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A Review of Reconfigurable Antenna for Wireless Communication Systems

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Abstract**—** Reconfigurable antenna is an antenna that capable to reconfigure its characteristics such as frequency, pattern, bandwidth, and polarization to adapt to the environment. The reconfiguration is not limited to a single characteristic but can be a combination of different characteristics depending on the application. The purpose of a reconfigurable antenna is to reduce the complexity of an antenna system operating over a wide frequency band, and to reduce the need of multiple antennas to perform a specific task, providing a relatively large bandwidth and achieving a dynamical reconfiguration within a few microseconds to meet the requirements of the modern wireless communication systems. This paper presents the concept of reconfigurable antenna and details the emerging technologies that make reconfigurable antennas possible, how to achieve reconfigurability in terms of different parameters with switching mechanism and the different feeding techniques used are discussed.

Keywords**—** Reconfigurable antenna, reconfigurable frequency, reconfigurable radiation pattern, a reconfigurable polarization.

I. INTRODUCTION

Modern wireless systems usually have multiple standards so that they require modern antenna systems with multiple capabilities and functions without enlarging occupied volume. The reconfigurable antenna becomes a popular solution because it provides variety in antenna performance to satisfy diverse communication requirements and decrease the interference [1]. Single antenna can be used for multipurpose application by changing their parameter such as frequency, pattern or polarization [2]. With multiband capability, reconfigurable antennas can utilize more efficiently radio frequency spectrum, facilitating a better access to wireless services in modern radio transceivers [3].

The ability to control the operating band of an antenna system can have many useful applications. Systems that operate in an acquire and track configuration would see a benefit from active bandwidth control. In such systems a wide band search mode is first employed to find a desired signal then a narrow band track mode is used to follow only that signal. Utilizing active antenna bandwidth control, a single antenna would function for both the wide band and narrow band configurations providing the rejection of unwanted signals with the antenna hardware. This ability to move a portion of the RF filtering out of the receiver and onto the antenna itself will also aid in reducing the complexity of the often expensive RF processing subsystems.

The radiation pattern and functionality of an antenna are related to the current distribution on its surface. Any slight change in the geometrical configuration of the structure will create new current paths and new radiation edges, which give the antenna new resonances and operational functionality, a lot of reconfigurable antennas make use of switches, rotating parts and many other components to vary the current distribution over the physical surface of the antenna. This constitutes a transformation or a translation from a physical activity into an electrical behaviour change. [4]

This paper aims to present a briefly survey on the different types of reconfigurable antennas and display the switching techniques that used to achieved the reconfigurability of the antenna.

II. SWITCHING TECHNIQUES.

The techniques that can be used for reconfigurability in antennas are many such as by using active switches based on micro electro mechanical systems (MEMS), PIN diodes, varactor diodes or using a mechanical movement of different patches by using stepper motors, bending of one or more of its parts or even using a photo-conductive switches. Another way to achieve controllable antenna features is to bias different antenna parts at different times, appropriately feed antenna array and reconfigure feeding networks [5]. Varactor diodes for frequency tuning. These are normally accompanied by biasing lines and high biasing voltages. PIN diodes in reconfigurable antennas have also gained in popularity, as they require lower biasing voltages. MEMS are limited by low-power handling capabilities and mechanical failure due to moving parts. All these designs require metallic biasing lines to be attached to the antenna which can interfere with the radiation patterns. Using fibre optic cables instead to activate optical switches have the advantage of being electromagnetically transparent and so do not interfere with the radiation patterns of the antenna [6].

Based on some properties, the basic comparisons between the different types of switches such as MEMS, PIN diodes, Varactor, optical switches, physical technique, and smart materials are tabulated in Table 1.

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TABLE 1 COMPARISON OF DIFFERENT WITH SWITCHING TYPES.

Tunable component	Advantages	Disadvantages
RF MEMS	Insertion loss is less, very high linearity, good isolation, low power loss and consumes no DC power used.	High control voltage is needed (50-100 V) poor reliability, switching speed is slow, discrete tuning, limited lifecycle.
PIN diodes	Driving voltage needed is less, tuning speed and power handling capabilities is high, very low cost, and very reliable as no rotating part.	In its ON state needs high DC bias voltage and consumes large amount of energy, on linear characteristics, poor quality factor and discrete tuning.
Varactor	It gives continuous tuning, and consumes less energy than others.	Highly nonlinear and have low dynamic range and require complex circuitry.
Optical switches	More reliable , linear characteristics , no biasing circuits	Lossy behavior, complex activation mechanism
Physical technique	Does not require bias circuits which eliminates interference , losses and radiation pattern distortion	Slow response, cost, power requirements, size, complex integration,
Smart materials	Size as it has high relative permittivity, permeability	Low efficiency[5]

III. TYPES OF RECONFIGURABLE ANTENNA.

The Ability to reconfigure any parameter of the antenna according to the requirement is defined as reconfigurability [7]. Antenna with reconfigurable feature can be of large variety and different shapes and sizes, there are four reconfiguration properties that a reconfigurable antenna can achieve. An antenna can exhibit a reconfigurable frequency of operation, a reconfigurable radiation pattern, a reconfigurable polarization behaviour, or a combination of any of these properties [8].

A. Frequency Reconfigurable Antenna.

An antenna operating on multiple frequency bands has gained a lot of attention due to the proliferation of modern wireless technology and customer demand for multiple services in a single device. Conventionally, a frequency band is associated with a particular wireless service; therefore multi-band antenna is required to support multiple services in a single wireless device. Multi-band antennas can operate over different frequency bands exhibiting good gain and stable radiation pattern. Albeit, multiband antennas transmit electromagnetic waves simultaneously at all the supported frequencies in addition to the desired frequency [9].

Below are some of the papers that explain how to implement and design changeable antennas by frequency, and the techniques used to switch.

Frequency Reconfigurable antenna they planned circular patch with back coaxial feed instrument and the PIN diode is used as a switch and it is mounted on the arc shaped slot in paper [10]. Five PIN diodes as switches are symmetrically located in the slot by 20º, 32º, 90º, 148º, and 160º. The simulated and measured results show that the antenna can operate from 1.82GHz to 2.46GHz, which is located in DCS1800 (1.71–1.88GHz), UMTS (2.11–2.20GHz), WiBro (2.3–2.4GHz), and Bluetooth (2.4–2.48GHz) frequency bands and so forth The simulated design is shown in Figure 1, the experimental results indicate good agreement with the simulation results with little resonant frequency offset as displayed in Figure 2.

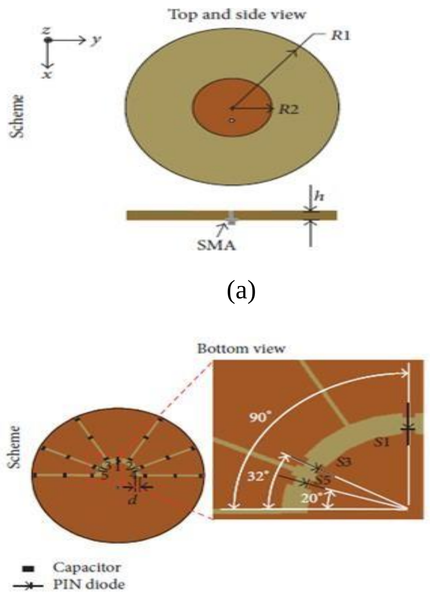

Figure 1. Simulated design, (a) Top view, (b) Side view

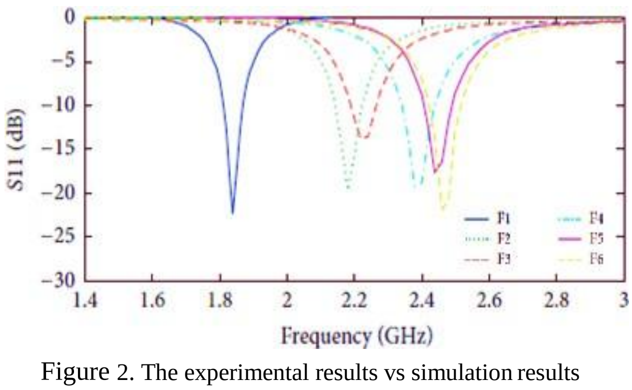

Figure 2. The experimental results vs simulation results

In [11], a reconfigurable printed patch (50 × 60 ×1.6mm3) antenna capable of communication over eight different 4G LTE bands is proposed. The reconfigurability in this patch antenna is achieved using three RF PIN diodes as switches. These switches are controlled by three separate DC lines. Figure 3 shows a top view and a fabricated prototype of the proposed antenna.

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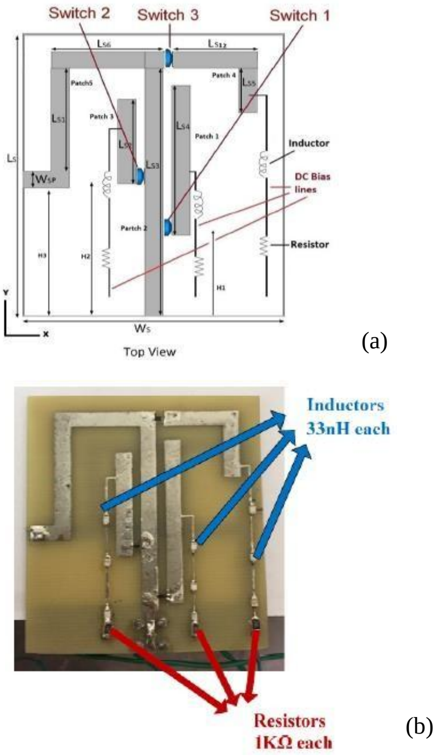


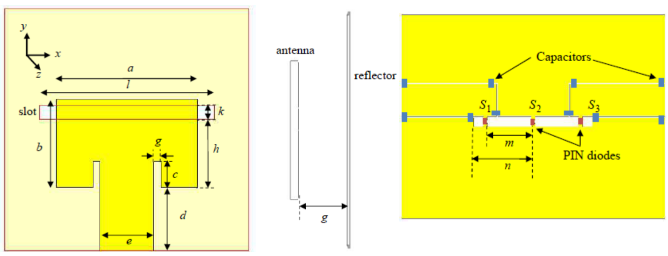
(a)

(b)

Figure 3. Proposed antenna. (a) Top view (b) A fabricated prototype

It is clear from the results for S11 < -10 dB that this reconfigurable antenna covers nine different LTE/WLAN frequency bands including 0.9 GHz, 1.4 GHz, 1.5 GHz, 1.6 GHz, 1.7 GHz, 1.8 GHz, 2.5 GHz, 2.6 GHz, and 3.5 GHz bands under different switching combinations/modes.

In paper [12], a frequency reconfigurable patch-slot antenna with directional radiation pattern has been designed and measured. Geometry of the antenna is shown in Figure 4.
It has been demonstrated that the frequency reconfigurability can be achieved by inserting switches in the slot of the antenna. The antenna is capable to reconfigure up to six different frequency bands from 1.7 GHz to 3.5 GHz.



(a) (b) (c)

Figure 4. Geometry of the proposed antenna, (a) front view, (b) side view, and (c) back view of the proposed antenna.

The microstrip patch antenna produces three different frequency bands with directional radiation pattern while the microstrip slot antenna produces another three frequency bands with bidirectional radiation pattern. Due to the reflector placed at the back of the antenna, the radiation pattern is directional at all frequency bands.
Simulated and measured reflection coefficient of the proposed antenna is illustrated in Figure 5. Form the results, it is clear that the antenna has a different resonant frequencies such as 1.9 GHz, 2.4 GHz, 3 GHz, and 3.5 GHz.

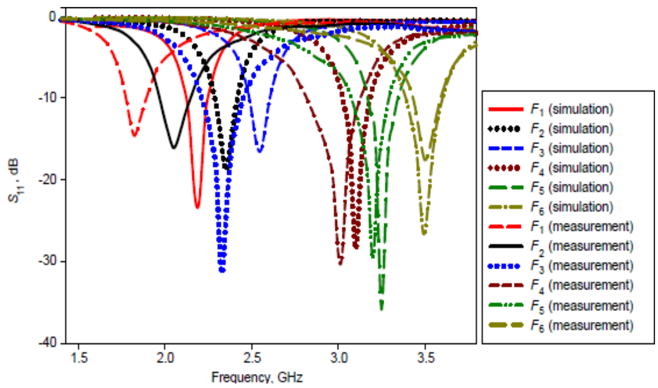


Figure 5. Simulated and measured reflection coefficient in dB of the proposed antenna.

In work [13], a reconfigurable antenna design is investigated. The antenna patch has a circular form that rotates to feed different shapes. Frequency reconfigurability is achieved while maintaining the same omni-directional radiation pattern in both the E and H planes. Four different rotations can be done making the antenna cover five different bands (from 2 GHz up to 7 GHz) correspondingly. A complete agreement was found between the simulated and the measured data. In this paper the photoconductive switch was used. Photoconductive switches usually require a high laser pumped power level to excite enough electrons from the valence band to the construction in order to make the switch conductive.
The corresponding antenna structure is shown in Figure 6. It consists of two layers. The bottom layer is a partial ground to allow radiation above and below the substrate, and the top layer is a rotating circular shape. The chosen substrate is Taconic TLY with a dielectric constant of 2.2 and a thickness of 1.6 mm.

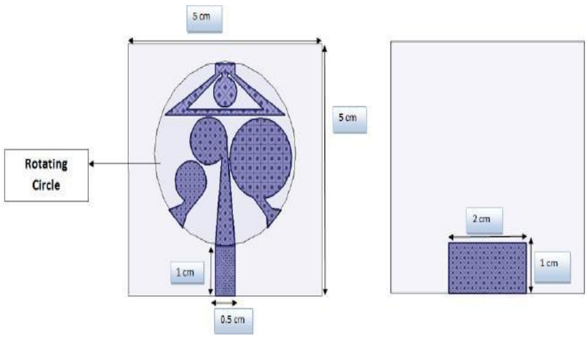


Figure. 6. Antenna structure (a) top layer (b) bottom layer.

A 4×4 frequency reconfigurable antenna array using periodic dumbbell slotted aperture is presented in [14], the antenna array with size 80×80 mm is designed and fabricated by considering

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the switching activities in ideal condition, meaning that without real PIN diode.

A corporate feed network is used as a power divider between antenna elements. The 50 Ω transmission line consists of 70.7 Ω λ/4 transformer with 100 Ω power divider is designed with two conditions by referring to the "OPEN" and "SHORT" condition of feeding network as shown in Figures 7 and 8, respectively.

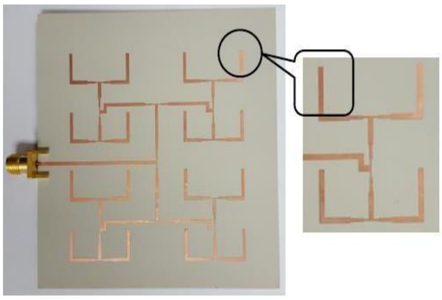


Figure 7. Feed line in "OPEN" condition.

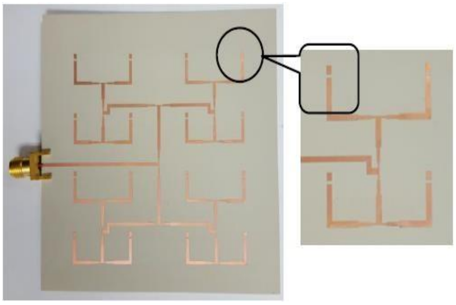


Figure 8. Feed line in "SHORT" condition.

The obtained results show the fabricated responses are slightly shifted compared with simulated response. Where in "OPEN" feeding line the antenna resonates at 7.39 GHz, while in "SHORT" feeding line the fabricated antenna resonate at 8.76 GHz. The directivity of the proposed antenna seems consistent where it is 15.26 dBi for "OFF" condition, and 17.78 dBi for "ON" condition for measured mode; and it provides very high values to support outdoor wireless communication systems.

B. Reconfigurable Radiation Pattern.

The pattern reconfigurable antenna in particular has received much attention because manipulation of the radiation pattern enables avoidance of noise sources, improved security by directing signals only toward intended users, sensibility of signal, intentional jamming, improved beam steering capability of phased array systems, and diversity systems [15]. Some of the papers that studied this type of antenna will be clarified.

In [16], a compact microstrip antenna with radiation pattern reconfigurability using MEMS switches is proposed and investigated. Six MEMS switches are used to respectively connect or disconnect the fan-shaped coupling cells and fan-shaped radiations cells of the proposed antenna, changing the current distribution and achieving radiation pattern diversity.

Twelve basic operation states (state 1 to state 12) are obtained for the proposed antenna. Sequentially switching operation states from state 1 to state 12 can rotate the main radiation beam by 30° from 0° to 330° in azimuth plane, maintaining 35° in elevation plane. Moreover, this novel pattern-reconfigurable antenna can operate around 4 GHz stably with all operation states. Figure 9 exposed Geometry of the proposed antenna.

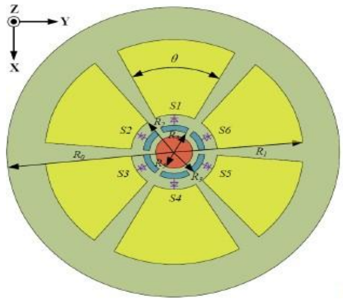
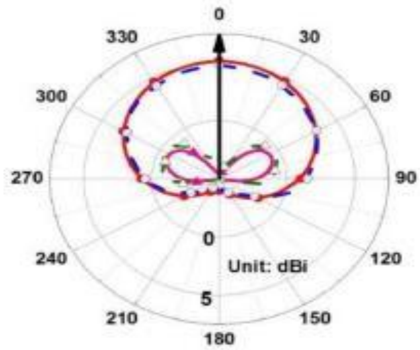
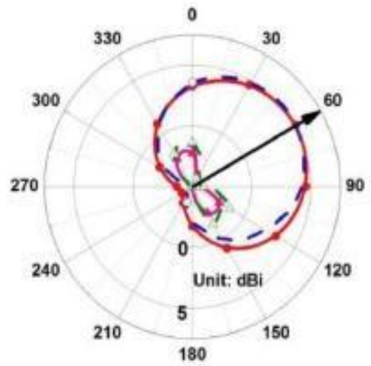


Figure 9. Geometry of the proposed pattern-reconfigurable antenna

Simulated and measured radiation patterns (azimuth plane) for different three operation states is shown in Figure 10, state 1when (S1=1, S2 ,S3, S4, S5 and S6=0), State 2 (S1=0, S2=1, S3, S4, S5, an S6 =0) and state 2 (S1, S2, S5, S6, =0 and S3, S4 =1).



State 1



State 2

Figure 10 Simulated and measured radiation patterns (azimuth plane) for different operation states

In [17], a compact and multidirectional pattern-reconfigurable antenna is presented. The antenna design is based on the

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principles of the common Yagi–Uda antenna. The main driven circular patch is surrounded by several parasitic circular patches, and four pin diode switches are used to short/open the parasitic patches to ground. The proposed antenna was fabricated and evaluated experimentally, and measured results are in good agreement with the simulated. The operating bandwidth ranges from 2.36 to 2.39 GHz, and the antenna can provide beam control at nine different angular directions (ϕ,θ) = (0° , 0°) (0° , 23°), (45°, 22°), (90° , 24°), (135° , 22°), (180° , 24°), (225° , 25°), (270° , 25°), and (315° , 22°) with realized gain levels greater than 7.0 dBi. In Figure 11. Geometry of the proposed antenna.

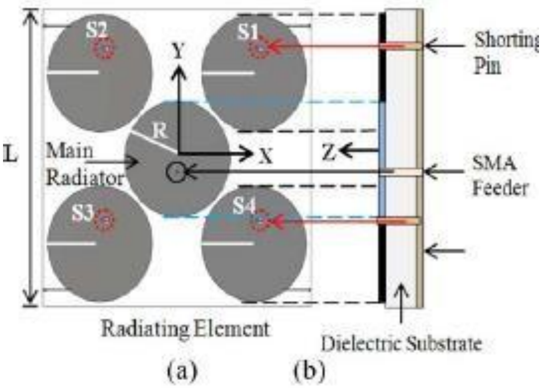
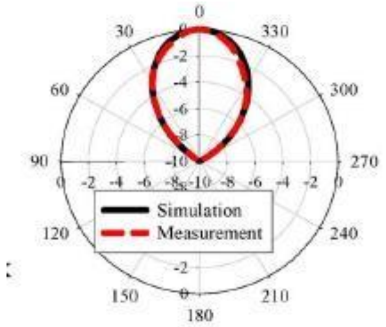
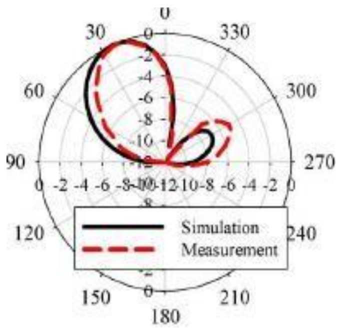


Figure 11. Geometry of the proposed antenna. (a) Top view. (b) Side view.

Simulated and measured radiation pattern at 2.38 GHz, for different states shown in Figure 12. (a) ALL PIN diodes are ON, Phi=0, (b) PIN diodes S1 and S4 are OFF, Phi=0.



(a)



(b)

Figure 12. Simulated and measured radiation pattern at 2.38 GHz.

In [18], this paper presents the use of micro-electromechanical systems (MEMS) switches to realize the radiation pattern reconfiguration of microstrip antenna, which works in Ka band. The antenna was fabricated on a silicon substrate and designed to reconfigure radiation pattern at the operation frequency of 35 GHz. The simulation results show that by controlling the states of MEMS switches between the driven element and two parasitic elements, the antenna can achieve reconfiguring into three maximum radiation directions in the H-plane. The layout of the antenna is shown in Figure 13. The measured maximum radiation directions of modes 1, modes-2, modes-3 and modes-4 are ϕ = 17°, -25.8°, 3.5°, 0.7° and gains of four modes at the maximum radiation direction are 5.78 dBi, 6.49 dBi, 7.24 dBi and 6.31 dBi, respectively. The measured results are closely consistent with the simulation ones.

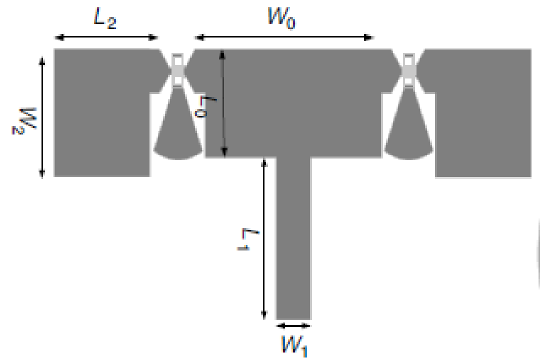


Figure. 13. Top view of proposed reconfigurable antenna

Figure 14 shown the simulation results of radiation pattern in H-plane for different modes.

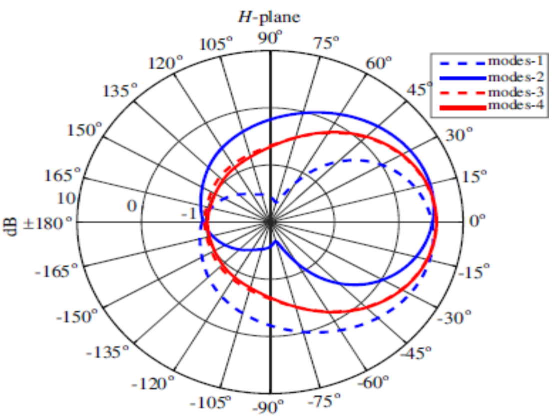


Figure 14. The simulation results of radiation pattern in H-plane for different modes.

A radiation pattern reconfigurable microstrip antenna is proposed in [19]. There is the presence of four PIN diodes as switches to control the main beam. Different possibilities of beam rotation is achieved by activating the switches; the antenna main beam rotates by 90° in every step in the azimuth planes, with 30° deflection in the elevation planes. Here the operating frequency attained is 3.44-3.6 GHz which is used for WiMAX systems. In Figure 15 proposed design and implemented antenna design is presented.

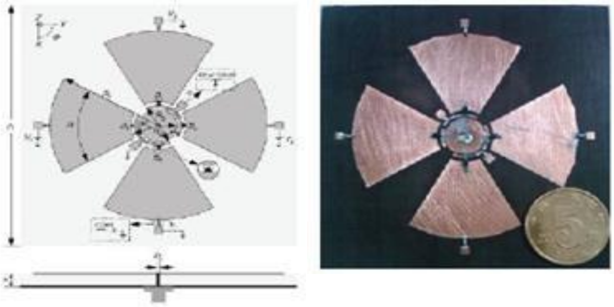
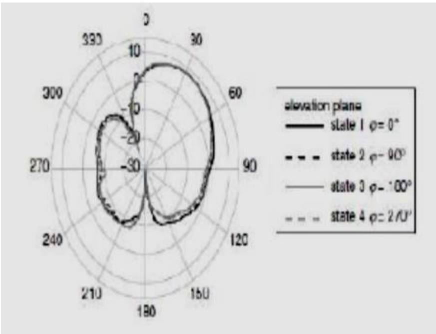
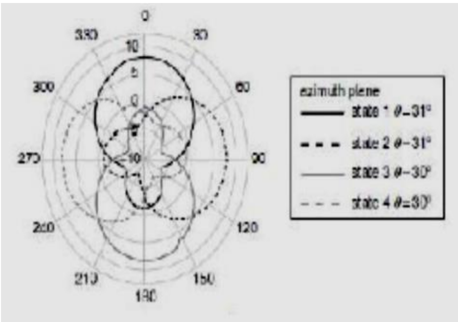


Figure 15. Geometry of proposed antenna

Measured radiation patterns at 3.5 GHz Elevation plane and Azimuth plane are given in Figure 16.



(a)



(b)

Fig 16.Measured radiation patterns at 3.5 GHz (a) Elevation plane , (b) Azimuth plane

In [20], The reconfigurable antenna consists of numerous metal cylinders arranged around the annular slot antenna. A shorting pin is inserted to allow the annular slot antenna to have an omnidirectional radiation pattern By controlling pin diodes associated with the metal cylinders, the antenna is capable of working up in different directions with a maximum working beam angle of 11.25° at a frequency of 1.05 GHz.

C. Reconfigurable Polarization.

The Polarization of Electromagnetic wave is defined as the orientation of electric field vector in space with respect to time. Polarization reconfiguration is the process of altering the orientation of the charges according to the requirement of the particular application. There are three types of EM wave polarizations Horizontal, Vertical and Circular (LHCP/RHCP) polarization.

In common horizontal and vertical polarization is termed as linear polarization and Reconfiguring the polarization among these three modes is said to be polarization reconfiguration. [8] Some related surveyed contents are listed.

In [21], this paper The antenna is capable of switching its polarization from right hand circular polarization (RHCP) to left hand circular polarization (LHCP) and vice versa. The design targets the WLAN IEEE 802.11 b/g frequency band (2.4–2.5 GHz) being used in various wireless communication systems. Good agreement is obtained between simulated and measured results. The antenna exhibits a 7% effective bandwidth from 2.4 GHz to 2.57 GHz with 8.7 dBic maximum gain. Figure 17 illustrates the geometry of a single-feed reconfigurable E-shaped patch antenna with integrated DC biasing circuit.

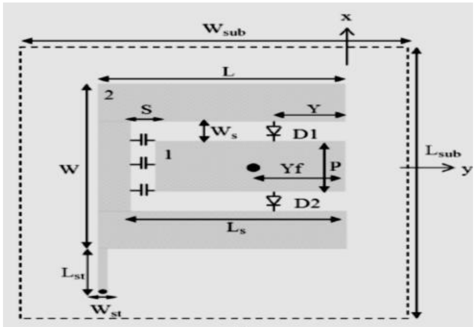


Fig 17 Geometry of a single-feed reconfigurable E-shaped patch antenna

Simulated and measured radiation pattern of the proposed antenna at 2.45 GHz shown in Figure 18: (a) x-z plane at state 3; (b) y-z plane at state 3; (c) x-z plane at state 4; and (d) y-z plane at state 4.

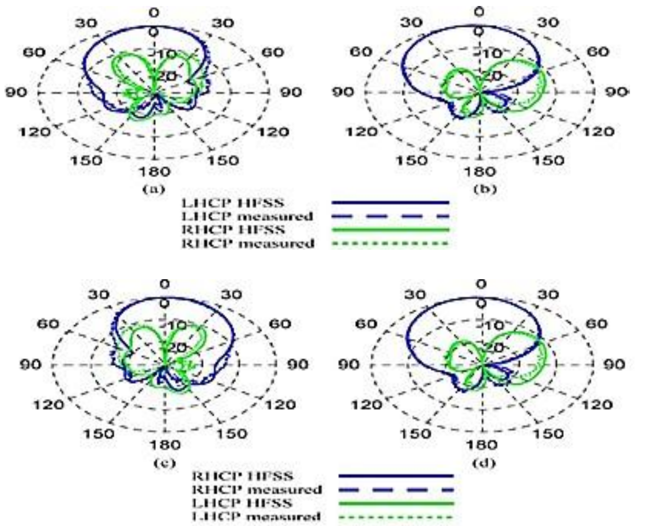


Figure 18. Simulated and measured radiation pattern of the proposed antenna at 2.45 GHz.

Paper [22] demonstrates a new microstrip dual-band polarization reconfigurable antenna for wireless local area network (WLAN) systems operating at 2.4 and 5.8 GHz. The antenna consists of a square microstrip patch that is aperture coupled to a microstrip line located along the diagonal line of

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the patch. By switching between the different states of PIN diodes, the proposed antenna can radiate either horizontal, vertical, or 45 linear polarization in the two frequency bands. Measured results on reflection coefficients and radiation patterns agree well with numerical simulations. The antenna consists of two substrate layers as shown in Figure 19 (a) and (b), respectively. A side view of the antenna structure is given in Figure 19 (c).

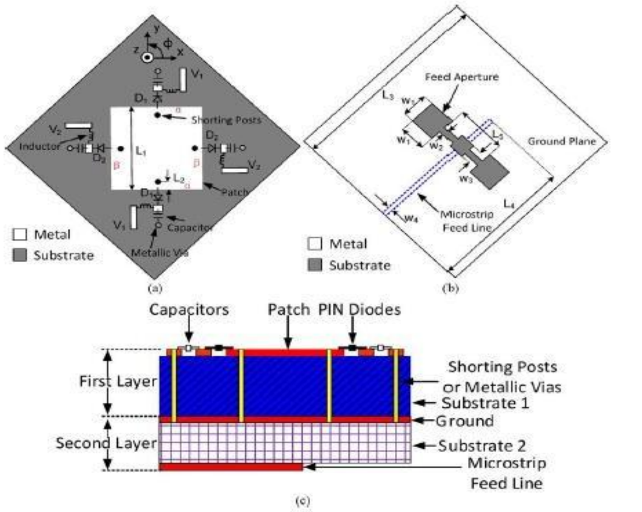

Figure 19. Schematics of the proposed antenna: (a) first layer, (b) second layer, (c) side view.

State 1, D1 is forward biased, D2 reversed biased and the polarization is oriented in x-direction. State 2, D1reversed biased, D2 forward biased and polarization y-oriented. And state 3 D1 and D2 is reversed biased, polarization is 45^{o}-oriented. Figure 20 shown simulated and measured E-plane normalized radiation patterns at 2.45 GHz for state 1, state 2 and state 3.

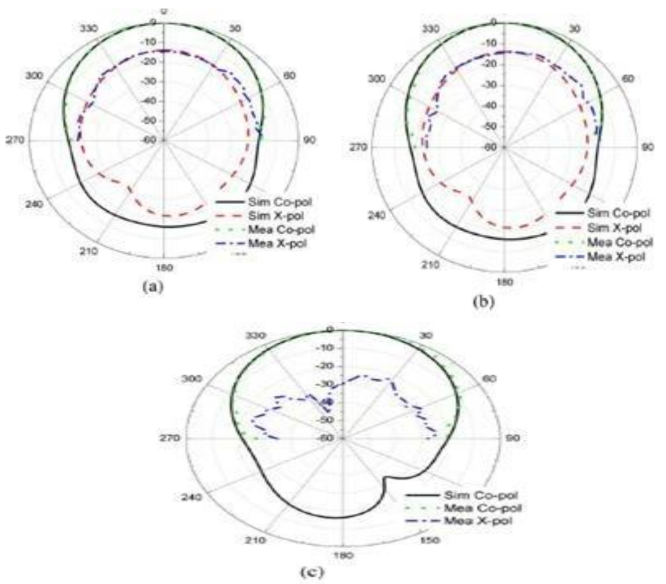

Figure 20. Simulated and measured E-plane normalized radiation patterns at 2.45 GHz: (a) State 1 (b) state 2 (c) state 3

A simple polarization and beam switching reconfigurable antenna is presented in [23]. The circular patch with annular slot is used as the radiating element. The circular metallic conductor positioned below the substrate with the air dielectric acts as the ground plane for the antenna. The proposed antenna is intended to operate at 2.4 GHz band with switchable polarization capability. Four PIN diodes have been placed diagonally covers the corresponding switch-ability, with good efficiency more than 80%. The detailed antenna geometry is shown in Figure 21.

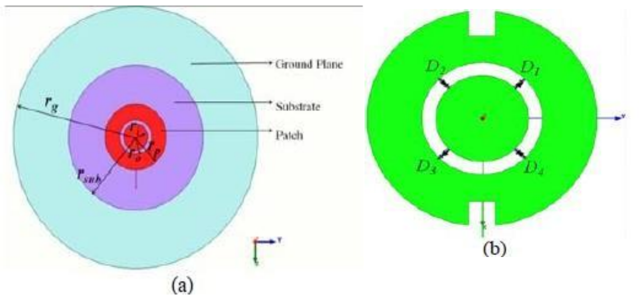

Figure 21. Geometry of Proposed Antenna (a) circular patch antenna with annular slot (LP Antenna) (b) with insertion of PIN diodes (CP Antenna)

The radiation patterns are obtained using EM simulations for E-plane is shown in Figure 22.

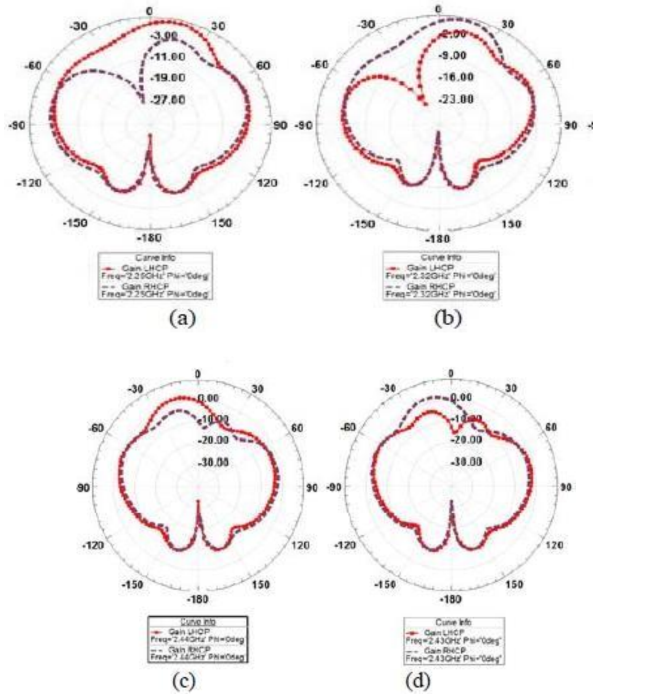

Figure 22. 2D-radiation patterns in E-plane for Antenna with four-diodes at resonant frequencies (a) D1 ON (b) D2 ON (c) D3 ON (d) D4 ON

In paper [24], a novel technique to design polarization reconfigurable antennas using two types of perturbations is presented. A square slotted ground plane and an L-shape microstrip segment are used simultaneously to obtain polarization reconfigurability. The square slot on the ground creates a negative perturbation. The negative perturbation can

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be eliminated by a positive perturbation that is made by adding an L-shape microstrip segment to the patch using a switching diode. The layout of the proposed reconfigurable antenna is illustrated in Figure 23. The polarization sense can be alternated between CP and LP at different frequencies by changing the state of a diode.

Moreover, the benefit of the this antenna is to use a single switching diode to achieve polarization and frequency diversities that helps to attain better gain than other conventional polarization reconfigurable antennas using multiple switching diodes.

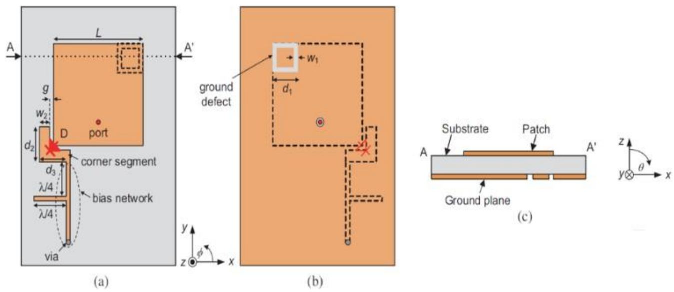

Figure 23. Schematic layout and cross sectional view (AA') of the proposed antenna.

In addition, this antenna is suitable to enhance polarization reconfigurability by integrating active components on the ground slot with simple bias circuit arrangement on the ground plane as the polarization reconfigurability achieved by defected ground perturbation is free from radiation performance degradation that is caused in the case of the patch side perturbation segment and bias networks. The antenna structure is very simple and compact; and it is attractive for wireless and satellite communication applications such as terrestrial digital broadcasting.

A new circular polarization reconfigurable antenna for 5G wireless communications is presented in [25]. The antenna that shown in Figure 24, containing a semicircular slot, was compact in size and had a good axial ratio and frequency response.

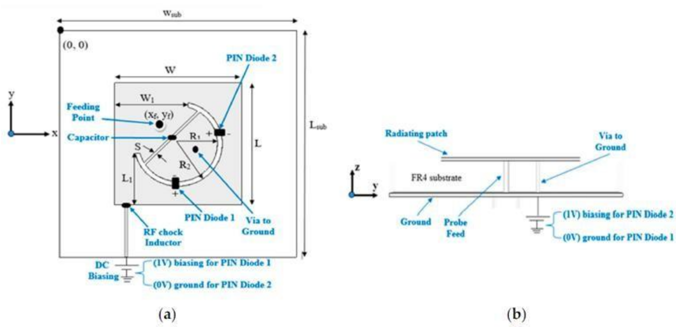

Figure 24. Proposed polarization-reconfigurable patch antenna: (a) Top view; (b) Side view.

Two PIN diode switches controlled the reconfiguration for both the right-hand and left-hand circular polarization. The proposed microstrip antenna was fabricated on an FR-4 substrate with a loss tangent of 0.02, and relative dielectric constant of 4.3. The radiating layer had a maximum size of $18.3 \times 18.3\ mm^2$, with 50 Ω coaxial probe feeding.

Reconfigurable orthogonal polarizations were achieved by changing the states of the two PIN diode switches, and the reflection coefficient |S11| was maintained, which is a strong benefit of this design.

The proposed antenna is reconfigurable for both RHCP and LHCP, by adjusting the DC biasing of two PIN diodes. The proposed design shows a 9.11% fractional bandwidth, with maximum realized gain of (3.1 to 4.8) dBi at 3.5 GHz, and a good axial ratio below 1.8 dB for both modes of operation.

Figure 25 shows the measured and simulated radiation patterns of the proposed structure for both configurations (RHCP and LHCP) at resonance frequencies.

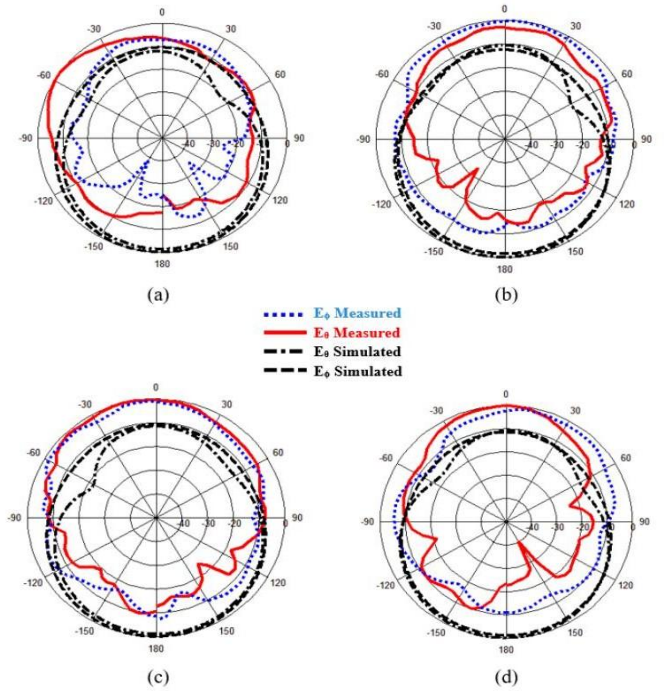

Figure 25. Simulated and measured radiation patterns of the proposed antenna: (a) ON-OFF state, xz plane; (b) ON-OFF state, yz plane; (c) OFF-ON state, xz plane; (d) OFF-ON state, yz plane.

D. *Hybrid Reconfigurable Antenna*

A dual-notch polarization and beam reconfigurable microstrip antenna is illustrated in [26]. It uses parasitic which incorporate switches to steer its beam away from boresight and dual notches that incorporate switches to reconfigure between linear and circular polarization. The antenna is a low profile microstrip patch antenna, which only uses a single feed, allowing it to be compact and simple in terms of its structure.

CP can be preserved for some steering angles. The dual-notch microstrip patch antenna is fed using a coaxial feed. The notches are located on a line angled at 45° to the location of the feed. The antenna is designed for LHCP operation; the size of the notches controls the CP operation of the antenna.

Figure 26 shows the structure of the proposed antenna. It is important to note that the copper switches are used; when

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copper is present the switch is ON when copper is not present the switch is OFF. However, PIN diodes can be used in the notches to switch between CP and LP.

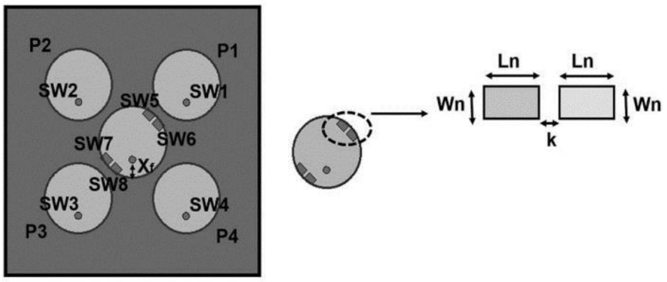

Figure 26. Structure of the dual-notch single element antenna

Form the results of mode 2 where the switches 1 and 4 are ON and other switches are OFF, it can be observed that the antenna supports CP over a range of steering angles at 10.3 GHz. More specifically, the AR is less than 3 dB from −55° up to 38°. This shows that the antenna is CP for several steering angles; and from the radiation pattern responses at mode 2, it can be observed that there is acceptable agreement between measurement and simulation. Measurement differs from simulation at the back lobe direction due to the presence of cables always affect the radiation performance of an antenna.

In [27] a novel flexible frequency and pattern reconfigurable antenna for wireless system is proposed. The antenna consists of two completely symmetrical radiating elements, a feedline and ground. Eight PIN diodes are loaded on the symmetric hexagonal split ring and monopole branches to select the radiation element. The geometry of the flexible reconfigurable antenna is presented in Figure 27.

The antenna with bias lines is fabricated on a Rogers5880 substrate. By controlling PIN diodes, the proposed antenna achieves frequency reconfiguration in the 1.9 GHz band with a bandwidth of 1.84–2.00 GHz and the 2.4 GHz band with a bandwidth of 2.27–2.49 GHz, and it is capable of steering the beam in two directions in each band.

When operating at 1.9 GHz band, the antenna can switch the pattern in the direction of φ = 60° and φ = 300°, and when operating at the 2.4 GHz band, the antenna can switch the pattern in the direction of φ = 34° and φ = 326°. Meanwhile, the antenna works at four states with omnidirectional radiation patterns.

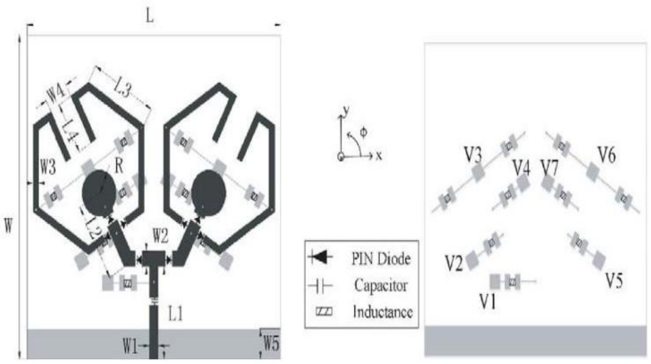

Figure 27. Geometry of the flexible reconfigurable antenna.

Simulated and measured radiation patterns of E plane at states of S1 (P1, P2 and P3 are ON and other diodes are OFF) and S3 (P5, P6 and P7 are ON and other diodes are OFF) are shown in Figure 28 at 1.9 GHz; and at states of S2 (P1 and P4 are ON and other diodes are OFF) and S4 (P5 and P8 are ON and other diodes are OFF) are shown in Figure 29 at 2.4 GHz. The simulation and measurement of the two states are basically in agreement.

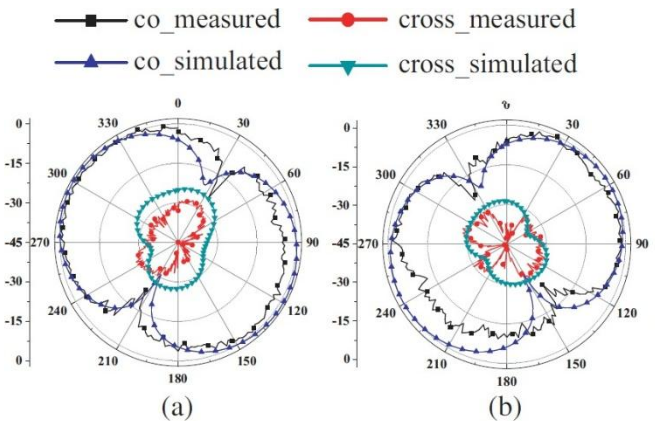

Figure 28. Radiation-patterns for different states of the proposed antenna at 1.9GHz. (a) E plane at S1. (b) E plane at S3.

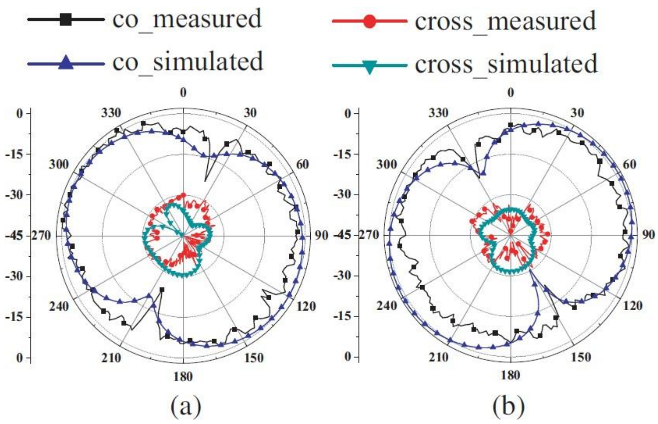

Figure 29. Radiation-patterns for different states of the proposed antenna at 2.4GHz. (a) E plane at S2. (b) E plane at S4.

IV. Conclusions

In this paper, a concepts of four types of reconfigurable antenna and switching techniques are presented in details.

From the brief survey of the reconfigurable antenna, it can be concluded that

The single reconfigurable antenna can be operated with more efficient for different modes than other types of antenna, and it gives an effective communication with low cost and less complexities.

The switching techniques that used to achieve a reconfigurability of the antenna are choice based on some specifications such as complexity of fabrication, biasing network required, time of switching, and the cost of switches. Each of the switching techniques has its own advantages and limitations. Due to the advantages of PIN diode, where it has a

low cost and a simple fabrication process, and possibility to avoid a complicated of the DC biasing circuit, it becomes a very common approach used to realize the reconfigurability of the antenna; and an important characteristic of PIN diode is it has a nearly pure resistance at microwave frequencies.
The good specifications of reconfigurable antennas make them a suitable choice to use in various communication applications such as radar systems, mobile and satellite communications.

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