's mission progresses. Another option for satellite and radar applications is to employ low-cost compact microstrip UWB and tri-band antennas. It achieves multi-frequency performance and dual notch features by integrating two opposite U-shaped slots on the radiated patch. Because of its small size, ease of fabrication, and consistent emission patterns in the far field, the antenna is excellent for satellite and UWB applications. The antenna of a low-earth-orbit satellite must be steered towards a geostationary satellite, which necessitates the use of a steerable antenna pattern. The core application is also used by this satellite platform. It has a low weight and complexity which facilitates the modification of the antenna beam's position. The antenna presented in this work is a one-of-a-kind multiband frequency-reconfigurable antenna. With minimal electrical tweaking, this designed antenna can operate in the L-band for single process and the S-band for dual operations. For L/S-band operation, radiators like annular ring and saw tooth patches are implemented, which are triggered by a broadband reconfigurable omnidirectional network via the connection of a T-shaped slot and a ring slot in the ground plane. The frequency ranges between the navigation state and the satellite link reception state can be varied by changing the bias of the PIN diodes loaded on the feed network.

10.2. Pattern Reconfigurable Antenna for MIMO Systems

Due to the high propagation loss of millimeter waves, MIMO and beam forming techniques are viewed as crucial for enhancing spectral efficiency with cost-effective and dependable coverage in 5G systems. Beam forming is a technique that combines many radiating devices that broadcast the same signal at the same phase and wavelength to build a single antenna that magnifies waves in specific direction to provide a more targeted stream. The antenna may drive a single beam in a specified direction using radiating elements with the same frequency, and the signal can be phase-shifted to a certain receiver. Reconfigurable antennas are used to increase the performance of MIMO systems. To transfer several data streams at the same time, various antennas are needed at both the transmitter and reception front ends. A reconfigurable antenna improves channel dependability, capacity, and overall performance in MIMO systems. The strategy and assessment of a radiation pattern reconfigurable antenna for MIMO applications, for example, is described. A millimeter-wave wideband antenna is presented for 5G applications. Reconfigurable antenna for cognitive radio systems provides considerable cognitive radio technologies and also boosts throughput and system efficiency significantly. To achieve a cognitive operation cycle, a typical system starts by detecting channel activity with a sensing antenna. When one observation is completed, a cognitive network selects an appropriate frequency for wireless communication. Following that, a CPU sends a command to the communicating antenna, ordering it to behave in the desired communication mode. The system then feeds data from the new arrangement back into the system and continues the process in order to obtain more system enhancements. Monitoring and modifying the transceivers' characteristics to the under-utilized frequency bands, for example, could help overcome interference from other wireless communication systems, enhancing overall signal quality. There are two techniques to implement cognitive radio systems.

10.3. Reconfigurable Antenna for Biomedical Applications

Researchers have become interested in communication, biotelemetry, and other domains as a result of improvements in microelectronic devices. Many different types of biomedical devices have been created to interact with the human body in order to monitor and diagnose diseases. In biotelemetry communication, implantable medical devices have been used to communicate wirelessly between implanted devices and external units. Industrial, scientific, and medical bands are used to apply implantable medical devices. A single broad band antenna with a distinctive shape is used in the biomedical application. An ISM wideband of 2.45 GHz with a total bandwidth of 660 MHz covers this antenna. In this design, a circular cut shaped patch or radiator has been made for the reduction, and a shorting pin has been inserted for frequency tuning. Many tissues in the human body, including the skin, brain, and small intestine, are employed to mimic this antenna system. It has a lot of power, with a gain of −12.98 dBi. This design is comparable to previous work; however, it has significantly increased bandwidth, gain, size, volume, and design distinctiveness. This antenna is appropriate for skin implantation as well as a range of other uses, such as pacemaker recharging and bio-telemetry.

11. CONCLUSION

The study discussed a variety of subjects connected to reconfigurable antennas, including their function, classification, reconfiguration procedures, feeding mechanisms, switching methods, and different design approaches, and applications. Reconfigurable antennas were classified as frequency reconfigurable, radiation pattern reconfigurable, polarization reconfigurable, and compound reconfigurable using electrical, optical, mechanical, and smart material based tunable architectures. The primary advantage of the technology was the efficient use of frequencies, the use of radiation reconfigurability, and the use of polarization diversity to transmit signals over the used frequencies, according to an analysis of the technique. There were several types of reconfigurable antennas discussed. It is crucial to use only one method. An antenna must undertake extensive study in order to achieve a specific application in order to achieve a larger number of aims. There was a detailed comparison of different reconfigurable antenna implementation methodologies. Reconfigurable antennas are used in a variety of applications, including cognitive radio, MIMO systems, satellite communications, and medicinal devices. Reconfigurable antennas for 5G and IoT applications are described here, along with some of the most recent designs, current trends, and future perspectives.

REFERENCES

1. Isa, S. R., "Reconfigurable pattern patch antenna for Mid-band 5G: A review," *Computers, Materials & Continua*, Vol. 70, No. 2, 2699–2725, 2022.
2. Patir, B., "A review on various techniques of microstrip patch antenna design for wireless application," *International Journal of Computer Applications*, Vol. 1, 15–17, 2015.
3. Sun, M., Z. Zhang, F. Zhang, and A. Chen, "L/S multiband frequency reconfigurable antenna for satellite applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 18, No. 12, 2617–2621, 2019.
4. Kumar, N., P. Kumar, and M. Sharma, "Reconfigurable antenna and performance optimization approach," *Wireless Personal Communications*, Vol. 112, 2187–2212, 2020.
5. Acharjya, D. and M. K. Geetha, *Internet of Things: Novel Advances and Envisioned Applications*, Springer International Publishing, 2017.
6. Dildar, H., F. Althobiani, I. Ahmad, W. U. R. Khan, S. Ullah, N. Mufti, and A. Glowacz, "Design and experimental analysis of multiband frequency reconfigurable antenna for 5G and sub-6 GHz wireless communication," *Micromachines*, Vol. 12, No. 1, 32, 2020.
7. Mokayef, M. and M. A. Summakieh, "An ultra-wideband for IoT connectivity," *International Journal of Internet of Things and Web Services*, Vol. 2, 76–79, 2017.
8. Kishore, N., A. Prakash, and A. V. S. Tripathi, "A multiband microstrip patch antenna with

defected ground structure for its applications," *Microwave and Optical Technology Letters*, Vol. 58, No. 12, Dec. 2016.

9. Singh, G., B. K. Kanaujia, V. K. Pandey, D. Gangwar, and S. Kumar, "Design of compact dual-band patch antenna loaded with D-shaped complementary split ring resonator," *Journal of Electromagnetic Waves and Applications*, Vol. 33, 2096–2111, 2019.
10. Awan, W. A., N. Hussain, S. A. Naqvi, A. Iqbal, R. Striker, D. Mitra, and B. D. Braaten, "A miniaturized wideband and multiband on-demand reconfigurable antenna for compact and portable devices," *AEU — International Journal of Electronics and Communications*, Vol. 122, 153266, ISSN 1434–8411, 2020.
11. Mohanta, H. C., A. Z. Kouzani, and S. K. Mandal, "Reconfigurable antennas and their applications," *Universal journal of Electrical and Electronic Engineering*, Vol. 6, No. 4, 239–258, 2019.
12. Elwi, T. A., "Electromagnetic band gap structures based on ultrawideband microstrip antenna," *Microwave and Optical Technology Letters*, Vol. 59, No. 4, 827–834, 2017.
13. Li, P. K., C. J. You, H. F. Yu, and Y. J. Cheng, "Mechanically pattern reconfigurable dual-band antenna with omnidirectional/directional pattern for 2.4/5 GHz WLAN application," *Microwave and Optical Technology Letters*, Vol. 59, No. 10, 2526–2531, 2017.
14. Chandra, S. and S. Dwivedi, "Comparative analysis of reconfigurable patch antenna array for different liquid crystal substrates," *URSI Asia-Pacific Radio Science Conference (AP-RASC)*, 2019.
15. Parchin, N. O., H. J. Basherlou, Y. I. A. Al-Yasir, A. M. Abdulkhaleq, and R. A. Abd-Alhameed, "Reconfigurable antennas: Switching techniques — A survey," *Electronics (Switzerland)*, Vol. 9, No. 336, 1–14, 2020.
16. Qin, P., F. Wei, and Y. J. Guo, "A wideband-to-narrowband tunable antenna using a reconfigurable filter," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 5, 2282–2285, 2017.
17. Sahu, N. K. and A. K. Sharma, "An investigation of pattern and frequency reconfigurable microstrip slot antenna using PIN diodes," *2017 Progress In Electromagnetics Research Symposium — Spring (PIERS)*, 971–976, St Petersburg, Russia, May 22–25, 2017.
18. Li, T., H. Zhai, L. Li, and C. Liang, "Frequency-reconfigurable bow-tie antenna with a wide tuning range," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 1549–1552, 2018.
19. Xu, Y., Y. Tian, B. Zhang, J. Duan, and L. Yan, "A novel RF MEMS switch on frequency reconfigurable antenna application," *Microsyst. Technol.*, Vol. 24, No. 9, 3833–3841, 2018.
20. Cai, Y.-M., K. Li, Y. Z. Yin, S. Gao, W. Hu, and L. Zhao, "A low-profile frequency reconfigurable grid-slotted patch antenna," *IEEE Access*, Vol. 6, 36305–36312, Jun. 2018.
21. Tran, H. H., N. Nguyen-Trong, T. T. Le, A. M. Abbosh, and H. C. Park, "Low-profile wideband high-gain reconfigurable antenna with quad polarization diversity," *IEEE Trans. Antennas Propag.*, Vol. 66, No. 7, 3741–3746, Jul. 2018.
22. Jin, G., D. Liu, M. Li, and Y. Cui, "A pattern reconfigurable antenna with broadband circular polarization," *IEICE Transactions on Communications*, Vol. E101B, No. 5, 1257–1261, May 2018.
23. Thummaluru, S. R., M. Ameen, and R. K. Chaudhary, "Four-port MIMO cognitive radio system for mid-band 5G applications," *IEEE Trans. Antennas Propag.*, Vol. 67, No. 8, 5634–5645, 2019.
24. Zainarry, S. N. M., N. Nguyen-Trong, and C. Fumeaux, "A frequency and pattern-reconfigurable two-element array antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 17, No. 4, 617–620, 2018.
25. Hussain, "Shared-aperture slot-based sub-6-GHz and Mm-Wave IoT antenna for 5G applications," *IEEE Internet of Things Journal*, Vol. 8, No. 13, 10807–10814, 2021.
26. Tran, H. H. and T. T. Le, "A meta surface based low-profile reconfigurable antenna with pattern diversity," *AEU — International Journal of Electronics and Communications*, Vol. 115, 153037, 2019.
27. Mohanta, H. C., A. Z. Kouzani, and S. K. Mandal, "Reconfigurable antennas and their applications," *Universal Journal of Electrical and Electronic Engineering*, Vol. 6, No. 4, 239–258, 2019.