Journal of Biological Engineering Research and Review, 2021; 8(2): 189-197
ISSN: 2349-3232 Online
Available online at www.biologicalengineering.in/Archive

Review Article

A Review on Reconfigurable Microstrip Antenna

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ARTICLE INFO:

Article History:
Received: 15/05/2021
Revised: 13/09/2021
Accepted: 11/10/2021
Published: 31/12/2021

Keywords:
Wireless communication, Microstrip antennas, Pattern polarization, Reconfiguration

Citation: Anjana Devarajan, Ashika K, Arjun Saji, P M Amritha, Sumi M, Harikrishnan A I. A Review on Reconfigurable Microstrip Antenna. Journal of Biological Engineering Research and Review, 2021; 8(2): 189-197

Abstract: As wireless communication systems are developing at a rapid pace, traditional antennas with fixed functionalities pose to be a limitation. Thus, reconfigurable antennas play a major role by incorporating multifunctional capabilities into a single antenna system. This paper reviews different types of antenna reconfigurations such as frequency, pattern, polarization and compound reconfigurable antennas. The design techniques employed to achieve reconfigurability along with its applications is also reviewed.

INTRODUCTION

The rapid development in technology demands the need for integrating multiple functionalities in a single system. This has led to research in the field of reconfigurable antenna where multiple antennas can be replaced by a single reconfigurable antenna [1]. Reconfigurable antenna is able to modify their geometry and adapt to the surrounding conditions. They address dynamic system requirements and provide the same throughput as a multiantenna system [2]. They find applications in cognitive radio (CR), space application and multiple input multiple output (MIMO) channels.

The ability of an antenna to modify its properties such as frequency of operation, polarization and radiation pattern is termed as reconfigurability. Reconfigurable antennas can be widely classified based on the property that is being reconfigured and also the technique used to achieve it. The various reconfiguration techniques can be grouped under electrical, optical and mechanical methodologies.

Electrical reconfiguration technique is employed with the help of PIN diodes, varactors and radio-frequency (RF) switches that redistribute the surface current and achieve reconfigurability as presented in [1]-[3]. For applications that demand high switching speed, PIN diodes and varactors serve as ideal candidates. Whereas, low power consumption can be established with the help of radio-frequency microelectromechanical system (RF MEMS). Optical reconfiguration involves the use of photoconductive switches that alter its physical structure and control bandwidth and radiation pattern. Examples include gallium arsenide (GaAs) switches that do not require complex circuitry for biasing and thus offer higher isolation over electrical switching techniques. Reconfigurability can also be achieved by using smart materials like ferrites or liquid crystals where the dielectric properties of the material can be controlled through varying voltage levels or by inducing a static field [1].

Defected Ground Structure enhance antenna performance by introducing defects on the ground plane. An antenna can be reconfigured mechanically using motors or actuators that help to modify the radiating structure. This mechanism eliminates the need to incorporate active elements or biasing systems but is found to be more power consuming [2].

Graph based modelling aim to reduce the redundant components and produce optimum antenna designs. [2] briefly describes how Neural Networks and software tools like Field Programmable Gate Arrays (FPGAs), Arduino boards and microcontrollers help in the automation of reconfigurable antennas.

In recent years, reconfigurable antennas have gained more importance due to their compact size, low cost, enhanced performance and their ability to adapt to different operating conditions. These antennas play a crucial role in cognitive radio (CR) systems as discussed in [3,4]. Wider bandwidth and improved spectrum utilization can be acquired using novel patch configurations.

This paper intends to review different types of reconfiguration such as frequency, pattern, polarization reconfigurability and also hybrid reconfigurable antennas. The structure of antenna and the techniques used to achieve reconfigurability is also studied in detail. This gives a better understanding of the type of reconfiguration required for a specific application and to determine a feasible technique that can be employed in order to obtain a cost-effective system that produces the desired functionality.

FREQUENCY RECONFIGURATION

Frequency reconfigurable antennas are capable of modifying their frequency of operation and are thus able to support systems that require multiband operation. A hexa band frequency reconfigurable antenna is presented in [5] that is suitable for application such as Wi-Fi and fixed mobile communication. A truncated ground is employed to obtain optimum gain and efficiency. It is compact in size and easy to fabricate. PIN diodes are used to obtain desired frequency of operation. An antenna with Pixel shaped ground along with RF switches operating at single and multiband frequencies is described in [6].

Paper [7] reports stub loading and slot etching techniques to achieve frequency reconfigurability. A slotted circular patch with a coplanar waveguide (CPW) feed and pin diodes is used to obtain dual and triband modes. Thus, a multiband behaviour with bandwidth enhancement is observed. Whereas, a cedar shaped frequency reconfigurable antenna also employing CPW feed shows alteration in resonant frequencies with the aid of pin diodes as in [8].

Frequency reconfigurability achieved using the principles of kirigami transformation and origami flasher is discussed in [9,10]. The origami flasher inspired antenna, beneficial for small devices is presented in [10]. The folded and unfolded states of antenna are easily achievable. The patch pole helps to extend the dipole length in the folded stage. Though the antenna is suitable for applications requiring accessible deployment, certain errors due to gaps and improper folding are inevitable.

A frequency reconfigurable antenna suitable for cognitive radio (CR) systems is reported in [11]. The ground plane is constructed with Ni-Ti shape memory alloy. It enables reconfiguration based on the bending of the ground plane and thus, frequencies in the narrowband and UVB range are observed. Paper [12] presents a frequency reconfigurable antenna design where the nonground portion is reduced to 1 mm. The design is further improved by adding USB, speaker box and steel sheet making it suitable for applications involving full display screen handset.

Slots can be introduced in antenna design to obtain a variety of functionalities as discussed in [13]-[15]. A multiband frequency reconfigurable antenna with an annular ring patch, sawtooth patch and T-shaped slot is presented in [14]. Single band and dual band are obtained with a tuning ratio of 1:64:1. Paper [15] presents a reconfigurable antenna with omega shaped slot for microwave sensing applications. PIN diodes are controlled by an IoT device with inbuilt Wi-Fi. A differential frequency reconfigurable antenna with 2 pairs of vertical arms that form two dipoles is discussed in [13]. A H-shaped slot on the ground plain improves matching and centre frequency of 3.5GHz and 5.5GHz is obtained.

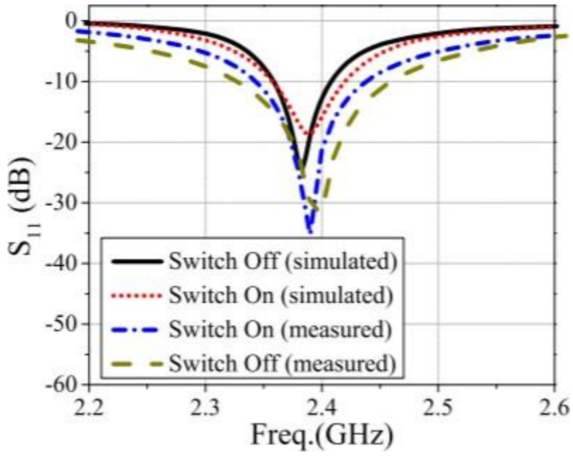
Fusion design method is demonstrated in [16]. The structure consists of an F-shaped probe with horizontal and vertical arms that suppress spurious radiation. Frequency tuning can be achieved with the help of varactors. A proximity coupling feeding technique adopted in frequency reconfigurable antenna is presented in [17]. The length of the feedline and excitation of the patch can be controlled with the help of pin diodes and hence reconfigurability can be achieved. Paper [18] reports a dual polarized frequency reconfigurable antenna which consists of feeding structures, filter branches and artificial magnetic conductor (AMC) structures. Better impedance matching is observed by adding a U-shaped element. The design is suitable for 5G applications and harmonic suppression is achieved.

A low-profile frequency switchable antenna is reported in [19]. Due to its compact size and efficient utilization of frequency spectrum, it is used in RF front end. An insertion loss of 0.4dB is observed. [20] demonstrates an antenna structure with Alford loop, which acts as a primary radiating source, electric field coupled (ELC) resonator, varactors, and 3D printed microwave lens to realize frequency reconfigurability. Horizontal polarization with an increased gain of 6.2 to 8.2 dBi and front-to-back ratio between 13 and 23 dB is observed.

A multiple input multiple output (MIMO) antenna system for achieving frequency reconfiguration is discussed in [21,22]. The antenna design discussed in [22] consists of a slot with dual functionality operating at 4G and 5G bands respectively. Shorted varactor diode provides a tuning range of 2.05-2.7GHz and a high pass filter ensures isolation of ports. Paper [21] reports a MIMO antenna system with eight elements which finds application in CR systems. The 4 element UWB antenna and a 4 element FR MIMO antenna was integrated with the aid of defected ground structure. Thus, reducing mutual coupling and increasing the efficiency of the design. Wide band frequency tuning is obtained by incorporating varactors into the design.

PATTERN RECONFIGURATION

A pattern reconfigurable antenna aims to intentionally modify the radiation pattern according to the requirement of the users. A low-profile Multiple Input Multiple Output (MIMO) based pattern reconfigurable antenna consisting of a rectangular monopole and two parasitic strips that operates as a reflector or director is demonstrated in [23,24]. With the aid of PIN diodes, bidirectional modes of radiation patterns are obtained. In order to improve isolation between the elements, two decoupling strips are also introduced. Thus, the simulation results with a bandwidth of 10.6 and isolation greater than 16.5 dB is observed. Whereas, a dual band MIMO pattern



reconfigurable antenna consisting of two monopoles, a truncated ground and a concave shaped parasitic element loaded with a switch is described in [25]. A low pass filter is used to suppress higher order harmonics which in turn reduces complication of back end systems.

Papers [26]-[28] describe different techniques used to accomplish dual band pattern reconfiguration. Parasitic directors are employed with diode switches that help to vary the length and achieve pattern reconfigurability. However, an electromagnetic band gap (EBG) structure is found to be more efficient due to the absence of RF switches in the radiating patch. The EBG is designed such that its surface wave covers the radiation of the antenna resulting in tilting of the radiation pattern.

Fig.1 depicts a coaxially exited antenna consisting of a conducting strip placed in the midway between the MIMO patch elements as reported in [29]. The ON and OFF states of PIN diodes direct the main beam at an angle of 30 degree. The reflection coefficient plot for the corresponding design is illustrated in Fig.2. With the use of MIMO system, the antenna design has become simpler and more cost efficient.

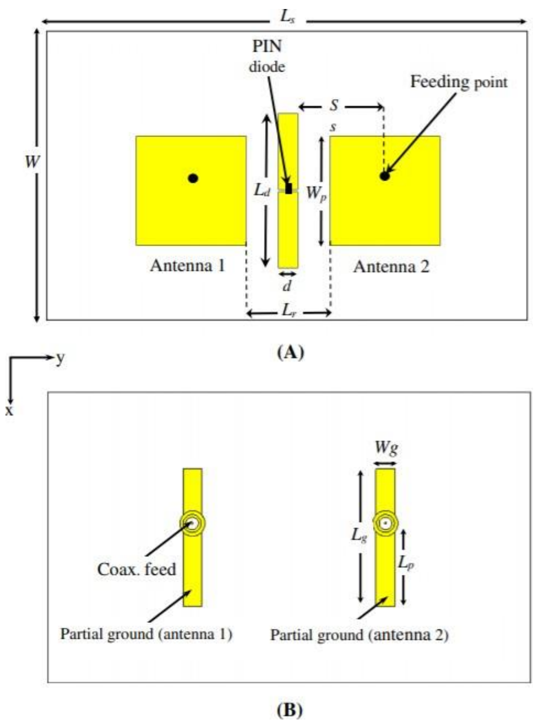


Figure 1. Top view and bottom view of Antenna as in [29]

Figure 2. S-parameter plot of Antenna described in [29]

Flexible reconfigurable antennas discussed in [30] are of great demand due to their flexible and reconfigurable nature. The substrate used is polyethylene terephthalate and they provide a variety of advantage such as less space requirement, small system volume and the ability to exhibit multiple functionalities. A metamaterial-based pattern reconfigurable antenna using millimetre wave band is reported in [31]. The change in refractive indices of the material aids to direct the main beam of the antenna at 28GHz or 5G band.

Papers [32,33] discuss about planar pattern reconfigurable antennas. An antenna with four parasitic patch elements suitable for wireless application is presented in [32]. It provides wider coverage by redirecting the main lobe of the beam. [34] describes an antenna design with a right angled slot where the ON state of a diode enables it to operate like a quarter wavelength slot antenna and thus reconfigure radiation pattern.

Pattern reconfigurable antenna based on shape memory alloys is reported in [35,36]. This is used for automobile applications as it enhances safety, comfort and their purpose of commercial usage. It also enables communication with near automobiles and roadside units. Through the proper alignment of the switches, radiation pattern is switched between forward and backward- broadside radiation pattern and omni direction radiation patterns. A high gain dual band pattern reconfigurable antenna suitable for vehicular communication is reported in [37]. The antenna design consists of four triangular patches integrated on a split square ring. In order to achieve gain enhancement, the structure is loaded with a plane reflector. A frequency selective surface as presented in [38] has also found to improve the gain. Paper [39] describes an antenna consisting of a segmented loop, pi shaped polygon, deployed with PIN diodes that is suitable for onboard communication as it enables low wind drag and metal ground compatibility in aircrafts. The direction of arrival of electromagnetic field is estimated accurately with an eight-port vector antenna having a circular array arrangement as presented in [40]. The design is further modified by adding parasitic directors so as to attain pattern reconfigurability.

POLARIZATION RECONFIGURATION

Polarization reconfigurable antenna acquire the ability to switch between different types of polarization hence minimising the mismatch losses developed in a device. A double square margin antenna which finds application in Self Injection Locked (SIL) radar is presented in [41]. The design incorporating two antennas one with patch square margin and other with chamfer on both corners of the patch is illustrated in Fig.3. Its corresponding S-parameter graph in shown in Fig.4.

Circular polarization antennas are widely used because of their anti-fading and anti-interference abilities. The analysis of a folded ground element (FGE) model is discussed in [42]. Similarly, paper [43] reports a jia-shaped patch antenna suitable for dual band circular polarization applications.

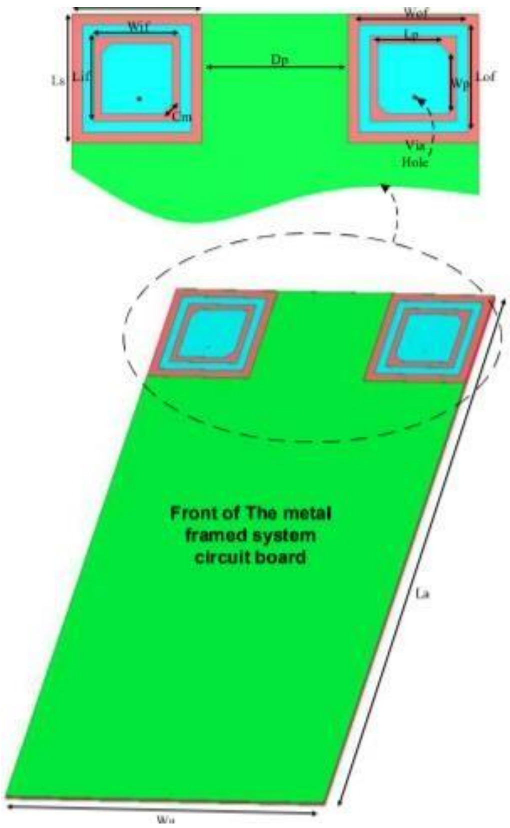


Figure 3. Antenna design as presented in [41]

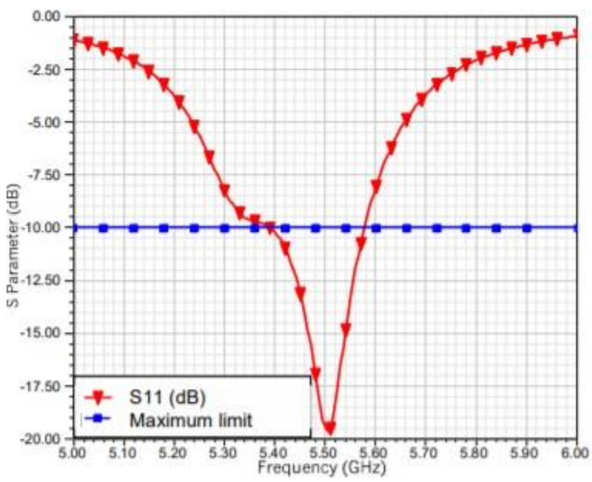


Figure 4. S-parameter plot of Antenna described in [41]

Different techniques used to achieve wideband polarization is discussed in [44]-[48]. An antenna with optical switches and a C-shaped radiator is used to obtain linear, left- hand and right-hand polarization modes. Slots are provided in the ground plane to improve its performance of operation. Tri polarization mode is described in [45] where a microstrip patch acts as a primary polarization source and reconfigurability is achieved through PIN diodes. Paper [46] reports a water Dielectric Resonator Antenna (DRA) which can be switched among linear polarization by injecting the pure water into the different cavities of the plexiglass holder. Wideband polarization can also be achieved by incorporating a circular metal ring structure with gaps as in [47]. PIN diodes are placed in the gap to achieve polarization reconfigurability.

A differential circularly polarized (PRDCP) antenna with wide impedance and axial ratio (AR) bandwidth for right-hand circular polarization (RHCP) or left-hand circular polarization (LHCP) is demonstrated in [49]. The antenna is composed of a bandwidth improved radiator and a sequential feeding network.

Metasurface inspired polarization reconfigurable antennas are described in [50]-[52]. The antenna design described in [50] consist of a coplanar waveguide fed slot, a metasurface superstrate, and a simple DC bias controlling circuit including PIN diode switches. A penta-polarized reconfigurable antenna with mushroom type metamaterial as reported in [51] achieves polarization reconfigurability with the aid of crossed H-shaped slot. [52] presents an antenna design with a truncated corner patch that works as a circular polarization source and a non-uniform metasurface acting like a parasitic element that aids to improve performance.

A low-profile broadband quad-polarization reconfigurable omnidirectional antenna is reported in [53]. The antenna design has a top loaded monopole for vertical polarization and a circular loop for horizontal polarization.

Paper [54] describes a structure consisting of ring radiation patch and six non-metallic columns. In both [53,54] PIN diodes are employed to obtain different polarization states.

A polarization reconfigurable antenna array for 5G application is discussed in [55]. The antenna is capable of switching its operation between two rotating modes with the help of four PIN diodes. Insertion loss is reduced and an improved matching of the feed circuit is observed. A defected Ground Structure is incorporated in [56]. The ground plane of the antenna is modified by embedding U-shaped slots in open ends and I-shaped slots in the short ends. A CPW fed antenna reported in [57] consists of two symmetrically placed inverted L-shaped slots that help to achieve polarization reconfigurability. Papers [55]-[57] are suitable for wireless applications.

HYBRID RECONFIGURATION

Frequency and Pattern Reconfigurable Antenna

Frequency and pattern reconfigurable antennas are used for radio navigations, satellite application and in 5G applications. Antenna designed in different shapes such as fork-shaped antennas, hexagonal shaped antennas and E-shaped patch can be made to operate at a certain frequency with the aid of PIN diodes as described in [58]-[61].

A fork shaped antenna presented in [58] exhibits frequency reconfigurability by varying the slot length and pattern reconfigurability is achieved by changing the path of current flow. Four oblique slits are introduced in a hexagonal patch antenna discussed in [60]. The structure thus is a combination of two hexagons and two pentagons. The antenna is suitable for big data wireless transfer and is used in cognitive radio application. Paper [61] reports a compact reconfigurable antenna with U-shaped and F-shaped slots designed on a polyimide substrate. On performing a bending analysis on the antenna structure, it was found that after a certain angle, the resonant frequency as well as the band of operation increase with the increase in bending angle.

An antenna which find application in 5G application is reported in [62]. NMOS transistors are used as switches that enable frequency tuning and pattern steering at different angles. Reconfigurability is hence achieved by changing the dimensions of patch and stub and steering angle depends upon the number of stubs incorporated. The design is fabricated using photolithographic techniques.

Coplanar waveguide feeding technique aims to achieve multi-band operation as observed in [63,64]. An electric-inductive-capacitive (ELC) resonator enclosed with a closed ring resonator (CRR) along with four parasitic elements exhibit frequency and pattern diversity. The omni-directional radiation pattern can be steered into bi-directional and unidirectional end-fire radiation patterns at multiple frequencies.

An asymmetric fractal antenna is designed by inserting a koch into the bow tie antenna to obtain the required frequency of operation for LTE WLAN applications. The optimization is done with the help of pattern search algorithms in [65,66]. The antenna proposed in [66] consists a U-shaped element constructed around an inset fed patch, separated by a slot in which a PIN diode is placed. The use of a single switching element and placement of control lines and biasing elements away from the radiating structure reduces the complexity of the design and helps to reduce distortions. Pattern search algorithms are used to optimise the length of the inset feed. This algorithm is fast and give accurate results thus reducing manual efforts.

While recent studies also focus on metamaterials and how they can improve antenna functionality, through the combination of a composite right/left-handed transmission line (CRLH-TL), an omni-directional pattern is obtained in the lower band and a broadside pattern in the higher band as in [67]. Varactors enable larger freedom for operation and help to control dispersion properties. The techniques of tuning dispersion can be further extended to other microwave circuits such as filters and resonators.

Table 1. Comparative study of frequency and pattern reconfigurable antenna

Ref	Resonant Frequency (GHz)	Number of Actuators	Antenna size(mm^2)	Gain
[58]	3.5-5.5	4 PIN diodes	23*29	1.1462–4.2702 dB
[59]	2.3-4.82	3 PIN diodes	30*4	Not specified
[60]	4.25/5.65/6.8/8.2	4 PIN diodes	40*40	6.4/2/3.6/1.9 dBi
[61]	2.3-3.8/4.5-5.1/6.3-6.8	2 PIN diodes	43*28	4 dB
[62]	28/38	18 NMOS Transistors	112*52	3.8/8.3/ 7.1 dBi
[63]	2.3-9.6.	15 PIN diodes	40*60	>2 dB
[64]	1.74-4.84	5 PIN diodes	34*29	0.86 -3.86 dBi
[65]	1.8/5.4	1 PIN diodes	30*24	4.5/3.9 dBi
[66]	2.47/3.8/5.36	1 PIN diodes	66*58	5.34 dBi
[67]	2.5/3.5	6 Varactors	80*80	1.21-6.9 dBi

Pattern and Polarization Reconfigurable Antenna

Radiation pattern and polarization reconfigurability can enhance the capacity of communication systems, avoid polarization mismatching and improve signal strength. In [68] pattern reconfiguration is realized by adjusting the PIN diode switches on the metasurface and the polarization reconfiguration is controlled by the PIN diode switches on the ground plane. Thus, reconfiguration can be achieved at every frequency point in a continuous frequency band. A semi loop antenna having only one metal surface is presented in [69]. Asymmetric coplanar strip line (ACPS) circular ring along with PIN diodes change the modes of the CPW, producing vertical and horizontal polarization. A resonance at 2.4GHz with low cross polarization is observed.A liquid-based reconfigurable antenna exhibiting omni directional and unidirectional patterns is reported in [70]. Pattern and polarization reconfigurability can be achieved by changing the flow of the dielectric liquid, thus forming a parasitic liquid dielectric resonator antenna (DRA) beside a central DRA.

A simple antenna structure composed of radiating metal strips and a bi-stable glass fibre-reinforced polymer (GFRP) substrate is proposed in [71]. Reconfiguration is achieved by mechanically deforming the substrate. The antenna is robust, easy to fabricate and does not use redundant components. They find applications in global positioning system, mobile communication and can also be used as payload of a satellite.

Frequency and Polarization Reconfigurable Antenna

A compact frequency and polarization reconfigurable antenna is presented in [72,73] that can be used for GPS, wireless and mobile telecommunication applications. Truncated corners of the patch help to switch between linear and circular polarization. Frequency diversity is established using strip lines parallel to the square patch in [72].

An active AMC structure loaded with varactors in reported in [74]. A frequency tuning of 1:56:1 is obtained in linear polarization (LP) and 1:28:1 for right-/left-handed circular polarization (R/LHCP) states is observed. Paper [75] reports an array fed by a microstrip-line power divider and short-circuited varactor diode used per patch element. Frequency and polarization reconfigurability is achieved through tuning and detuning of the varactor capacitance. Due to its simple geometry, the design is further extended to larger arrays. An ellipsis Super shape Patch Antenna (SPA) discussed in [76] produces a wider intrinsic bandwidth compared to a rectangular patch antenna of comparable dimension. By introducing PIN diodes into the design, the operating bandwidth of the antenna can be changed. Desired polarization can be obtained by varying the values of amplitude and phase of ports.

A dipole antenna for frequency and polarization reconfigurability is reported in [77]. The antenna structure consists of two symmetric bow-tie arms and switching circuits. PIN diode help to vary the surface current at different frequencies. Six modes: two single-band linear polarization (LP) modes, two dual-band LP modes and two dual-band cross polarization (CP) modes are obtained. The antenna is suitable for applications involving indoor wireless communication and mobile communication.

CONCLUSION

In this paper various types of reconfiguration are classified and reviewed. The structural design of antenna along with the techniques used to achieve reconfigurability which can be broadly classified as electrical, optical and mechanical methodologies is discussed in detail. A reconfigurable antenna is capable of modifying its properties according to the changing system requirements. Whereas, a compound reconfigurable antenna modifies its dual characters within the same antenna system. While, the development on reconfigurable antenna has been mainly focused on the innovations in antenna structures and their feeding mechanisms, it is also necessary to focus on features like gain enhancement, wideband operation and mechanisms to handle high power. As the changing scenario creates an increasing demand for multifunctional antenna systems, it is also necessary to understand the different reconfiguration techniques and commercial applications of reconfigurable antennas.

FUNDING: None

CONFLICT OF INTEREST

The author declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

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