Chapter 9
Reconfigurable Antenna: Analysis and Applications

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9.1 Background and History of Reconfigurable Antenna

The idea and concept of reconfigurable antennas have been investigated since the last few decades, and recently it gained much attention in industry and research due to advancement in modern wireless communication systems. In the early 1920s, some antennas with reconfigurable properties were designed for tuning the frequency and beam-steering purpose. However, the shifting between the frequencies and their characteristics parameters was controlled by external parameters.

The initial work related to the frequency reconfigurability was related to a patent by Norton in 1926 [1], and the frequency shifting was achieved by using variable inductive loading. In the early 1930s, another reconfigurable antenna consists of the nulls in the form of the two-element array was explained in [2], and it was steered by using a calibrated variable phase changer to determine the direction of arrival of a signal. The radiation pattern reconfigurable antenna was presented in [3] as shown in Fig. 9.1. It is rhombic-wire antenna, and the authors used motor with counterweights to change the dimension and angles of the proposed antenna. The Multiple-Unit Steerable Antenna (MUSA) was a six-element array of rhombic antennas with phase shifters at five of the elements [4], and the beams were steered in the elevation plane. The development of antennas with radiation pattern agility took place towards the

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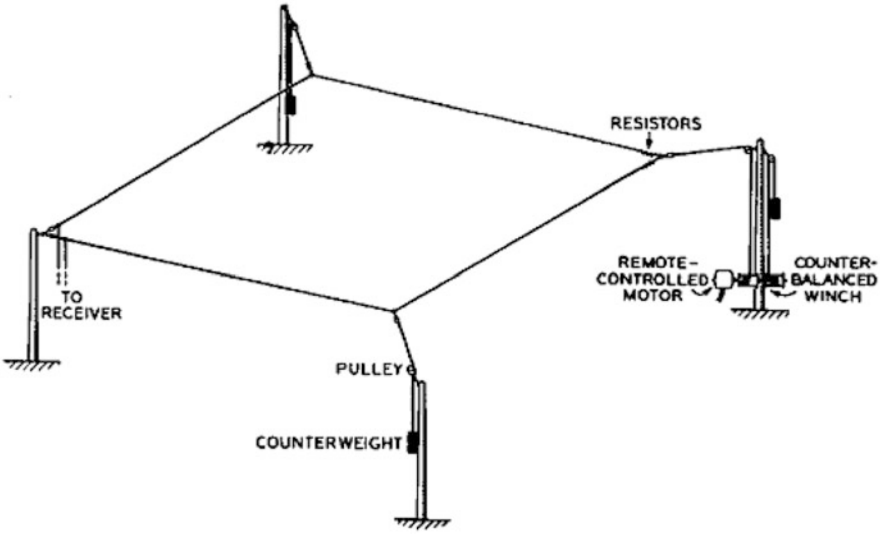


Fig. 9.1 Beam steerable rhombic antenna

1940s, basically driven by World War II when beam-scanning antennas played a key role in radar applications. The main techniques to achieve beam scanning were movable and multi-feed reactors and phased arrays. However, one can argue that strictly speaking, these designs are not reconfigurable antennas since there is not a clear interaction between the reconfiguration and the radiation mechanisms. Another example of a frequency tunable antenna was found in a patent by E. Werndl in 1942 where it is proposed to adjust the length of the dipole antenna by using a liquid metal [5]. This array had 13 rotary phase changers for beam steering [6].

In 1960, Rotman and Maestri reported one of the first few reconfigurable antennas that were realized by direct interaction between the reconfiguration and the radiation mechanisms [7]. This antenna is basically a radiating waveguide whose leaky modes were tuned electromechanically (mechanical movement by an electric motor) to produce multiple scanning beams. Some years after the first frequency tunable antennas, the first design of antennas with steerable radiation pattern appeared. In 1979, “reconfigurability” was defined as “the ability to adjust beam shapes upon the command” [8]. The authors used a six-beam antenna to dynamically change the coverage area for a communications satellite. Several additional papers reported other reconfigurable space-based arrays. On the other hand, the first hybrid patented reconfigurable antenna was claimed by Schaubert in [9], which demonstrates the concept of frequency agility and polarization reconfigurability. Even though most of the early stage designs involved bulky mechanical controls and limited functions, these pioneering works paved the way for furthering research and development on numerous reconfigurable antenna concepts. Inspired by the early RA concepts, researchers continued their investigations on this kind of controllable antenna and dealt with the implementation aspects for different practical applications.

In the 1990s, the advancement in the cellular networks, vast development of wireless sensor network, and telecommunication-based services open a new era of modern communication systems. To make the wireless system robust and portable was the priority at that time. Additionally, in the following years, other wireless standards (e.g. WiMAX, WLAN, Bluetooth, GPS, UMTS) were introduced in the market to fulfil the desire of modern communication systems. To support the different wireless standards and cover the wide area for quality service, a single wireless device must be multitasking to prove the high data rate, reliability, and high efficiency. To cover the problem, multiple fixed frequency antennas are a big challenge for compatible and small-size communication systems.

In the 2000s, there were vast researches conducted in the field of reconfigurable antennas on the different designs of frequency shifting, radiation pattern, and polarization switching applications [10, 11]. It is still a positive trend of research in the field of reconfigurable antennas in industry and academia. Due to recent development in the modern communication system, the pace is on the research of reconfigurable antenna to make controllable and adjustable according to the environment. Several designs have been explained in the past few years.

As mentioned, the physical modification technique is not always reliable, so electronic switching is a more promising technology, which is implemented in many of the latest designs. The changes in the smart materials were also incorporated in some designs [12–14]. Furthermore, other novel and robust designs investigated the printed antenna technology, which can be easily integrated with switching/tuning elements. Many antenna types like monopole, patch, Yagi-Uda, and dipole have been explored in the last few decades.

However, it remains a significant challenge to create a multi-mode, multi-functional integrated antenna to cope up with the latest wireless communication systems.

9.2 Introduction

Antenna development plays a key role in wireless technology with the rapidly increasing number of users in broadcasting, telecommunications, navigation, radar systems, military applications, and perhaps for future wireless communications, e.g., the cognitive radio. Passive antennas have reached a limit, and the use of a frequency reconfigurable antenna to extend operational bandwidth is a promising solution. The increasing number of users may lead to congestion of the existing spectrum allocation for wireless local area network (WLAN), wireless personal area network (WPAN), and cellular communications.

Since 2010, the reconfigurable antenna received a lot of attention due to its numerous applications and versatility in a wireless communication system such as radar system, cellular radio system, smart weapons protections, and wireless local area network system, as well as future applications, including the cognitive radio system. The reconfigurable antenna is capable of tunable adjustment on various parameters such as operating frequency, polarization, and radiation pattern.

9.3 Reconfigurable Techniques

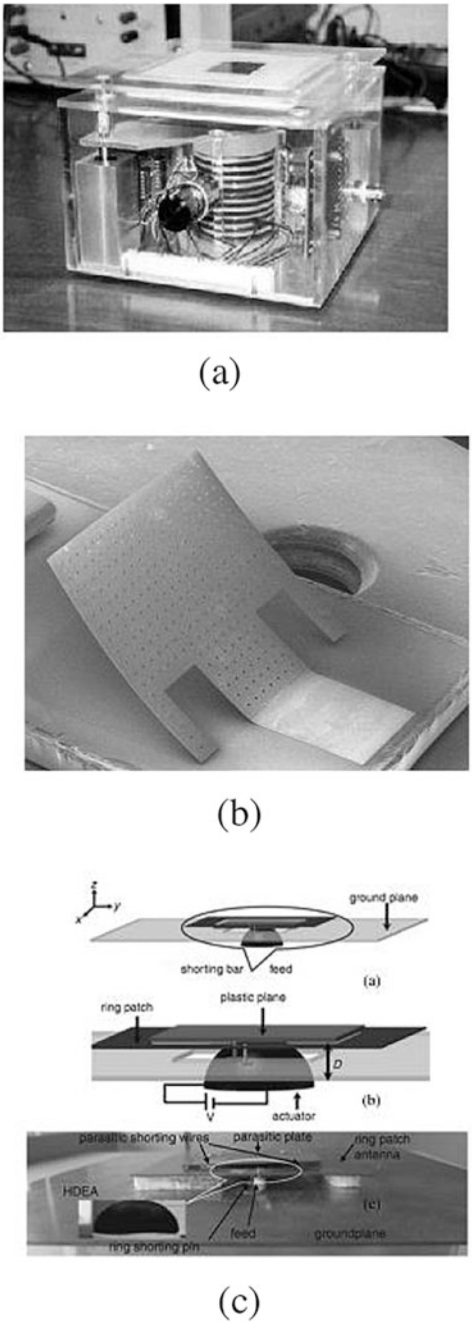
The concept of reconfigurability, when is referred to as the antenna, means the capability to change the characteristic antenna electrical parameters through electric or mechanic mechanisms. Ideally, a reconfigurable antenna is designed to change the resonant frequency, input impedance, bandwidth, polarization, and radiation pattern as a function of the required systems. Broadly speaking, there are five different mechanisms to reconfigure the antenna characteristics, which are discussed as follows.

9.3.1 Physical Reconfigurable Antenna

Physical reconfiguration is one basic and classic technique that was used in the early designs. In this scenario, the antenna characteristics can be modified by changing the antenna structure by mechanical systems. Over time, some novel and innovative ideas were developed by implementing the actuation methods, and this helps to change the antenna structure and shifting radiation parts to get the reconfigurable antenna parameters. For example, some devices like a stepper motor and linear actuators were implemented to fully and partially change the antenna dimension physically. The motor-control-based [15] and rotatable antennas [16] were presented successfully. Moreover, reconfigurable antennas based on electrostatic/magnetic actuator were also presented in [17], and they achieved satisfactory results. A frequency reconfigurable antenna consisting of parasitic elements was presented in [18] as shown in Fig. 9.2a, and frequency is tuned with the help of piezoelectric actuator. In another example, as shown in Fig. 9.2b, where frequency reconfiguration is obtained by adjusting the inclination angle, it was controlled magnetically to get the required resonant frequency [17]. Besides these, physical adjustment by using the liquid metals can also be used to attain the reconfigurability in the form of the stretchable antenna [19] as shown in Fig. 9.2c and metal parasitic beam-steering antenna.

Although physical modification has been presented successfully in many designs, it has some drawbacks like slow speed, less life cycle, and dependence on the antenna physical dimensions. Despite these, it is still a promising technology for higher frequency band application where other technologies are limited due to some electrical characteristics.

Fig. 9.2 (**a**) Peizoelectric actuator, (**b**) magnetic actuator, (**c**) electromechanical system



9.3.2 Electrical Switching Reconfigurable Antenna

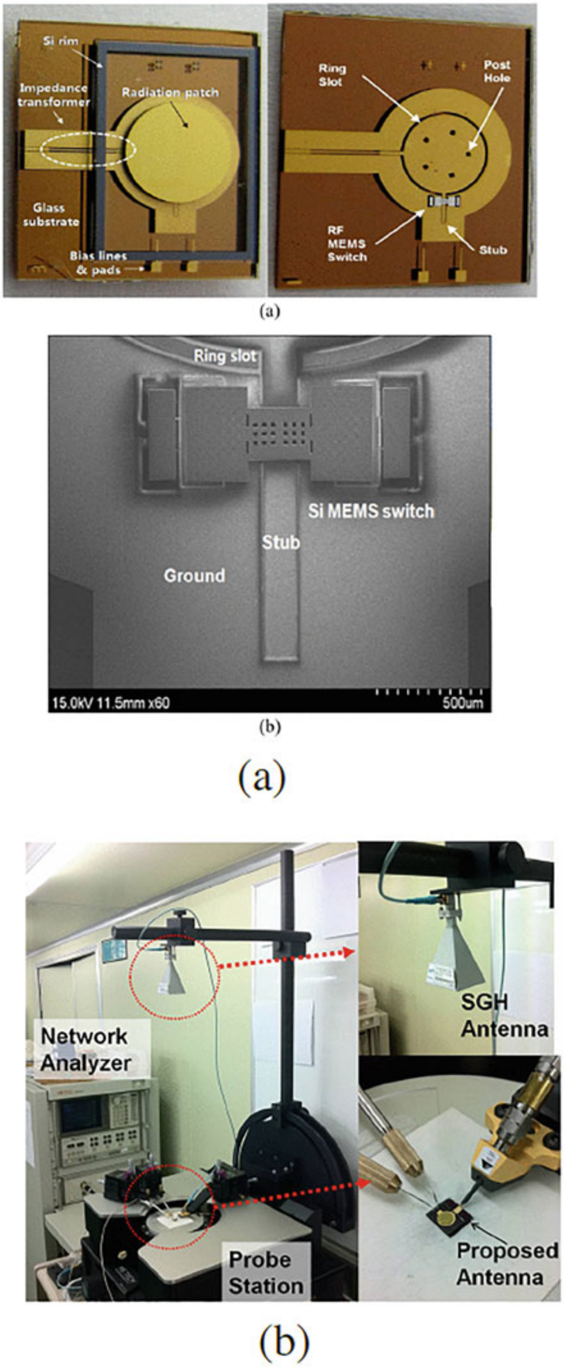
The antenna reconfiguration by using the electrical mechanism is the most promising technology, as it is easily integrable and very compatible with low-profile antenna technology. In this technique, no physical adjustment technology is required to change the antenna parameter to get the required frequency/radiation pattern/polarization. Some lumped elements are inserted at the specific position of an antenna for the reconfiguration purpose. There are two types of electrical reconfiguration technology-RF switch like PIN diode, RF MEMS, and GaAs FET [20], and the other one is tunable capacitors called varactor diodes. These switching elements can produce the change in impedance matching, surface current distribution, and electrical behaviour of an antenna [21].

PIN diode consists of heavily doped p-type and n-type regions that are separated by lightly doped intrinsic region. PIN diodes behave good RF switch by shifting between forward and reverse biasing states. It has a very low resistance at high frequencies in forward biasing and behaves as an open circuit in the reverse-biased state. PIN diodes are current-controlled, so they take very few milliwatts power to turn on the diodes. PIN diodes are widely used in practical application due to their properties like robustness, low insertion losses, ability to control large RF signal power, and fast switching speed.

The alternative elements for the semiconductor technology are the RF-MEMSs that are considered as tiny mechanical switch. The RF-MEMS uses low-power consumption, low insertion loss, high isolation, and better linearly properties. The polarization reconfigurable antennas using RF-MEMS switches were explained in [22]. The antenna consists of the ring slot and feeds with coupled ring slot aperture. A stub is added to generate the CP, and RF-MEMS switches are inserted between them to switch the polarization between linear and circular as shown in Fig. 9.3. The measurement results show that antenna impedance bandwidth of 22.90% and 3 dB axial ratio bandwidth is 13.07%. These are not a good candidate for microwave and mm-wave frequencies due to bad power handling capabilities and expensive packing process to protect it against the environment.

Despite the numerous advantages, they have some issues due to the non-linearity of the switches, signal loss, and interference due to biasing circuit and these disturb the impedance matching and reduce the antenna efficiency. The coupling between the biasing circuit and antenna radiation elements can damage the antenna performance parameters as well. Some techniques to reduce the coupling are to minimize the length of biasing line and, if possible, use the available biasing circuit and put biasing lines on the less intense near field for example on the ground plane. Another method is to load the biasing line inductively or on high resistive material.

Fig. 9.3 (**a**) Antenna prototype with intergration of RF-MEMS. (**b**) Setup for radiation pattern measurement



9.3.3 Material-Based Reconfigurable Antenna

The smart material with tunable properties is another prominent technology for antenna reconfiguration. The changes in the material characteristics are used to design the reconfigurable antenna design, and it is achieved by changing the material permittivity which modify the electrical length of an antenna. The electromagnetic characteristic (permittivity, r and permeability, r) of the material has a great impact on the properties of the antenna and RF microwave devices [11, 23, 24]. A static electric field is used to change the permittivity of a ferroelectric material, while the permeability of ferrite material is changed by applying the magnetic field [25, 26]. These materials have been used in many novel research works to obtain the antenna reconfigurability [27]. The frequency reconfigurable microstrip patch based on the ferrite material was presented in [25]. The required tuning frequency is obtained by changing the DC magnetic field. The reconfigurable microstrip antennas [24, 26] based on ferrite material show nonuniformity in the biasing and multi-field distribution, which limits their practical use.

Beam-steering antenna has been exclusively explored by the industry and academia. A leaky-wave antenna with stub array was explained in [28], and the phase shift can be tuned by changing the material properties. Another leaky-wave slot array antenna was designed in [29]. The ferroelectric base was used for this design. The permittivity of the material can be changed by applying the applied voltage between the top conducting layer and the bottom ground substrate. While changing the bias voltage, the permittivity of the ferromaterial changed and hence changes the beam direction.

Liquid crystal (LC) is another type of reconfigurable smart material, whose properties are affected by the molecular direction of the liquid and characteristics are also changed by applying the electric or magnetic field [30]. The beam-switchable reflection array antenna based on LC substrate was explained in [31]. By applying the voltage, the beam of the antenna can be tuned. Recently, some work has been done on this technology [32, 33]. Another material called vanadium dioxide (V_{O2}) by applying the thermal induction was also used for antenna reconfiguration [34] as shown in Fig. 9.4.

These smart materials provide the continuous reconfigurability; however, these are lossy and only provide solutions for short-range radios.

Tunable materials can achieve continuous reconfigurability with a simple control system; however, they are lossy and can provide reconfigurability for a limited range only. Additionally, proper modelling in the design process and reliability, sensitivity in the antenna operation, etc. are still notable, challenging issues. By overcoming these limitations and utilizing its potential, this technology could offer a great possibility for antenna reconfiguration soon, both at lower and higher frequency bands.

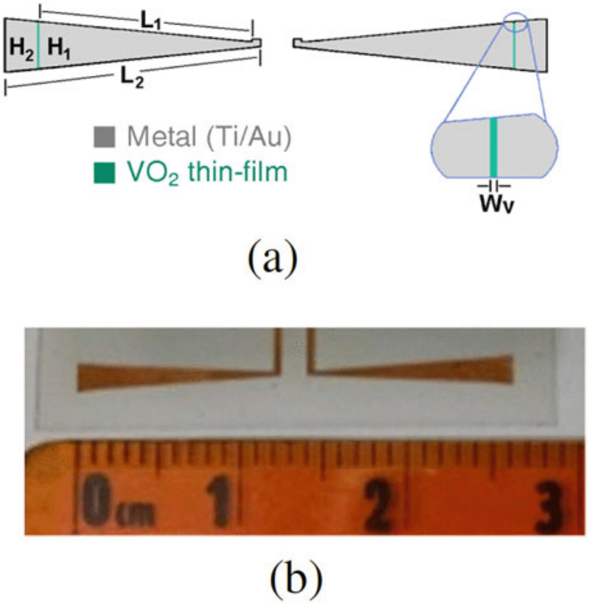


Fig. 9.4 (**a**) Layout of the reconfigurable bowtie antenna with (V_{O2}) and (**b**) fabricated bowtie antenna

9.3.4 Optical Switching Reconfigurable Antenna

Except for the techniques, optical reconfiguration has also gained much attention in recent years [35–37]. It deals with the photoconductive switches and does not need any complex biasing circuit and physical modification. Optical fibres are used for this purpose, and they need light for photo-switching [38]. When the laser is used to put the light, the charge density increased in the material, which also increases the conductivity of the semiconductor devices. This optical switching technique has a complex structure and needs some extra fibre that is costly. Although they have low distortion, they have lossy behaviour and slow switching speed as compared to lumped element switching technology. This technique has been implemented successfully in many designs.

As shown in Fig. 9.5, the frequency reconfigurable annual ring circular patch antenna by using the photoconductive switches was designed in [39], and these switches were activated by using the laser light and frequency is tuned between two application bands.

The frequency and beam reconfigurable antennas based on CPW to CPS (coplanar stripline) feed were explained in [40]. Two silicon switches are used in this printed dipole antenna as shown in Fig. 9.6. The antenna prototype shows good agreement, and there is a frequency shift of 40%. There are also 50 shifts in beam nulls of the bore-sight gain.

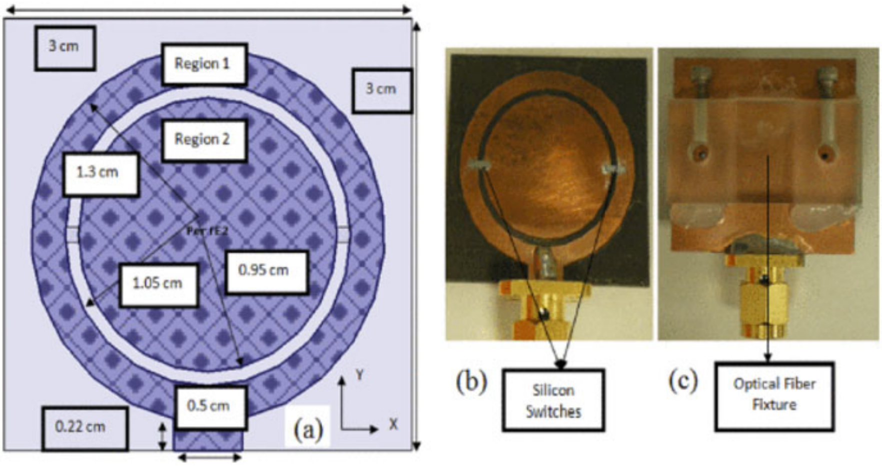


Fig. 9.5 (**a**) Antenna dimensions. (**b**) Antenna top layer. (**c**) Bottom view

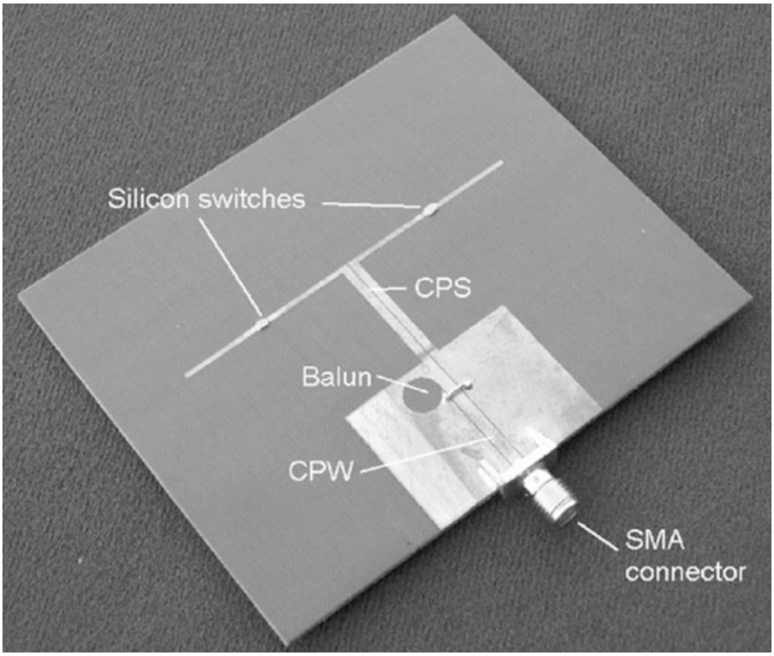
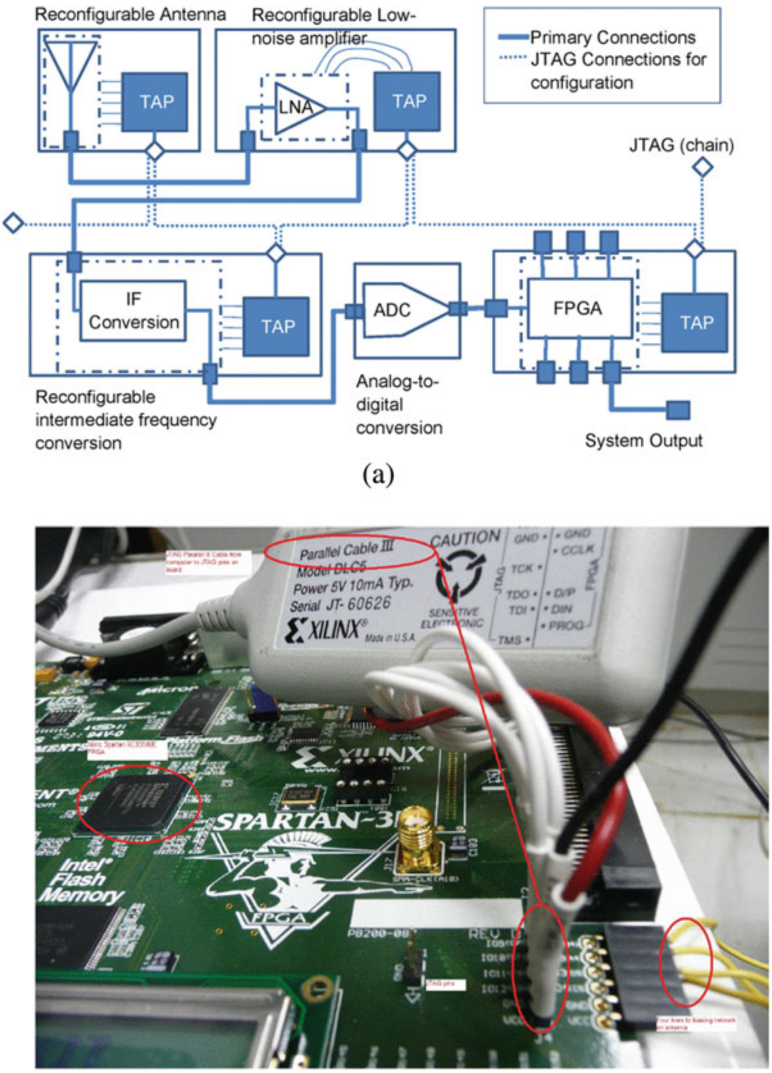


Fig. 9.6 The switched dipole antenna

The extensive research on this technology was not studied, but some attempts are made to further investigate technology in the form of frequency reconfigurable patch antenna [37] and notch-band UWB antenna [35] by using optical switching.

9.3.5 Software-Based Reconfigurable Antenna

Controlling a reconfigurable antenna with software can be done using many platforms such as Field Programmable Gate Arrays (FPGAs), Microcontroller, or Arduino Boards [69]. The frequency reconfigurable antenna based on FPGA was explained in [41]. In this work as shown in Fig. 9.7, the FPGA is used to on/off the



(a)

(b)

Fig. 9.7 (**a**) Reconfigurable antenna system (**b**). The paralleled III cable with FPGA board

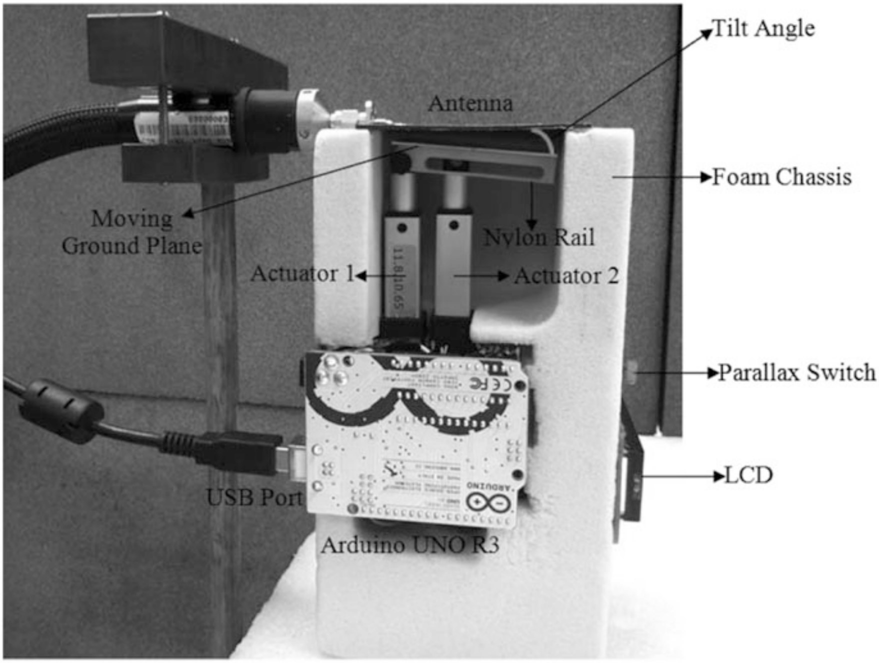


Fig. 9.8 Antenna prototype with controlling circuit

PIN diodes, which further connect and disconnect the different parts of an antenna to get the required frequency.

In another work [16], the LabVIEW is used to control the rotation of the stepper motor that is used for antenna reconfiguration purpose. The software control using LabVIEW and FPGA is a simple approach, and there is no need for complicated programming skills for antenna designer. Arduino boards are also used for antenna reconfigurability. In this scenario [42], the user can control the antenna movement and device when and how to change the antenna parts as per the requirement as shown in Fig. 9.8.

The surrounding activities also affect the antenna's operation. Such an example is explained in [43], where temperature sensors activate the thermal switches on the antenna structure. Motion detection is another technique, which also behaves as an active part for the biasing of the antenna reconfiguration. An infrared motion detector sensor [44] is used in the biasing circuit of varactor diode as shown in Fig. 9.9. It detects the motion and changes the voltage level of varactor diode to get the different frequency tunings.

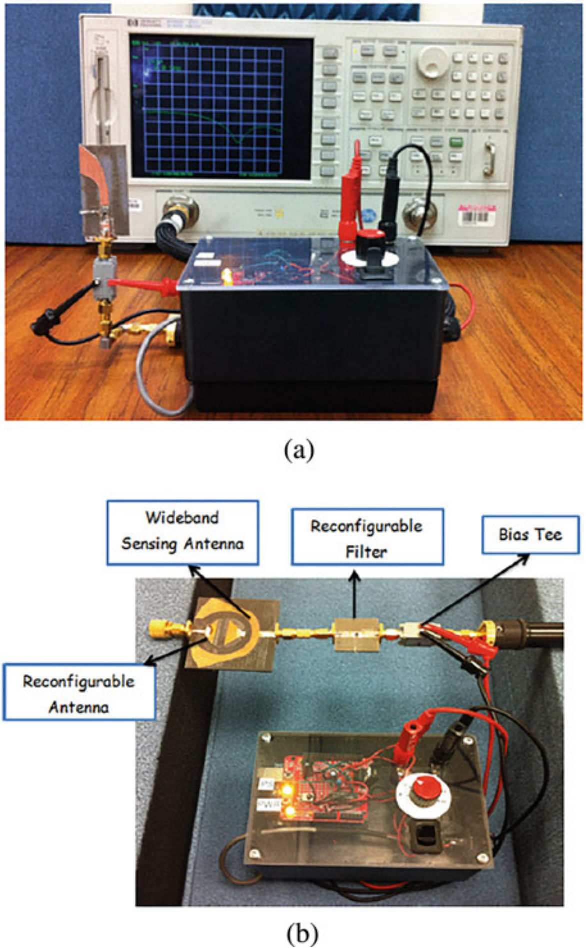


Fig. 9.9 (**a**) Measurement setup of the filtenna with surrounding (**b**). Reconfigurable filter with the wideband antenna awareness

9.4 Reconfigurable Antenna Properties

Reconfigurable antennas can be classified into four different categories.

9.4.1 Frequency Reconfigurable Antenna

Frequency reconfigurable antenna can adjust dynamically their frequency of operation. It can be achieved by changing the effective length and by connecting/disconnecting the different parts of an antenna to get the required resonant frequency. The successful application by changing length variation has been found in dipole [40, 45, 46], monopole/patch [47, 48], and slot antenna [49–51]. Moreover, the length of an antenna can adjust by changing the material property of the antenna without any physical alteration. The resonant frequency changes by changing the dielectric constant of the material. One can receive lower or higher resonant frequency with higher or lower permittivity, respectively. The printed antenna with dielectric variation was designed in [52, 53].

In the reactive method, the input impedance of the antenna changed by connecting the reactive parts then gets the required impedance matching to resonate at normal frequency. To get the continuous tuning of frequency, varactor diode is used with required impedance matching in a certain frequency range. The reconfigurable antenna with varactor tunability for the notched band was proposed in [54–56].

To better understand the working principle of frequency reconfigurability, an antenna was proposed in [57] as can be seen in Fig. 9.10. In this chapter, a new technique substrate integrated waveguide (SIW) has been introduced for low cost, easy fabrication, and more convenient for high-speed communication applications. The proposed antenna consists of right/left-handed transmission line that is the combination of capacitance, inductance, and shunt capacitance. The operation frequency can be modified by changing the capacitance of varactor diode embedded on the meander line. The resonance frequency is changed from 4.13 to 4.50 GHz by varying the biasing voltage from 0 to 36 V. The proposed antenna showed the good agreement between the simulated and measured results and promising candidate for the front end of the RF component and CR applications.

Similarly, another frequency reconfigurable antenna with miniaturized wideband and multi-band properties was presented in [58]. The antenna shape consists of a triangle patch connected with the microstrip transmission line. The main radiating patch relates to two serpentine-shape stubs at the edges with the help of two PIN diodes. The biasing circuit is designed on the backside to avoid the radiation pattern and connected with serpentine stubs with the help of shorting vias. The biasing circuit is the combination of the resistors to provide reasonable voltage and inductors. The antenna dimension is shown in Fig. 9.11. The proposed antenna resonates at eight different frequencies by changing the different states of the PIN diodes. The antenna prototype is shown in Fig. 9.12. When D1 is forward biased and D2 is reverse biased, the proposed antenna has three resonance frequencies at 3.05, 4.1, and 6 GHz. The values of the gain at resonance frequencies is 0.5, 1.62, and 1.74 dB, respectively, as can be seen in Fig. 9.13b–d. In another case, when D1 is forward biased and D2 is reverse biased, the resonance frequency and radiation pattern can be seen in Fig. 9.14. When both diodes are forward biased, the antenna has triple band at 3.3, 5, and 6 GHz. The gain as well as return loss can be seen at Fig. 9.15. The slight difference between the measured and simulated results is due to the imperfection fabrication.

They are particularly useful in situations where several communication systems converge because the multiple antennas can be replaced with a single reconfigurable antenna. Frequency reconfiguration is generally achieved by modifying antenna's dimensions physically, electrically using RF switches, impedance loading, or tunable materials.

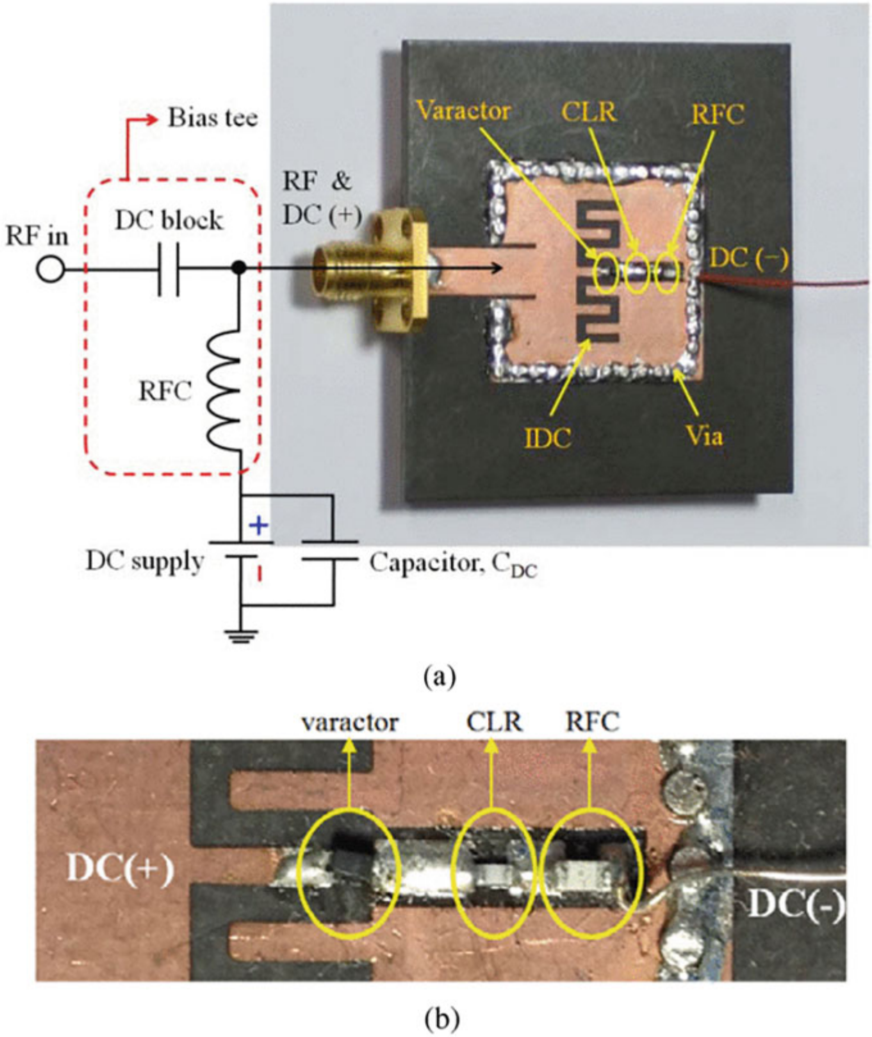


Fig. 9.10 (**a**) SIW–IDC antenna prototype. (**b**) Bias network section

Such antenna is widely used in wireless communications that require a change in operating frequency and to switch from one channel to another. Cognitive radio is an exemplar application for this antenna.

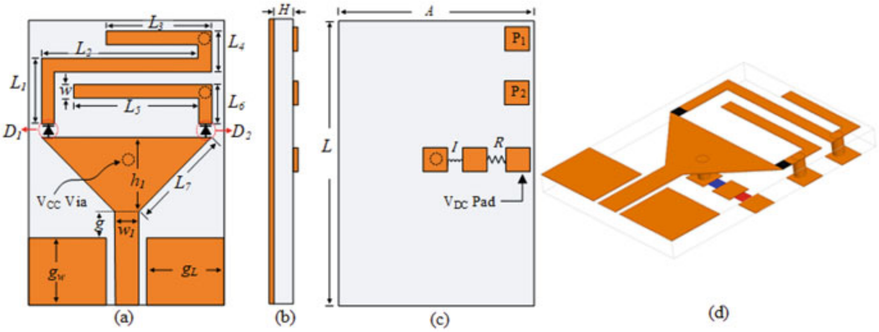


Fig. 9.11 Antenna schematic. (**a**) Top side. (**b**) Side view. (**c**) Bottom side. (**d**) Perspective view

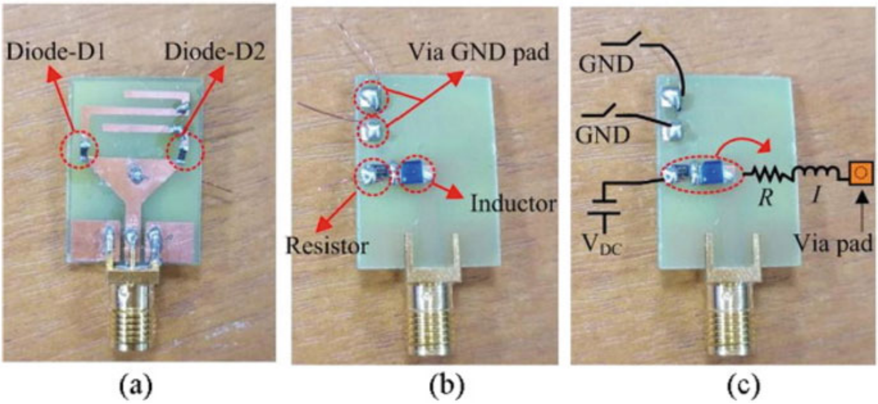
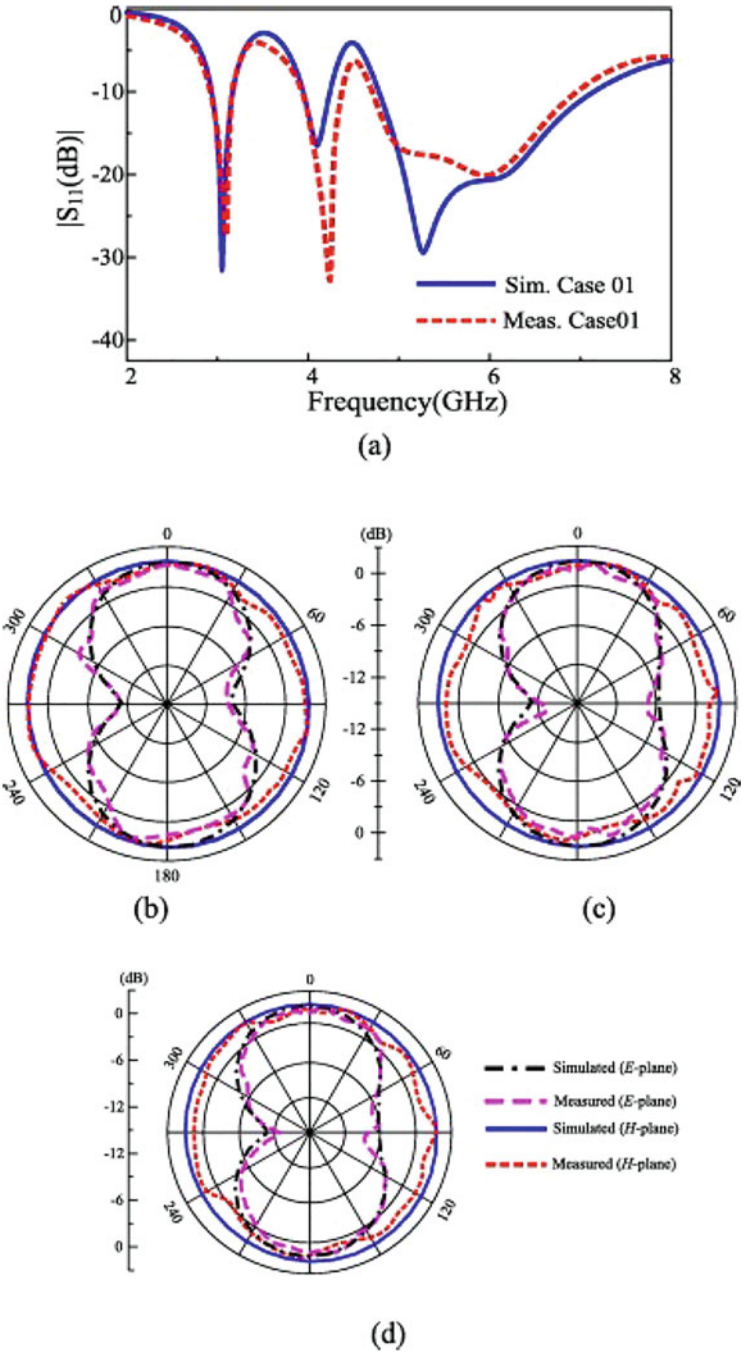


Fig. 9.12 Antenna prototype. (**a**) Top view. (**b**) Bottom view. (**c**) Bottom view with biasing circuit

9.4.2 Polarization Reconfigurable Antenna

Polarization reconfigurable antennas can switch between different polarization modes. The capability of switching between horizontal, vertical, and circular polarization can be used to reduce polarization mismatch losses, strong signal strength, and multipath fading in portable devices. In this case, the antenna can change, for example from vertical to left-hand circular polarization [59]. Different design techniques like slits, slots, cross on the ground plane, truncated corner of main radiation patch parasitic, and addition of electrical switches are employed to get the polarization reconfigurability [60, 61]. Additionally, reconfigurability in impedance matching network [62] also helps to switch between linear (vertical/horizontal) and circular (RHCP/LHCP) polarization at resonate frequency.

A novel wideband tri-polarization reconfigurable dipole antenna based on magneto-electric (ME) for WLAN application was designed in [63] The proposed



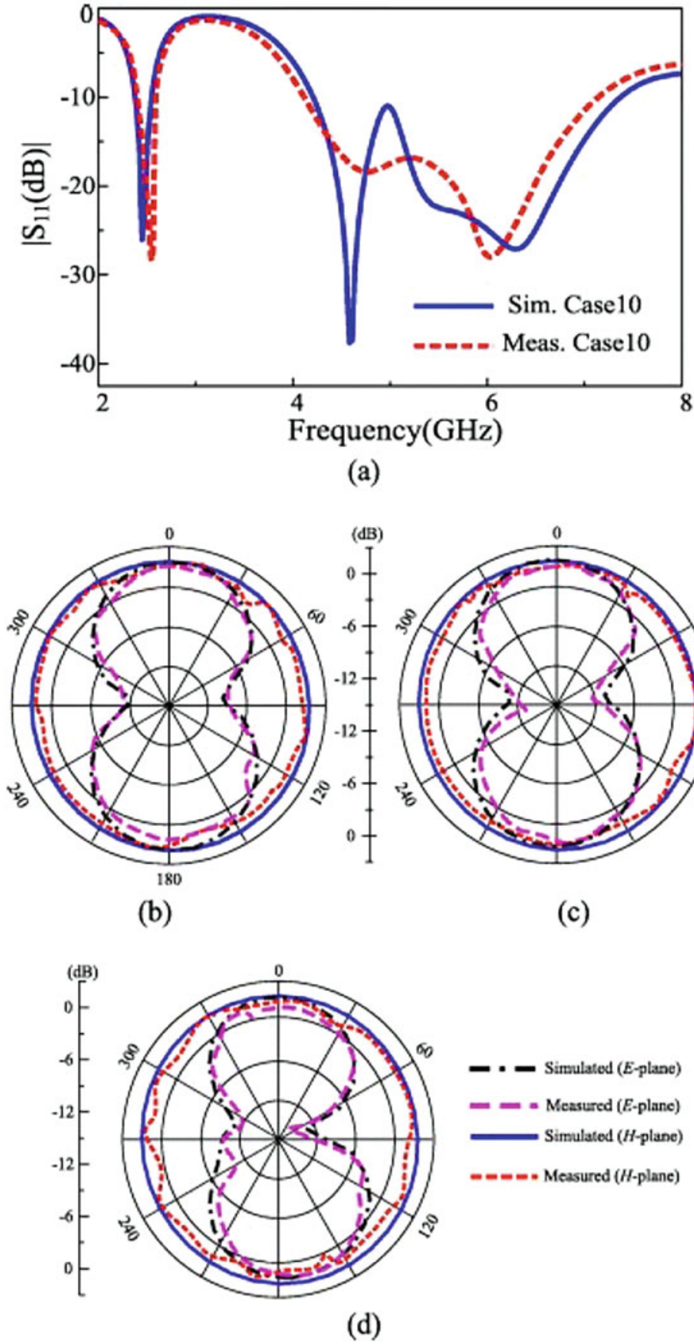
(a)

(b)

(c)

(d)

Fig. 9.13 Comparison among simulated and measured results of (**a**) S-parameters and radiation pattern at (**b**) 3.05 GHz (**c**) 4.1 GHz (**d**) 6 GHz, for D1 is reverse and D2 is forward biased



(a)

(b) (c)

(d)

Fig. 9.14 Comparison between the simulated and measured results of (**a**) S-parameters and radiation pattern at (**b**) 2.45 GHz, (**c**) 4.6 GHz, (**d**) 6.2 GHz, for D1 is forward and D2 is reverse biased

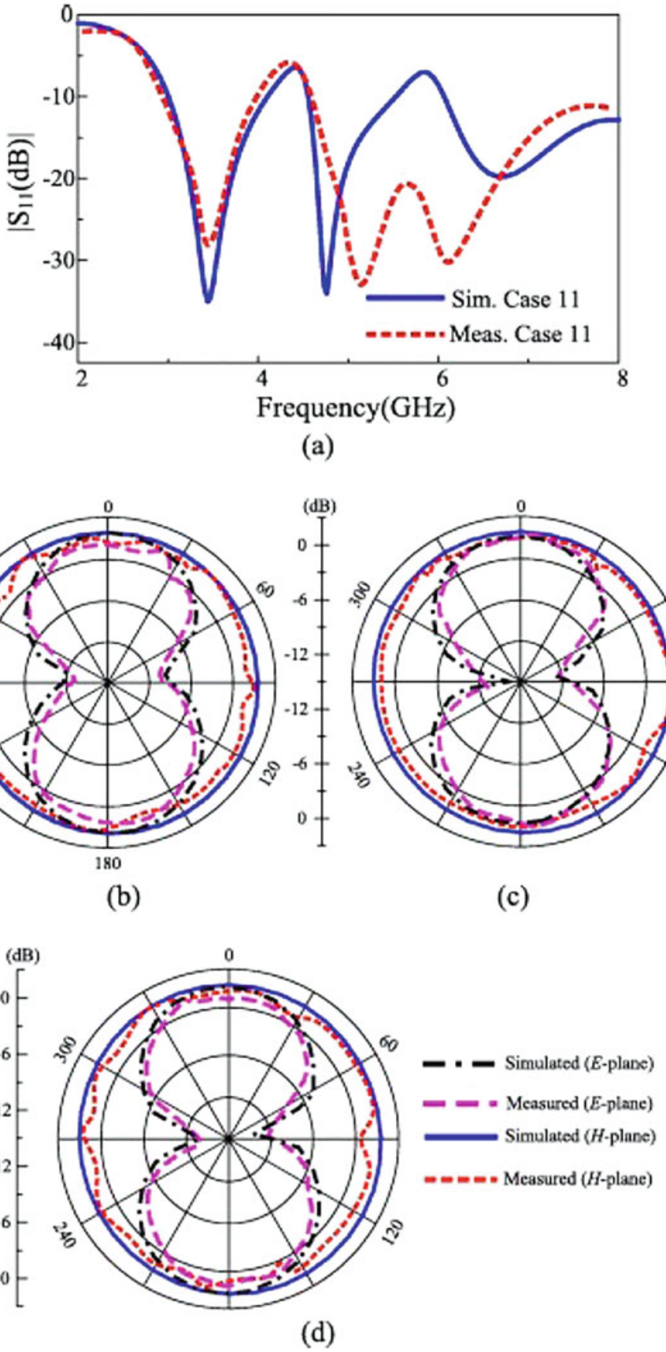


Fig. 9.15 Comparison between the simulated and measured results of (**a**) S-parameters and radiation pattern at (**b**) 3.3 GHz, (**c**) 5 GHz, (**d**) 6 GHz, for D1 and D2 are forward biased

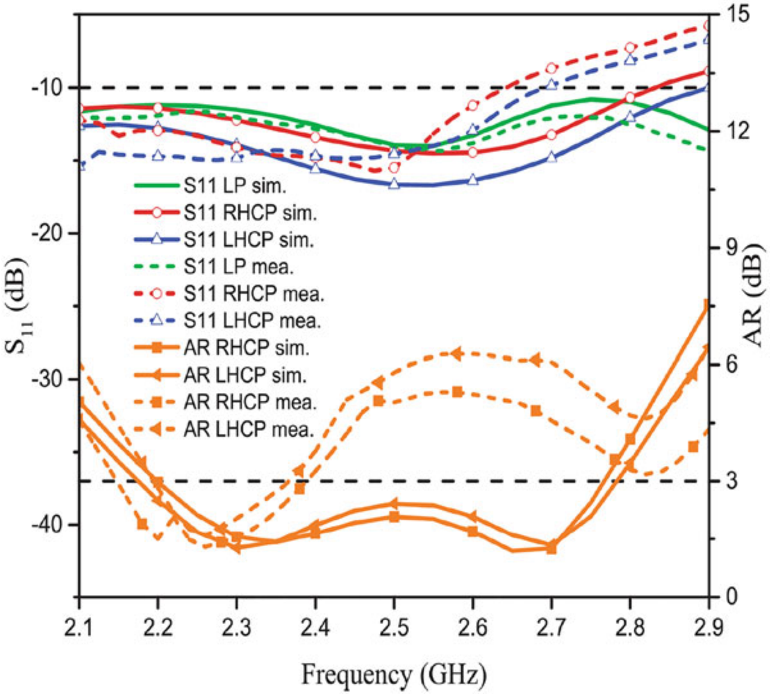
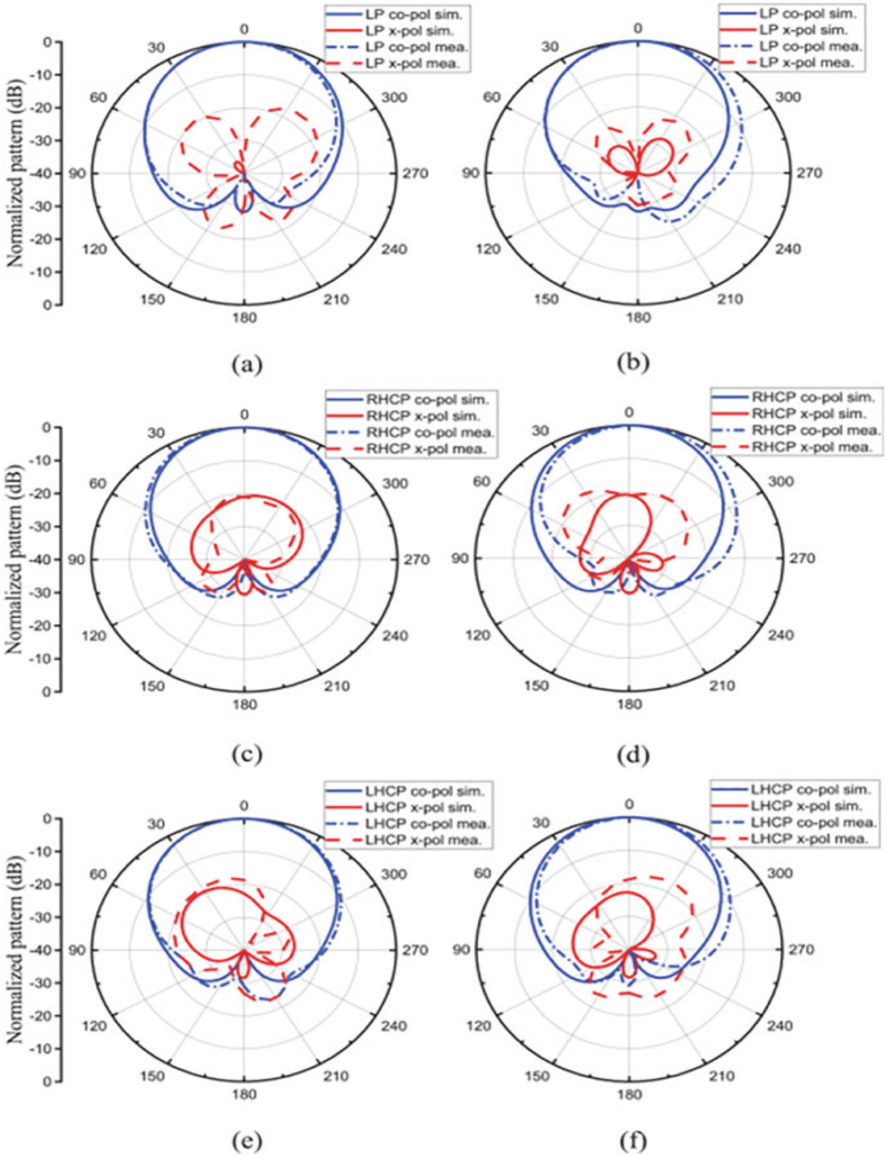


Fig. 9.16 Simulated and measured reflection coefficients under three polarization states and AR under two CP states, respectively

antenna operates in one linear polarization and two circular polarizations, and it is achieved by using four PIN diodes. The linear polarization is obtained by using T-probe fed on dipole antenna having four-sectional structure. The antenna prototype shows an impedance bandwidth of 31%, an axial ration BW of 7.9%, and an high efficiency of 80–90% for all polarizations. The simulated and measured reflection coefficients and AR can be seen in Fig. 9.16. The radiation pattern of the proposed antenna at different polarizations is shown in Fig. 9.17. It can be seen that the radiation pattern is the same for all three operation modes. The measured 3-dB bandwidth for LP, RHCP, and LHCP are 60, 62, and 66°, respectively. Another tri-polarization antenna was investigated in [64] and can be seen in Fig. 9.18. The antenna design is multi-layer PCB and consists of the radiation patch, ground plane, and cross-probe fed that is incorporated with pin diodes. On the bottom side of the radiation patch, there are horizontal and vertical metallic posts that form the L-shaped coupled fed, and it helps to increase the bandwidth of the proposed antenna design. Pin diodes and biasing circuit are designed on the ground plane, and the different states of pin diodes are to shift the polarization between linear and circular (RHCP/LHCP) polarizations. The measurement results of the proposed antenna



(a) (b) (c) (d) (e) (f)

Fig. 9.17 Simulated and measured radiation patterns under different polarization states at 2.3 GHz. (**a**) LP mode, xoz plane. (**b**) LP mode, yoz plane. (**c**) RHCP mode, xoz plane. (**d**) RHCP mode, yoz plane. (**e**) LHCP mode, xoz plane. (**f**) LHCP mode, yoz plane

show good agreement with the simulated results, and it is a promising candidate for the WLAN and satellite communication applications.

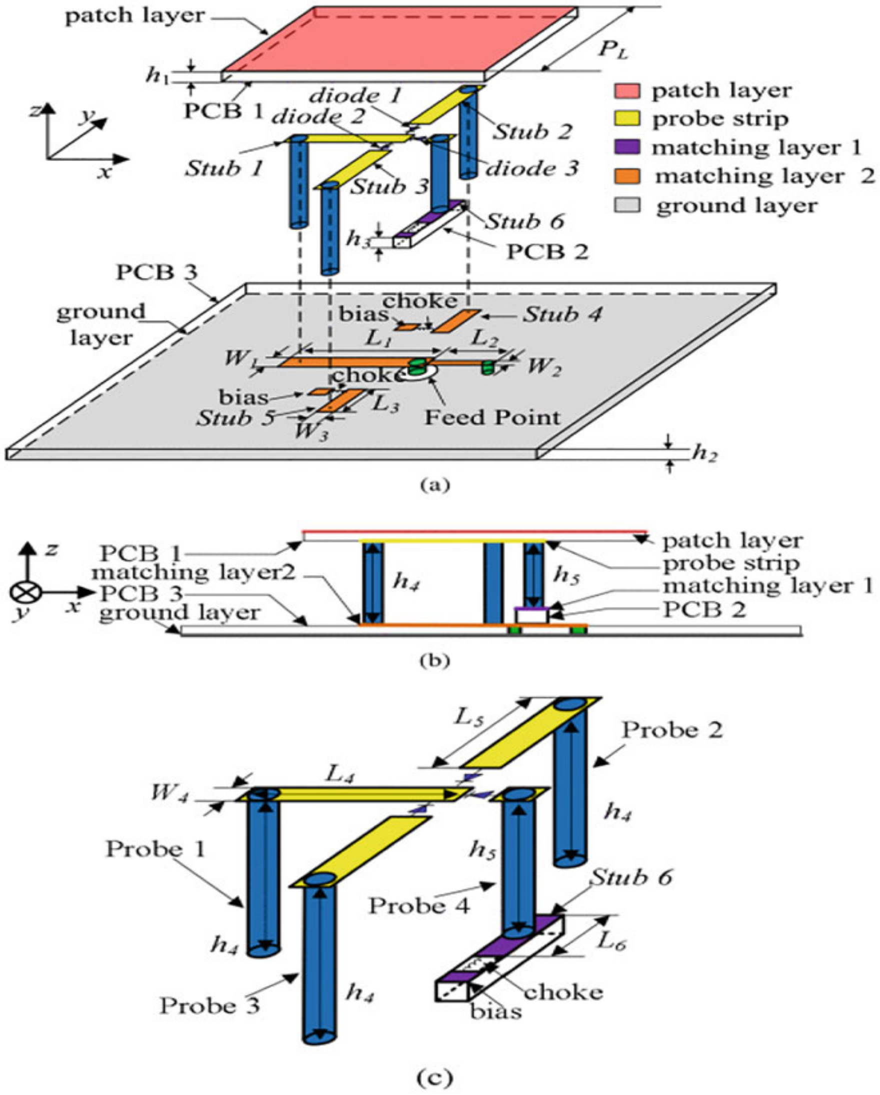


Fig. 9.18 Geometry of the proposed antenna

The compact-size, low-profile, wideband omnidirectional patch antenna with polarization reconfigurability for wireless communication was explained in [60]. The antenna geometry is the combination of circular patch and ground plane. The radiation patch and ground plane are connected via nine shoring pins. The annular slot and six radial slots are etched on the bottom side.

9.4.3 Radiation Pattern Reconfigurable Antenna

Radiation pattern reconfigurability is based on the intentional modification of the spherical distribution of radiation patterns. Beam steering is the most extended application and consists of steering the direction of maximum radiation to maximize the antenna gain in a link with mobile devices. In this technique, impedance matching is kept constant while changing the current distribution, which is challenging. Some conventional methods to get tunable radiation patterns are rotating the arms of a dipole or rotating the antenna itself in the orthogonal plane [65, 66]. One of the most frequently used methods is using tunable elements as parasitic with other main radiators. They behave as the coupled current and do not disturb the impedance matching as they do not have any electrical connection. This technique was implemented in designs with dipole/Yagi dipole [67, 68], monopole antenna [69], slot antenna [70–72], patch antenna [73–75], and Yagi antenna [76, 77].

Another method of pattern reconfiguration is multi-mode excitation that is obtained by activating the mode of an antenna [78, 79], though it has very limited applications. The electronics reconfiguration method was applied in many designs using SIW configuration, water grating, and periodic structure to control the mode and phase properties [80–83]. Leaky-wave antennas are famous for larger beam steering, but it is still challenging to increase the beam-scanning range.

The most attractive application of the pattern reconfigurable antenna is surveillance and tracking because they provide different directions with the same resonate frequency [84]. Mobile antenna systems are the example of this type.

9.4.4 Compound Reconfigurable Antenna

Antenna under this group can simultaneously change multiple characteristics in their operation. These antennas can, for example, change their operating frequency as well as their polarization scheme for each frequency of interest. They can also reshape their radiation pattern while changing their operating frequencies or polarizations. The most common application of hybrid reconfiguration is the combination of frequency agility and beam scanning to provide improved spectral efficiencies.

9.4.4.1 Frequency and Radiation Pattern Reconfigurable Antenna

In this property, the frequency and the radiation pattern of the antenna can be changed simultaneously. One can switch the radiation pattern between omnidirectional, broad-side, and end-fire modes. A dual-band frequency and radiation pattern reconfigurable antenna was explained in [85]. The antenna has a simple patch shape with a row of shorting vias in the centre. The antenna shows monopolar and

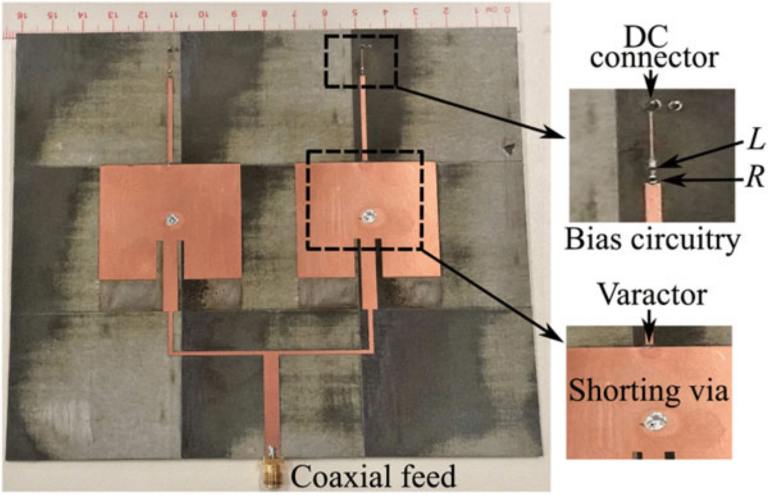


Fig. 9.19 Antenna prototype with biasing circuit

broad-side radiation patterns for its lower and upper frequencies, respectively. The presence of the shoring vias does not disturb the conventional mode of the microstrip patch antenna but helps to create another mode for radiation reconfigurability. Two separate biasing voltages and four varactor diodes are used for the independent switching of the resonant frequency. An antenna array for frequency and radiation patterns was designed in [86]. The proposed antenna is the combination of two patches, open stubs, and varactor diode with independent biasing voltage. The T-junction power divider is used to connect and feed the two-patch antenna array as shown in Fig. 9.19. The resonant frequency tuning range is from 2.15 to 2.38 GHz and beams steering across ±23 across the broadside. The reflection coefficient of the proposed antenna design for different combinations of biasing voltages is shown in Fig. 9.20. There is good agreement between the measured and simulated results. In this antenna, the frequency tuning range is 10% due to the difficulty of impedance matching. The gain pattern at three selected frequencies tuning is shown in Fig. 9.21. The antenna can be switched between the right and left directions by changing the values of capacitors.

The combination of monopole and patch antennas was studied in [87] to get the radiation pattern and frequency reconfigurable antennas. It consists of patch etched on the front side and monopole on the bottom side with the defected ground plane as shown in Fig. 9.22. The monopole and patch antennas are used to get lower and higher resonate frequencies, respectively. To get the omnidirectional radiation pattern, the substrate is truncated at the far end from the feed. By changing the states of two diode groups, the proposed antenna behaves as omnidirectional pattern mode at 2.21–2.79 GHz resonant frequency, unidirectional pattern mode of higher frequency at 5.27–5.56 GHz, and both working simultaneously. To cover the S and

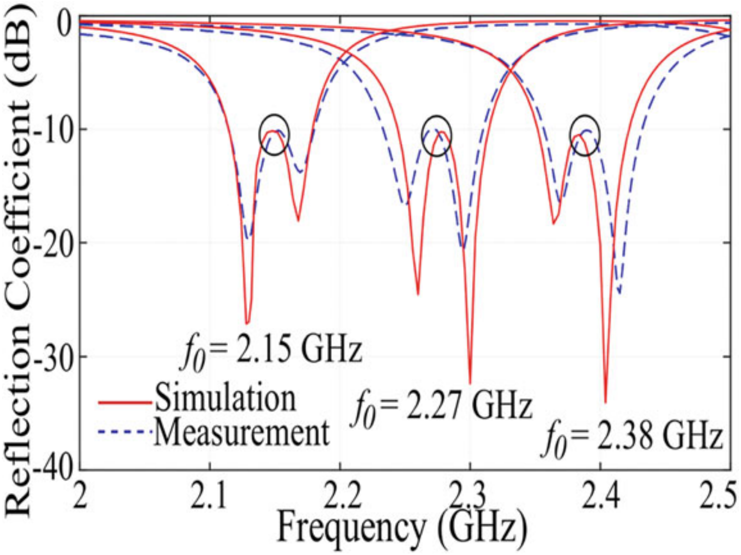


Fig. 9.20 Comparison between the simulated and measured reflection coefficients for different combinations of bias voltages

C, a microstrip antenna was presented in [88]. The reconfigurable antenna has a patch with inset feed on the front side, while it has two rectangular-shaped slots on the ground plane. The six PIN diodes are inserted into the slots on the ground plane. The different states of the PIN diodes resonate antenna at 3 frequencies of the S-band and 8 different frequencies of the C-band.

A wideband slot antenna for LTE and C-band applications was investigated in [89]. The substrate has a sickle-shaped slot with a ground plane on one side and fork-shaped microstrip line on the other side. Two PIN diodes are inserted into sickle-shaped slot for frequency reconfigurability, while two diodes are used for the connection of vertical and horizontal arms of the fork-shaped feed line for pattern reconfigurability. There is good agreement between the simulated and measurements results, and antenna shows 25 and 20 beam steering at 3.4–3.8 and 3.7–4.2 GHz, respectively. Another slot antenna to switch between three different frequencies (1.8, 1.9, 2.1 GHz) and beam steering for three angles (0, ±15) were presented in [90]. The proposed antenna consists of the main radiator slot on the front side and upper and lower slits on the ground plane. Two switches are placed on the main radiator, while three switches in each slit. To produce the directional radiation pattern, an aluminium reflector was placed behind the antenna as slot normally behaves as bidirectional radiation pattern.

The frequency and radiation pattern reconfigurable antennas consist of the centre-fed patch, and four identical BTFB (back-to-back F) elements were explained in [91].

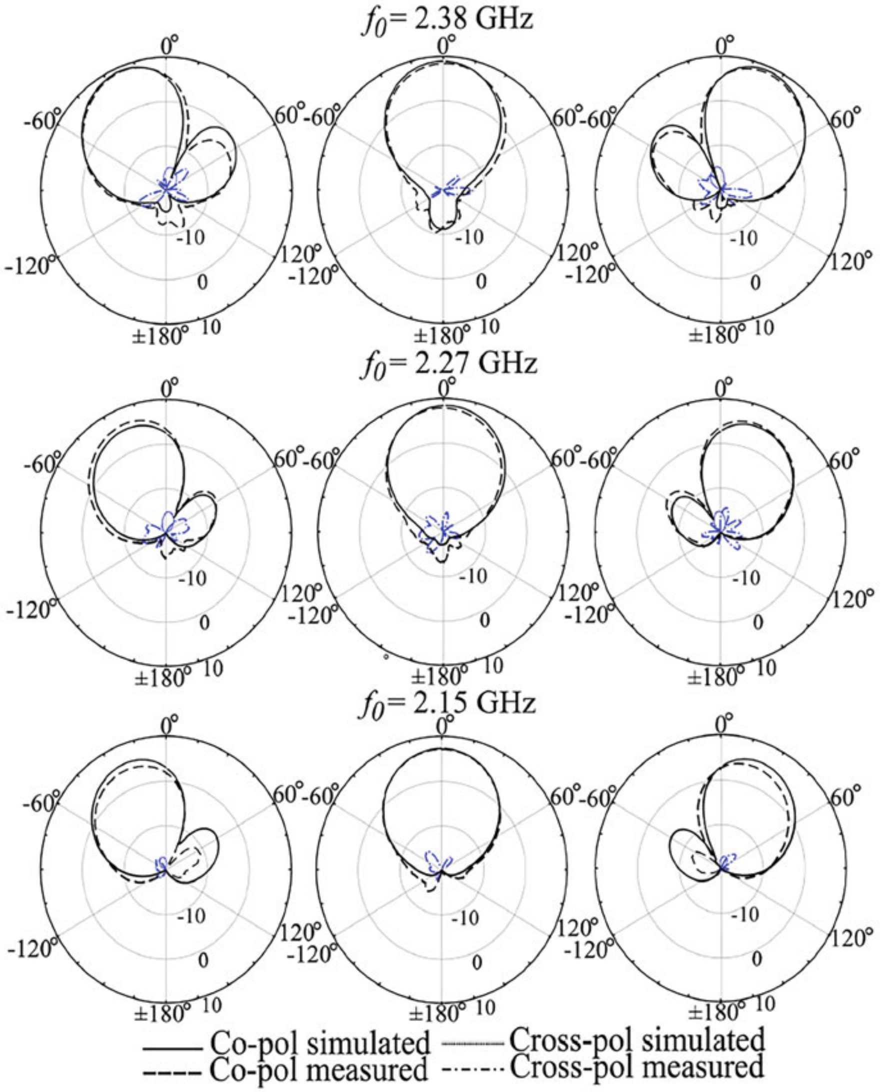


Fig. 9.21 Realized gain patterns at f_0 = 2.38, 2.27, and 2.15 GHz from top to bottom

9.4.4.2 Frequency and Polarization Reconfigurable Antenna

In this technique, the frequency can be tuned for the available band, and polarization switching helps to reduce the multipath effect and increase the channel capacity. Recently, it has gained much attention due to its useful applications like tracking, sensing, and radar, etc., and some design examples are explained below. A novel frequency and polarization reconfigurable antenna based on electromagnetic bandgap

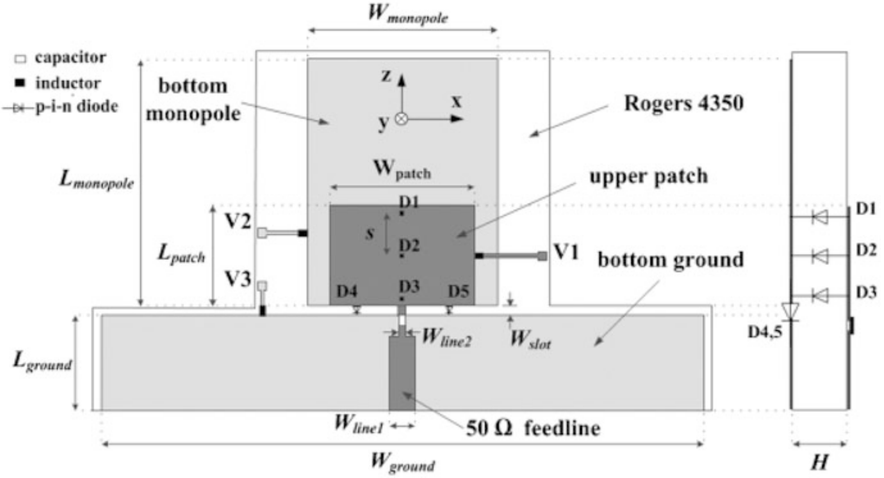


Fig. 9.22 Dimension of the proposed antenna

(EBG) for satellite navigation was explained in [92]. The proposed antenna consists of EBS surface that has the same metallic rectangular patches array on both sides of the thin substrate, and it has active biasing circuit on each surface that helps to rotate the reflection phase orthogonally concerning the incident waves. A CPW fed is used for the proposed antenna design and provides good impedance matching for the frequency tuning and switching the circular polarization (RHCP/LHCP). Measurement results show the good agreement with simulated and mathematical analysis, and antenna prototype shows the measured 3 dB AR bandwidth to 40%.

Another low-profile antenna based on EBG structure was presented in [93] for frequency tuning and shifting between linear and circular polarizations. The proposed antenna has a three-layer structure. The EBG pattern is on the top layer, which has 12 × 12-unit cells square patch at the centre and four strips at the edges. The central patch has a gap that was used for loading PIN diodes. By controlling the biasing voltage of pin diodes, the proposed antenna resonates at the required frequency with polarization switching.

A high-gain antenna with the combination of the metasurface, a planar slot, and the metallic reflector was investigated in [94] as shown in Fig. 9.23. The metasurface consists of 64 identical patches, and due to symmetry of the structure, the equivalent circuit of MS is considered as symmetry RLC circuit because the diagonal corner of the unit cell is not cut in a zigzag shape. Figure 9.24 shows the simulated and measured return losses with different rotating angles. Figure 9.24a shows the results when h_1=9.3 and h_o=19 mm, while Fig. 9.24b represents the results when h_1=7.2 and h_o=16 mm. It can be seen that the operating frequency range is from 8 to 11.2 GHz having return loss values less than −10 dB during the entire bandwidth. The AR of the proposed antenna with angles of $\theta°$=0 and 90° is shown in Fig. 9.25. The 3-dB AR bandwidth is obtained by adjusting the size of h_o and h_1.

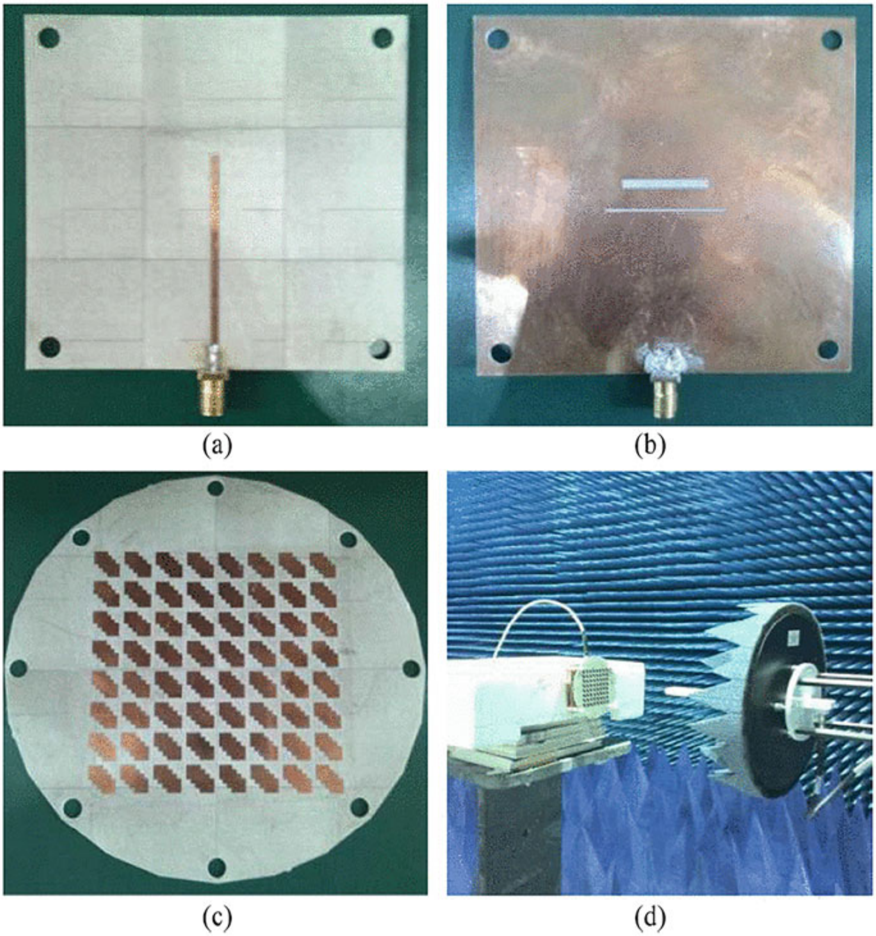


Fig. 9.23 (**a**) Feed line of the proposed antenna. (**b**) Surface of slot antenna. (**c**) MS. (**d**) Measurement setup

For the extension of the bandwidth, the slot antenna is converted into the double-slot structure. The polarization of the proposed antenna can be achieved by rotating the metasurfaces around the centre of the slot structure, and frequency can be tuned by the adjustment of the distance between slot, MS, and metallic reflector. The measured gain for the proposed antenna was 16.5 dBi with a fractional bandwidth of 33.33%.

A stub-loaded patch antenna microstrip patch antenna for smart communications was designed in [95]. The antenna consists of square microstrip patch and 12 identical stubs at the four edges of the patch. The varactor diodes are used for the connection between the stubs and the patch as shown in Fig. 9.26. The biasing circuit is at the other end of the stub and consists of a resistor and a choke inductor. The

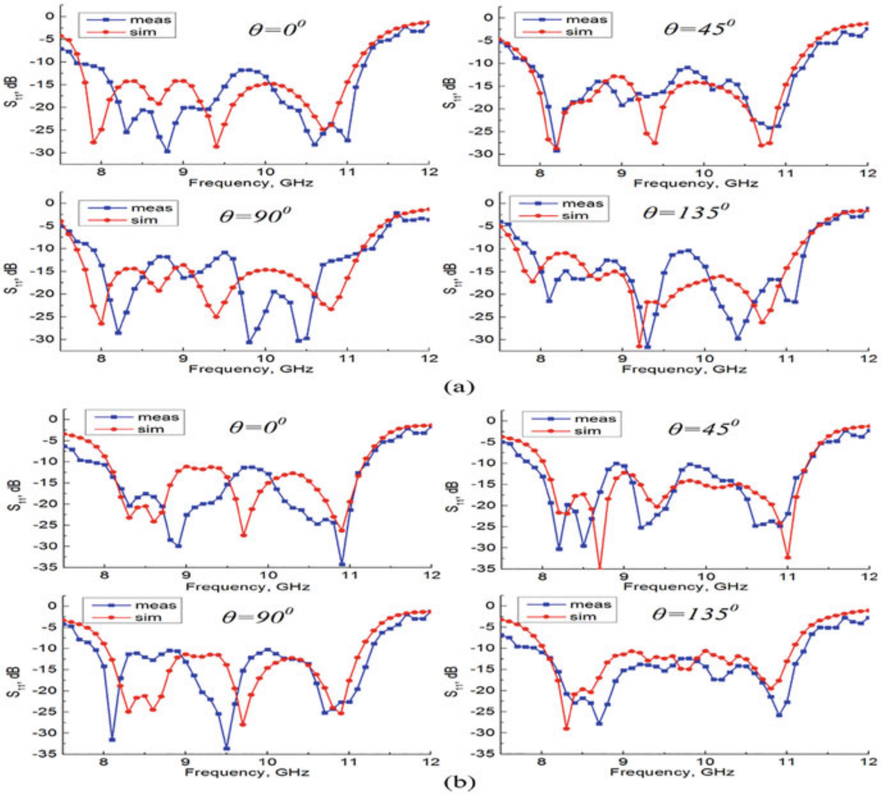
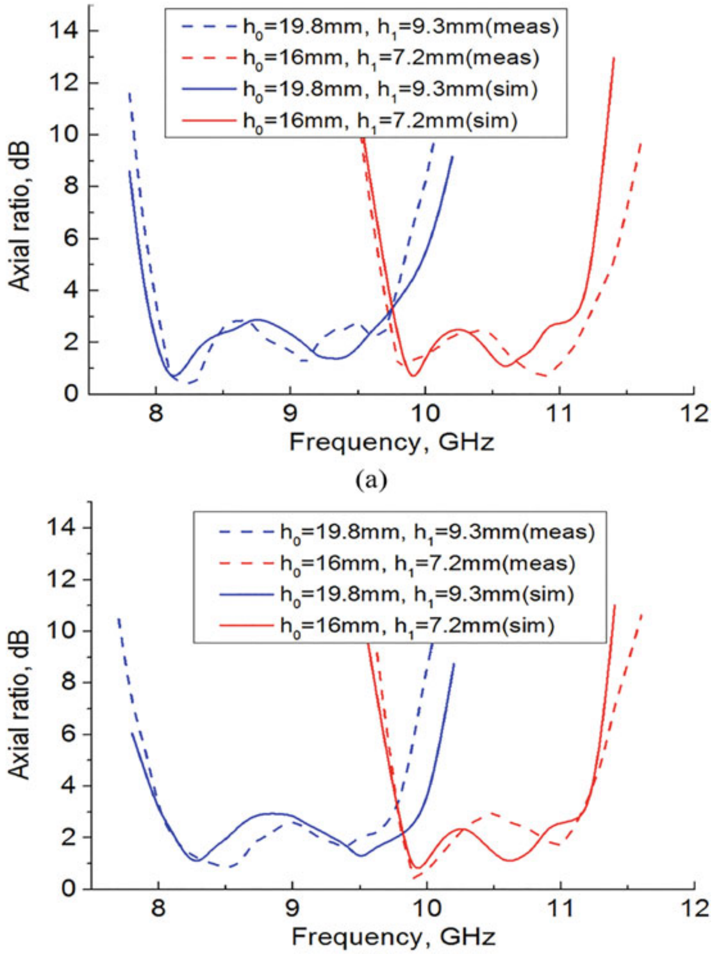


Fig. 9.24 Comparison between the measured and simulated reflection coefficients S_{11}; (**a**) $h_1 = 9.3\,\text{mm}$, $h_0 = 19.8\,\text{mm}$, and (**b**) $h_1 = 7.2\,\text{mm}$, $h_0 = 16\,\text{mm}$

12 varactors and stubs are divided into two groups and provide independent dc-bias voltage. The antenna prototype shows the wide tuning of frequency around 40%.

The reconfigurable antenna with frequency and polarization capability was presented in [96], and it consists of monopole structure, defected ground plane, and reflector. Two slots are etched, and pin diodes are inserted on the ground plane with the addition of metal vias along with the slots. The antenna shows four different behaviours by changing the different states of the pin diodes and shows linear polarization at states 1 and 2, while shows circular polarization at state 3 (LHCP) and state 4 (RHCP).

The frequency reconfigurability [97] can also be achieved by truncating the square patch at the corner as shown in Fig. 9.27. The truncated square patch is separated from the corner by a narrow slot, it behaves as radiation patch, and the diode is also inserted into the slot to change the circular polarization at different frequencies to make it suitable for modern communication systems.



(a)

(b)

Fig. 9.25 Comparison between the measured and simulated axial ratios with different rotation angles. (**a**) $\theta = 0°$. (**b**) $\theta = 90°$

A dual-probe feed reconfigurable antenna was explained in [98]. The antenna consists of circular-shaped microstrip patch on the top layer and branch line coupler feed etched on ground plane at the bottom layer. The varactor diodes are inserted into the gaps of the circular patch at the top layer, and a reverse bias voltage is applied with the help of biasing pad that is at the side of the patch. An additional BLC feed network was used for simultaneously tuning of the frequency from 2.05 to 3.13 GHz along with circular polarization.

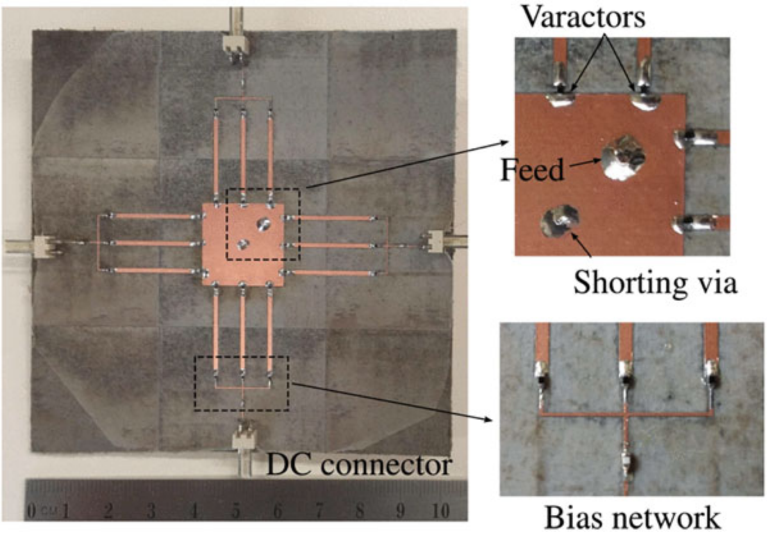


Fig. 9.26 Antenna prototype

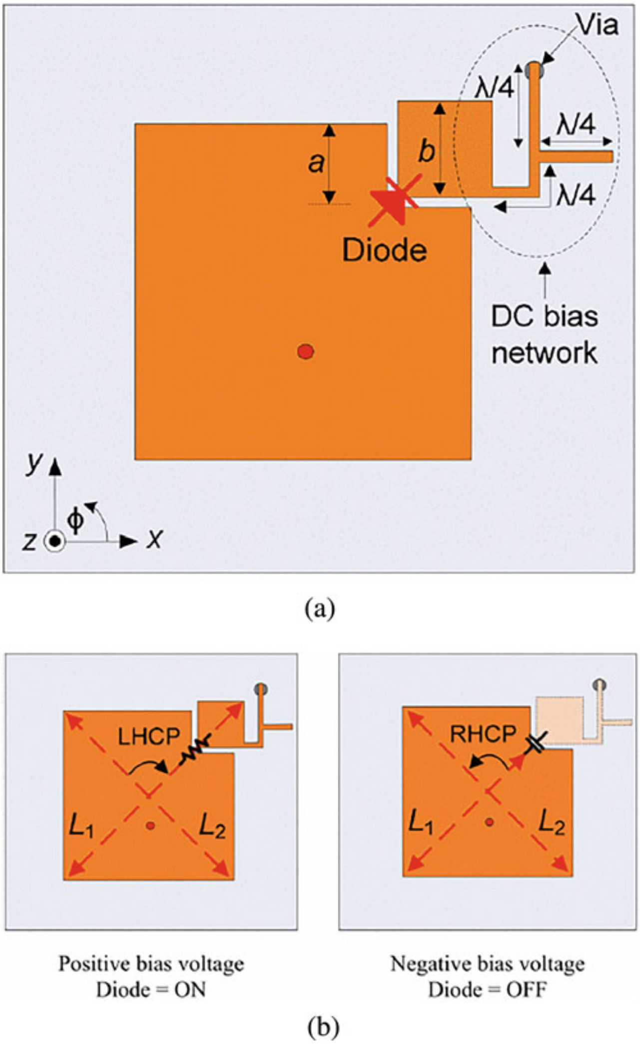
9.4.4.3 Radiation Pattern and Polarization Reconfigurable Antenna

The reconfiguration in radiation pattern along with polarization supports beam steering and multiple polarization shifting on a single antenna radiator. They increase the capacity of modern communication systems and improve signal strength and radiation coverage. These types of examples are presented in recent years.

An omnidirectional patch that operates at two orthogonal ±45 linear polarizations and produces a dipole-like radiation pattern for convening both polarization and radiation pattern reconfigurability was explained in [99]. The proposed antenna consists of two back-to-back coupled patches with common ground. The antenna has four input ports, and polarization can be achieved by the port selection, while the phase difference between the ports is utilized for radiation pattern reconfigurability and promising candidate for the MIMO applications.

A compact-size, low-cost, and smart antenna for beam switching and polarization reconfiguration was designed in [100]. The antenna has dual-port inset fed patch, parasitic elements, and driven elements as shown in Fig. 9.28. The driven element is the combination of square patch antenna with simple feeding network, and parasitic element consists of the printed dipole with PIN diodes. The radiation pattern can be obtained by placing reconfigurable parasitic elements around the driven antenna over the three polarization states.

A simple, low-profile PIFA antenna for radiation pattern along with polarization reconfiguration for WLAN application was presented in [101]. The antenna consists of the printed inverted-F antenna on the top-left corner and another printed inverted F parasitic element for pattern reconfiguration on the bottom-right corner. The



(a)

Positive bias voltage
Diode = ON

Negative bias voltage
Diode = OFF

(b)

Fig. 9.27 (**a**) Schematic of the proposed antenna. (**b**) Biasing operation mechanism

antenna prototype shows a good gain of 1.2 and 4.2 dBi for ON and OFF states, respectively, and it can be used for wireless router applications. A circularly polarized switchable feed network antenna with reconfigurable beam pattern for the wireless system was expressed in [102] as shown in Fig. 9.29. A high-gain radiation pattern and polarization reconfigurable antenna using metasurface was explained in [103]. The antenna structure consists of three layers. The top layer consists of metasurface that is the combination of 4 × 4 nonuniform rectangular metal films. The pin diodes are inserted between these films and used to get the

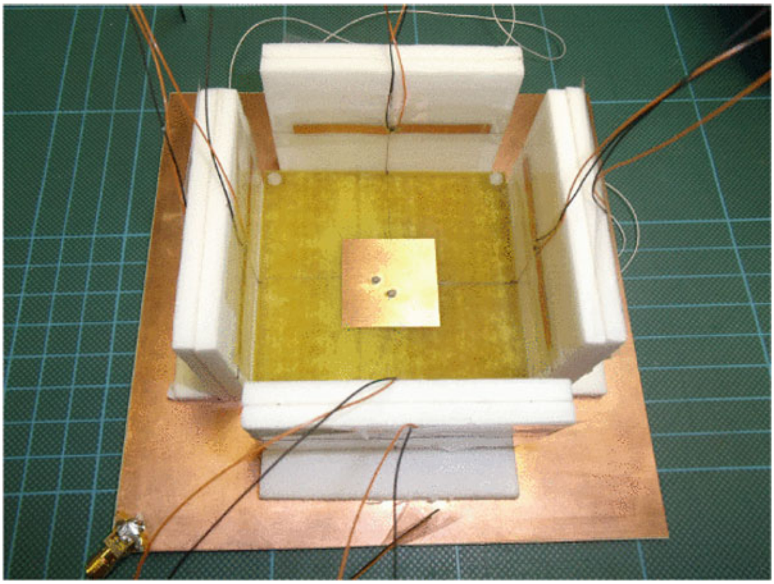


Fig. 9.28 Antenna prototype

pattern reconfiguration between ±20 in the direction of the Z-axis. The middle layer is the ground plane, and pin diodes are also used between the slots to get the polarization reconfiguration. The proposed antenna resonates between 4.95 and 5.05 GHz, and the gain of the main lobe is 7–8 dBi.

A compact-size cuboid quadrifilar helical antenna (QHA) to operate at 0.9 GHz with radiation pattern and polarization reconfigurability was explained in [104]. The proposed antenna is the combination of a reconfigurable radiator and switchable feeding network. The reconfigurable radiator consists of folding the thin substrate that behaves like a cuboid, and the radiation arms on the surface. The switchable feeding network consists of out-of-phase power divider and two reconfigurable couplers. The proposed antenna prototype resonates between two orthogonal CP and switch radiation pattern between broad-side and back-fire modes. The measured and simulated return losses are shown in Fig. 9.30. It shows the wide impedance bandwidth of 36.2% from 0.32 to 1.04 GHz for all resonating states. The measured and simulated ARs are shown in Fig. 9.31. The measured 3-dB AR bandwidth is 22% with frequency range (0.8–1 GHz). The slight difference between the simulated and measured results is due to the equivalent circuit of PIN diode model, which is not equal to the actual effect of the PIN diode. Another frequency and radiation pattern reconfigurable low-profile antenna was explained in [105]. The antenna consists of simple patch radiator and parasitic elements that relate to the help of pin diodes.

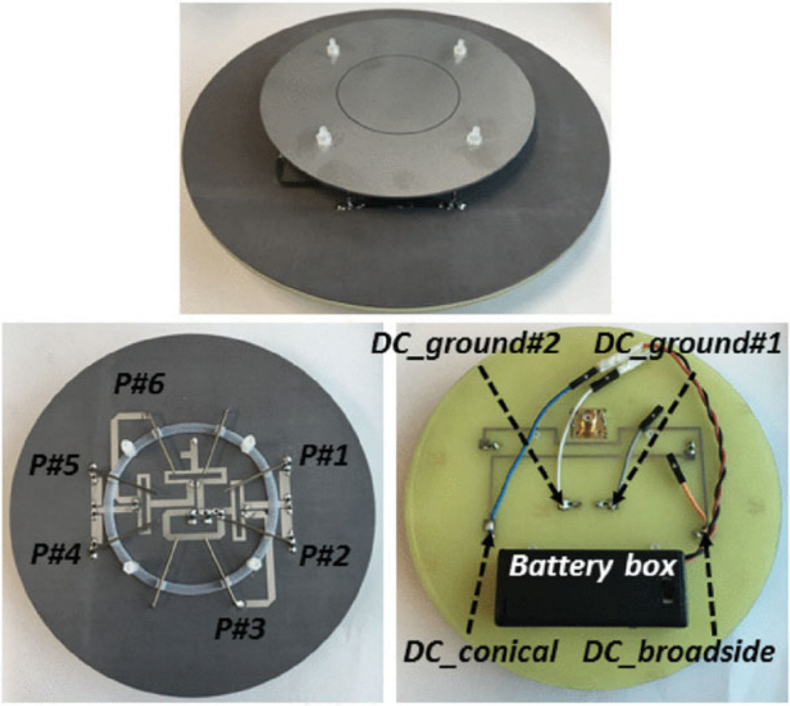
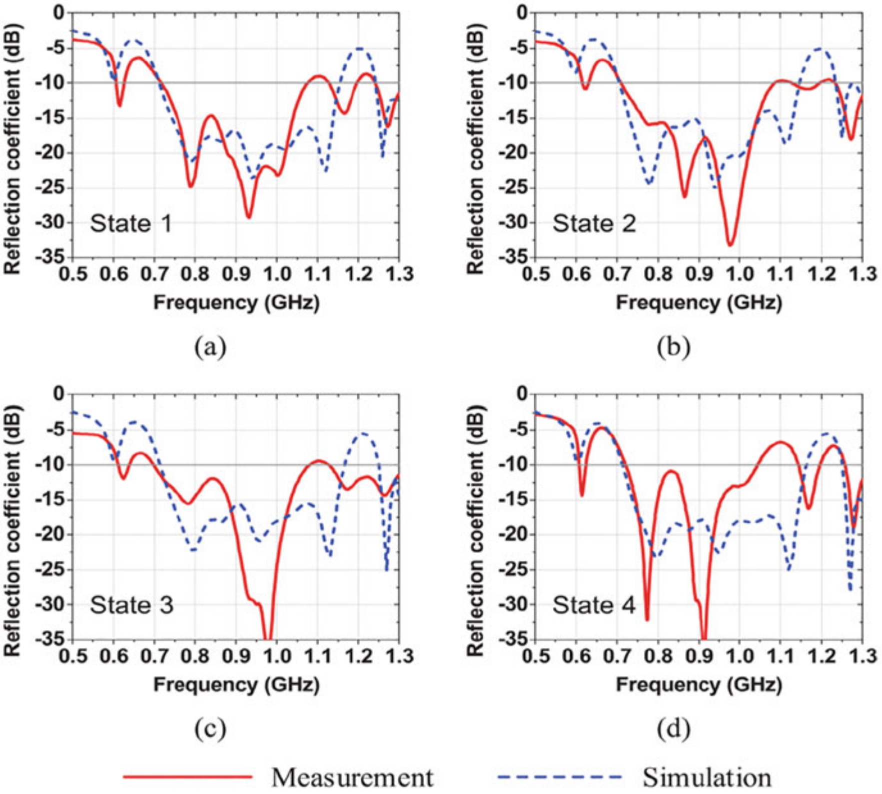


Fig. 9.29 Proposed antenna prototype

9.4.4.4 Frequency, Radiation Pattern, and Polarization Reconfigurable Antenna

Mostly designs explained in the above examples are either single or dual-characteristic reconfigurable antennas. In this technique, one can tune the antenna parameters (frequency, radiation pattern, polarization) simultaneously, and they help in multipath scenarios, fading, and shadowing effects. A little work has been done on this category. The first work on this technique was presented in [106]. This antenna consists of small metallic patches known as pixel surface, radiation patch, and 60 PIN diode switches as shown in Fig. 9.32. The antenna prototype shows the frequency tuning over 25% range, beam steering over ±30 in two principal planes and switching between four different polarizations (Fig. 9.33).

Another antenna of this type was explained in [107]. The antenna structure is the combination of a rhombus-shaped radiator, three excitation lines at different angles, and connected with common feed line. The required configuration can be obtained by changing the biasing states of three pairs of PIN diodes. The proposed antenna can tune frequency between 5.2/5.8 GHz, linear/circular/±45 polarizations with beam titled at 30 in right- and left-hand directions. The measured and simulated reflection coefficients, when D6 is off and on, can be seen in Fig. 9.34a, b,



(a) (b)

(c) (d)

Fig. 9.30 Simulated and measured reflection coefficients of the proposed reconfigurable cuboid QHA. (**a**) State 1, (**b**) State 2, (**c**) State 3, and (**d**) State 4

respectively. The measured percentage bandwidths at 5.8 and 5.2 GHz frequency are 3.50 and 3.59%, respectively. A novel cavity-based slot antenna for frequency, radiation pattern, and polarization reconfiguration was investigated in [108] as shown in Fig. 9.33. The reconfigurability can be obtained controlling the states of the switches between the two cross slots etched on the surface of the SIW cavity.

9.5 Reconfigurable SIW Antenna

The invention of SIW provides low loss, good power handling capacity, and effective functionality with planar circuits [109]. The structure of SIW is similar to conventional cavity slot and provides a low profile, flexibility, and simple integration with planar circuits [110, 111]. The SIW is composed of fittingly divided vias with a similar distance between them engendering with least radiation loss. The dispersion

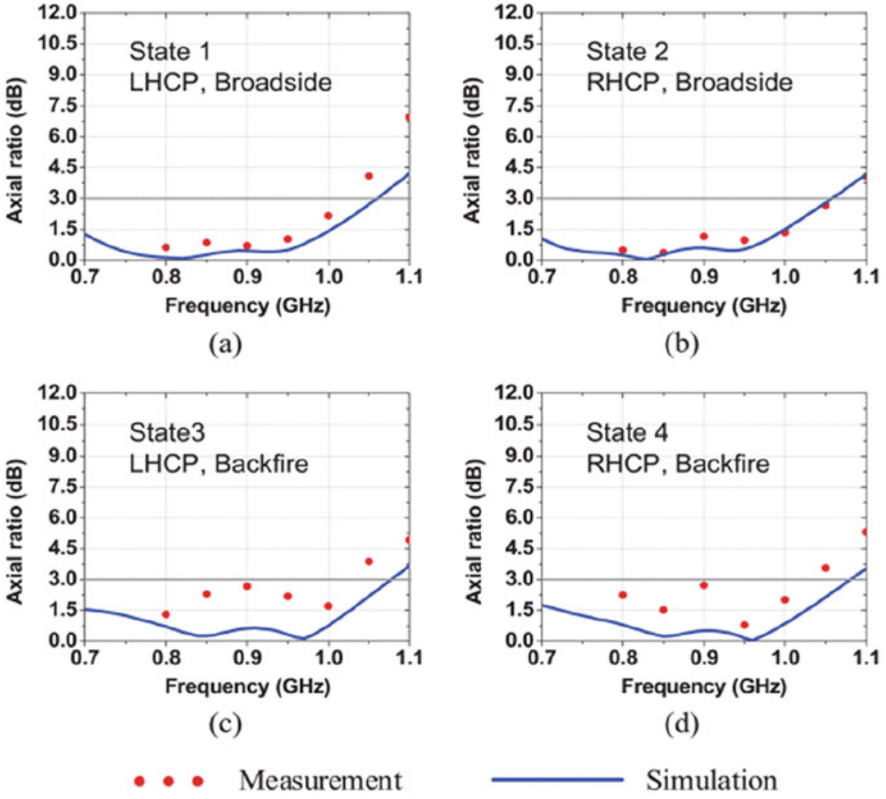


Fig. 9.31 Comparison between the simulated and measured ARs of the proposed reconfigurable antenna in different states; (**a**) State 1, (**b**) State 2, (**c**) State 3, and (**d**) State 4

between the vias controls the field spillage of the waveguide. The SIW waveguide shapes with rectangular waveguide shape along with two conveyor planes, which are separated by dielectric substrates with channel sidewalls by lines metalized through vias. The SIW technology is an elective strategy for the minimal effort of waveguide like the parts integrated with simple PCB standards [112, 113]. It is much better in comparison with existing technologies as for lightweight, ease of integration, and straightforward. A novel leaky-wave antenna with fixed frequency and switchable beam steering for 5G application was explained in [114]. In this chapter, the pin diodes are used to control the phase shift angle and position of the feeding slots as shown in Fig. 9.35. A new technique of central excitation based on four coupling plated through hole was introduced. The holes relate to the ground plane and top wall as well. The reconfigurable feeding method is applied by using the pin diodes. The measured and simulated return losses for the proposed antenna are shown in Fig. 9.36. The frequency range is from 26.2 to 27.3 GHz with reflection coefficient magnitude lower than −12 dB. The radiation efficiency varies between

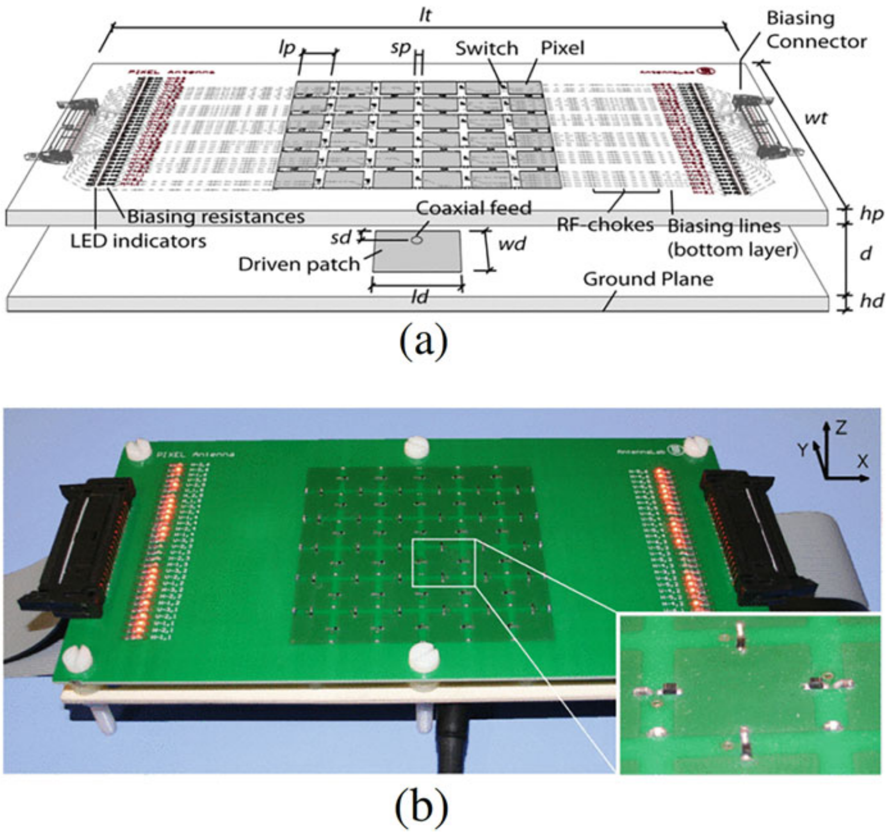


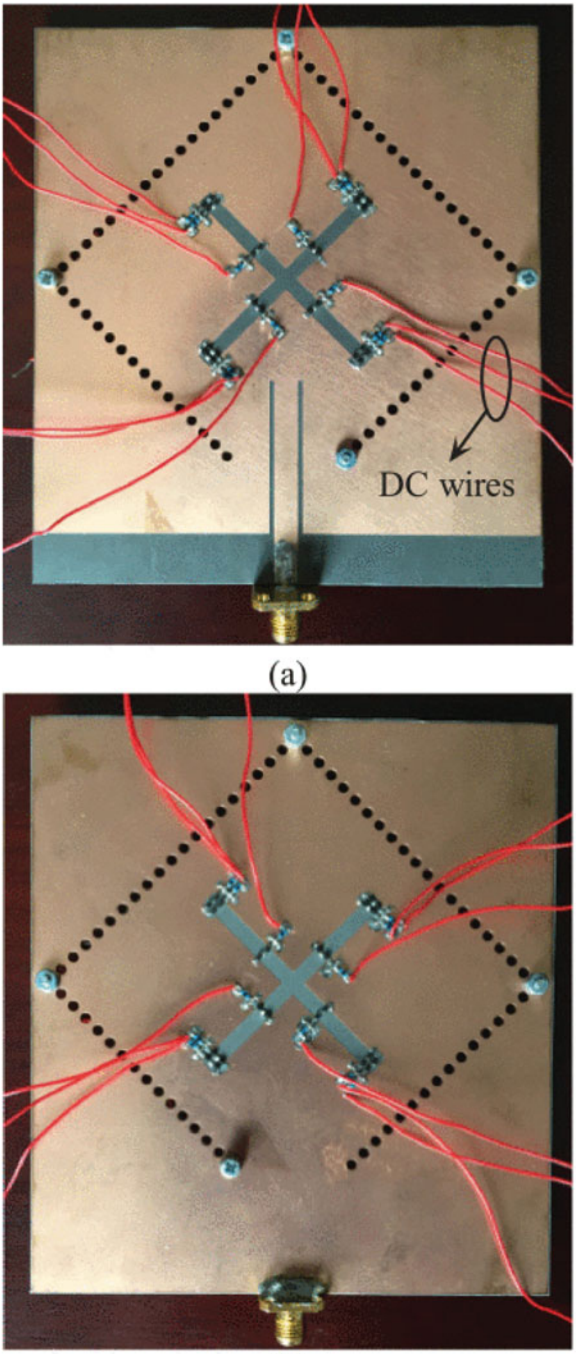
Fig. 9.32 (**a**) Schematic of the parasitic pixel layer. (**b**) Pixel antenna prototype

60 and 94% depending on the excitation configuration. The discrepancy between the measured and simulated results is due the construction of biasing circuit, which was not considered during the simulation.

9.6 Reconfigurable Band-Notch UWB Antenna

In the last few years, UWB technology gained much attention due to its advantages like low-power consumption, wide bandwidth, low cost, less complexity, and high data rate transmission [115, 116]. Due to these properties, UWB technology is widely used in many applications like indoor communication, cognitive radio, radar, localization, and automotive, etc. [117–119]. There are several other narrow band standards coexist within the UWB like IEEE 802.16 WiMAX (3.3–3.6 GHz; 5.25–5.825 GHz), IEEE 802.11a wide local area network (WLAN) (5.15–5.35 GHz;

Fig. 9.33 Proposed antenna prototype



(a)

(b)

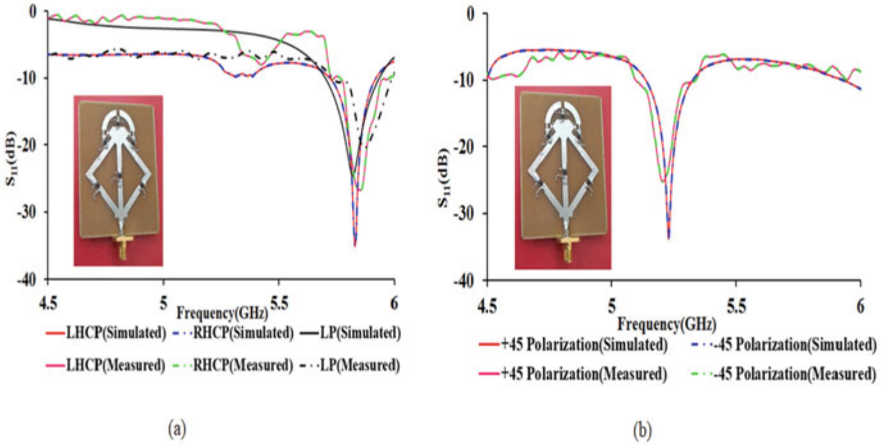


Fig. 9.34 (**a**) Comparison between the simulated and measured S-parameters, when PIN diode D6 is "OFF." (**b**) Comparison between the simulated and measured S-parameters, when PIN diode D6 is "ON"

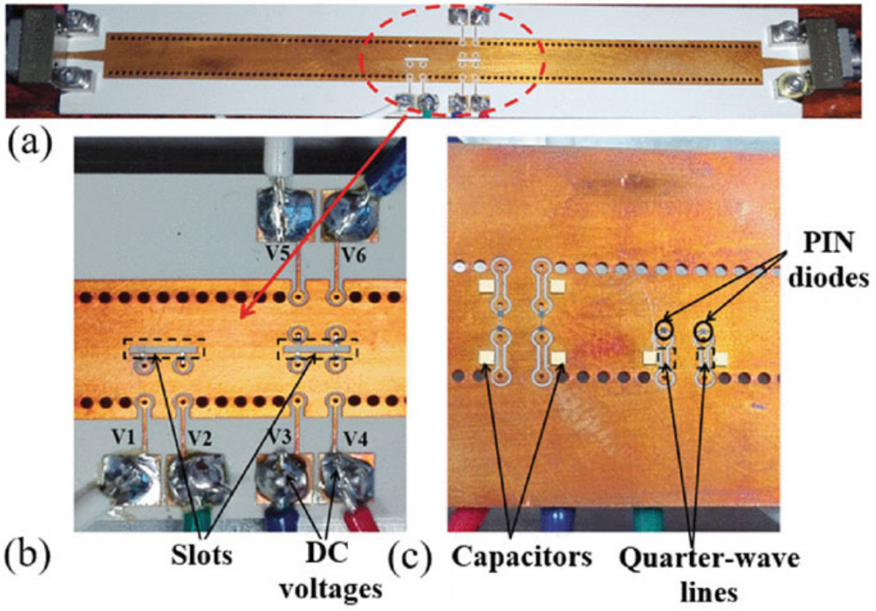


Fig. 9.35 (**a**) Prototype overview. (**b**) Front view. (**c**) Back view

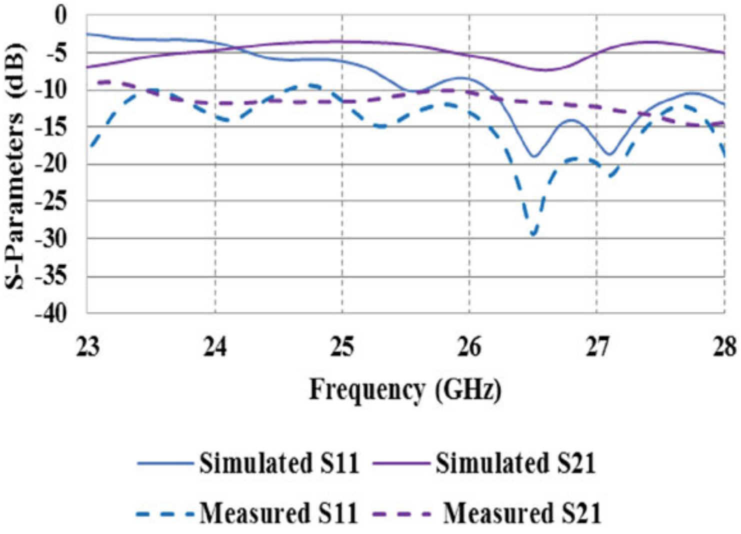


Fig. 9.36 Simulated and measured reflection coefficients of antenna array

5.725–5.825 GHz), and ETSI HiperLAN /2 (5.15–5.35 GHz, 5.47–5.725 GHz). This overlap band creates the electromagnetic interfaces with UWB technology when they are operating at the same time in other wireless devices [120–122]. Normally, filter is used to stop the unwanted band and increase the communication efficiency, but the addition of the filters in the latest compact communications systems increases the overall size, cost, makes more complex, and increases the insertion losses [123, 124]. So, much research is going on to design the UWB antenna with band-notch characteristics. The UWB antenna with band-notch characteristics was developed by using slot or slit [125–127], slots in the feeding network [128–130], slot in the ground plane [131–133], and parasitic patches [134, 135]. Hence, they are fixed band notched UWB antennas, and they are not applicable to utilize all frequency ranges of the UWB technology. By using the reconfigurable band-notching technique, one can use the required frequency band as per system requirement

The low-profile reconfigurable UWB antenna with single or dual-band rejection property was expressed in [136] as shown in Fig. 9.37. The proposed antenna is the combination of monopole structure, pin diode, biasing circuit, partial ground plane along with arc-shaped slot, and open-ended L-shaped stubs for band rejection. The antenna operates in four modes: full UWB (3.1–10.6 GHz), single-band rejection of WiMAX or WLAN, and dual-band (WiMAX, WLAN) band rejection. The dual-band reconfigurable notched slot-type split ring resonator (ST-SRR) antenna for WiMAX and WLAN applications was explained in [137]. The defected ground plane is used to for impedance matching, and ST-SRR is used in the feed to get the required band notch for UWB antenna. The measurement results show that antenna gains a fractional bandwidth of 138.63%. A novel compact triple band-

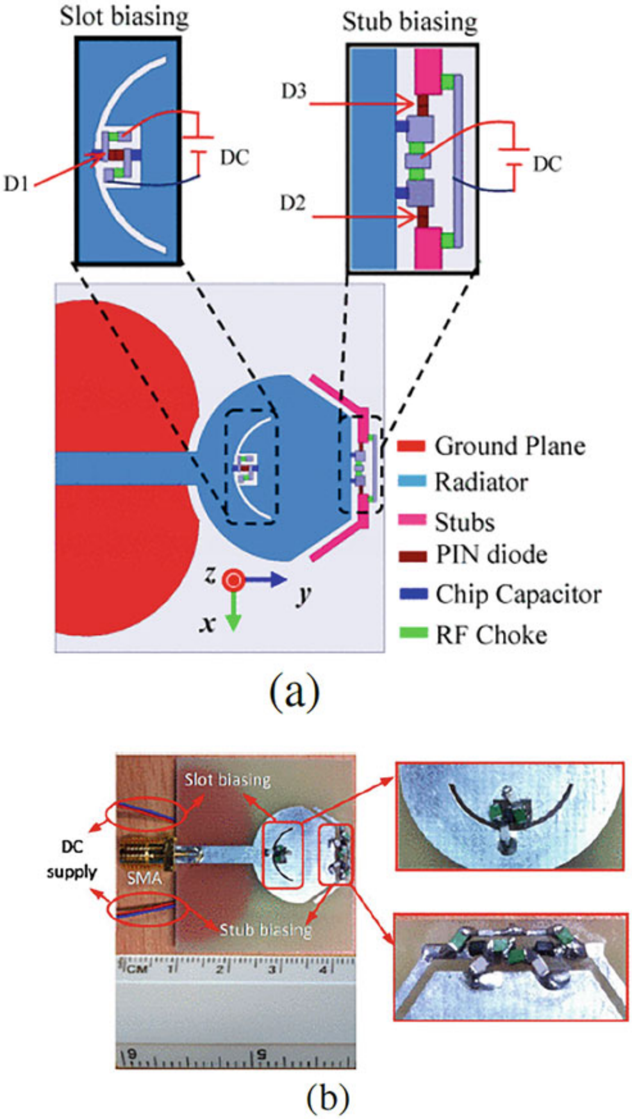


Fig. 9.37 (**a**) Antenna dimension. (**b**) Antenna prototype

notched reconfigurable fractal antenna was explained in [138]. By using the fractal technique, the overall size of the proposed antenna is reduced to 53% as shown in Fig. 9.38. The proposed antenna consists of circular patch, slots, pin diodes, and split ring resonator (SRR). The proposed antenna behaves as notched frequency at WiMAX, WLAN, and X bands.

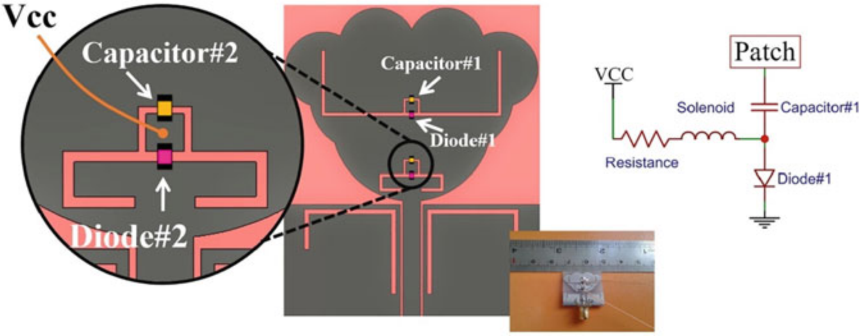


Fig. 9.38 Antenna structure with biasing circuit

9.7 Reconfigurable Metamaterial Antenna

The advancement in metamaterial and metasurface has brought more opportunities in the field of microwave devices. According to the definition, metamaterials have artificial and unusual characteristics such as negative permittivity and permeability that do not occur in natural materials [139]. Except for low profile, metamaterials also provide more flexibility in the design of microwave device and more functionality for the control. Metasurface (MS) is two-dimensional equivalent of metamaterials, and it helped to improve the return loss and gain along with the polarization of an antenna [140]. The frequency and polarization reconfigurable antenna using double-layer metasurface was explained in [141]. The polarization reconfigurable metasurface (PRMS) is in the uppermost layer on the side face to the middle layer, while frequency reconfigurable metasurface (FRMS) is on the opposite side of the patch antenna. The proposed antenna shows the frequency between 4 and 5 GHz and the polarization switching between LP, RHCP, and RHCP.

A wideband polarization reconfigurable antenna is presented in [142]. The metasurfaces in this chapter are the combination of 4 × 4 periodic metal plates. The proposed antenna consists of square patch radiation, metasurface, and four tunable switching feeding probes. The switchable feeding network is the combination of a 2-way power divider and SPDT switches that consist of pin diodes as shown in Fig. 9.39. By changing the biasing voltage, the proposed antenna is tuned between x and y direction linear polarization and RHCP/LHCP. The beam switching reconfigurable antenna was expressed in [143]. The reconfigurable metasurface is the combination of double-slit square ring and pin diodes.

9.8 Reconfigurable Antenna for Flexible Material

In recent years, wearable antenna technology has gained much attention in industry and academia due to its vast feathers like lightweight, flexible, low cost, and easily integrable with modern communication systems. In the medical field, wearable

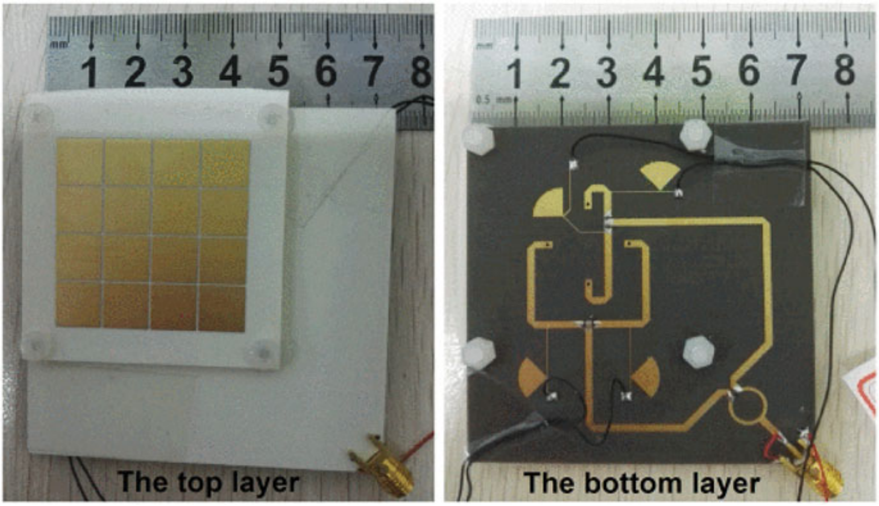


Fig. 9.39 Antenna prototype

antennas are used to monitor the critical health condition of the patient, check sugar level, and investigate the inner intestinal system, blood pressure, heartbeat, and temperature of the body. In the recreation side, they contribute in the way of augmented reality glasses, touchscreen computer, and smartwatches. The flexible antenna with reconfigurable technique provides the small-size and low-cost solution for modern electronics and advanced wireless communication systems. There are some challenges related to the integration of reconfigurable components such as switches, biasing circuits, and mechanical stability. Extensive research and antenna prototypes have been developed on the rigid and conventional substrate in the last few decades. The requirement of the flexible antenna with reconfigurable technique has been increased as they are the main component of the wearable technology and cope up with the advance wearable devices.

The CPW-fed-based quad-band and penta-band flexible reconfigurable antennas are presented in [144], [21], and [145], respectively. The copper tape is used in these antenna prototypes, making it difficult to predict the exact behaviour of PIN diodes for practical applications. The flexible reconfigurable antenna on PET film for WLAN/WiMAX wireless applications was presented in [146]. The antenna has folded slot and CPW-fed but with large antenna volume. The dual-band CPW-fed flexible reconfigurable antenna was explained in [147]. It is monopole antenna incorporated with U-shaped slot to get the required frequency. The frequency and polarization reconfigurable flexible antennas were investigated in [148]. The antenna consists of a folded slot, stub, and artificial magnetic conductor (AMC) surface to reduce the SAR value. The antenna prototype shows good agreement in a flat and curved situation, and measurement on the human body as well. A robust, flexible, and frequency reconfigurable antenna was presented in [149]. The antenna

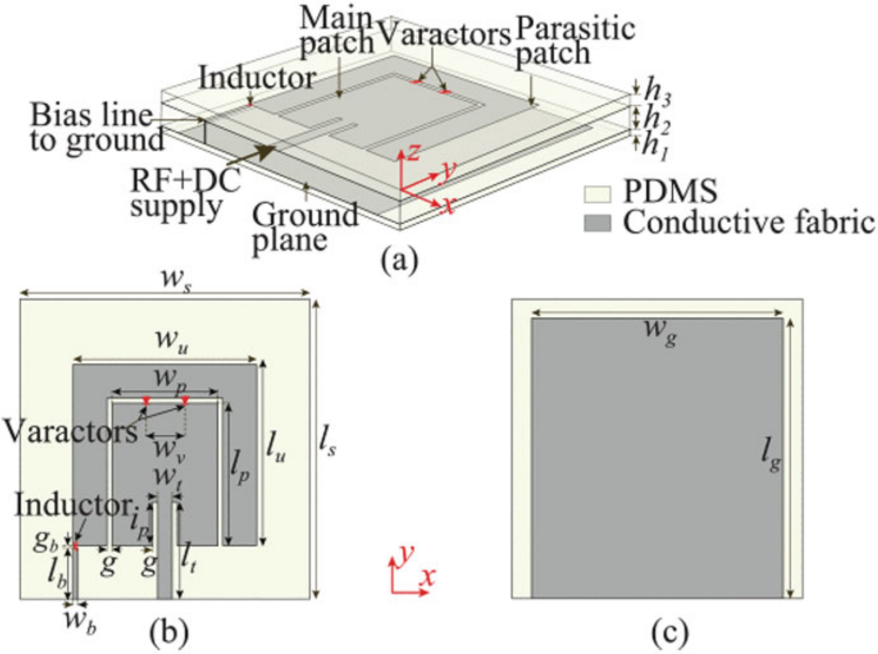


Fig. 9.40 Antenna configuration. (**a**) Cross-sectional view. (**b**) Patch layer. (**c**) Ground layer

consists of conductive fibre on polydimethylsiloxane (PDMS) substrate as shown in Fig. 9.40. The antenna prototype and other lumped components were encapsulated with an additional layer of PDMS. The antenna bending characteristics were investigated in free space, on body phantom, and in the household washing machine. These tests show that antenna working order is normal even in extreme bending (radius 28 mm) and after washing. An inkjet-printed frequency reconfigurable antenna on a paper substrate for wireless applications was explained in [150]. The antenna consists of a main radiator, L-shaped, U-shaped radiators, and the ground plane. With the help of a PIN diode, the proposed antenna can tune between 1.5 and 4 GHz.

9.9 Application of Reconfigurable Antenna

The new era of antenna design must generate an antenna that is cognitive and adjust to the environment and ever-changing conditions. Also, there is a need for antennas that can overcome failure and swiftly respond to new developments. Cognitive radio, massive multiple-input multiple-output (MIMO), wireless body area networks, satellite, and space communication platforms are all possible applications for the integration of highly, reliable, and efficient reconfigurable antenna.

9.9.1 Reconfigurable Antenna for MIMO Communication System

To fulfil the requirements of current and future modern communication systems, MIMO system plays a vital role to cover the high data rate and signal strength requirements within a defined bandwidth. The MIMO technology depends on the multiple antennas that are implemented on both sides of the communication systems. The implementation of MIMO reconfigurable antenna at the front end will improve the data capacity and directivity significantly.

A frequency reconfigurable antenna for MIMO applications was explained in [151]. The single element of an antenna is the combination of 4 × 4 MIMO antenna, and it is designed to operate 2.4 and 2.6 GHz frequency. The single element MIMO antenna is either two 2 × 2 MIMO antenna or a single 4 × 4 array as shown in Fig. 9.41. The proposed antenna is coaxially fed, and pin diodes are inserted on the backside. The different states of the pin diodes are controlled by microcontroller module. To get the high gain, an air gap is introduced between the radiation patch and the ground plane.

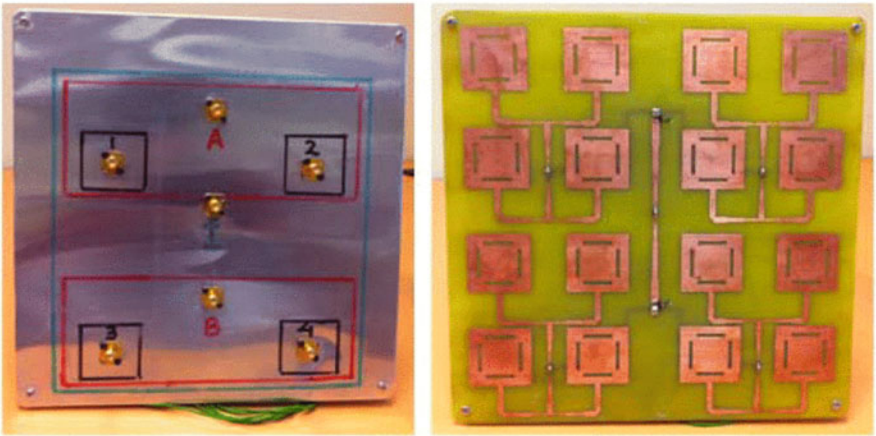


Fig. 9.41 Antenna prototype

9.9.2 Reconfigurable Antenna for Cognitive Radio Applications

With every passing day, the wireless subscribers are gradually increasing. It is a big challenge to provide a high data rate and fast browsing speed. Secondly, the distribution of the band spectrum is not uniform, which also badly affects the overall efficiency of the system. To overcome this limitation, a new technique named cognitive radio was introduced that uses the unoccupied/idle band spectrum for communication and increases the system efficiency. Wideband and reconfigurable antennas are a promising candidate for cognitive radio communication. Additionally, compact-size antennas are the requirements for portable mobile devices.

A compact novel broadband antenna was presented in [152]. In this chapter, both the discrete and continuous tuning was implemented to get a large frequency range. The antenna consists of UWB monopole antenna with reconfigurable impedance matching network as shown in Fig. 9.42. The proposed design has two independent paths to cover the 430 MHz and 5 GHz frequency. The first path is directly connected with a UWB antenna that covers the 1–5 GHz frequency range. The second path is controlled through a varactor-diode-based matching network. Two discrete switches are used to move between wideband and reconfigurable modes.

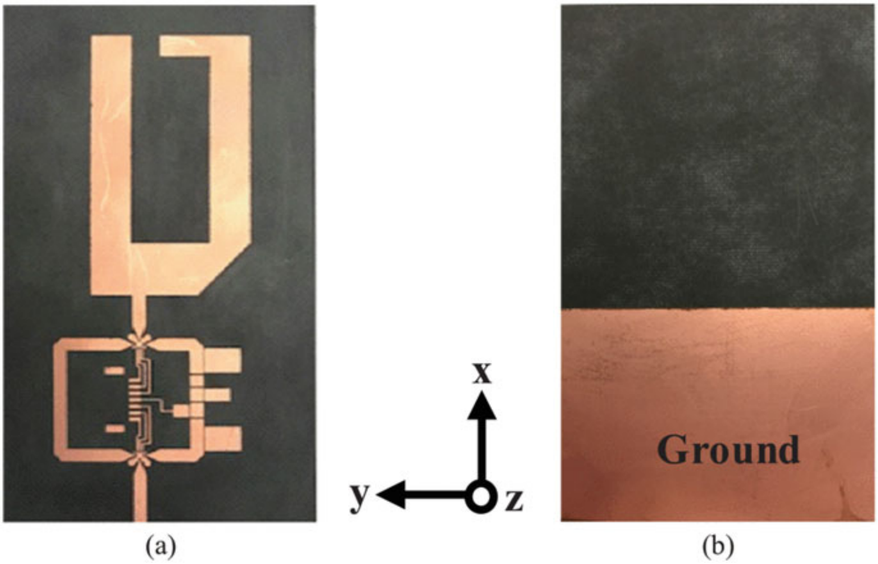


Fig. 9.42 Antenna prototype

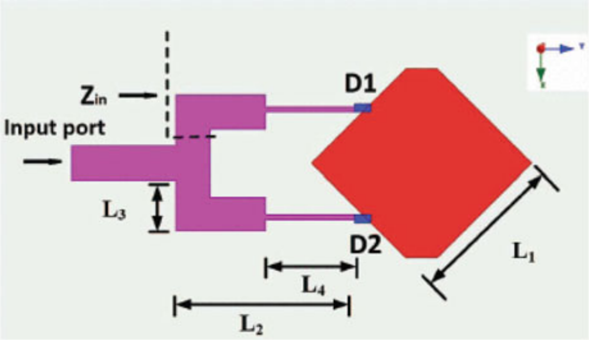


Fig. 9.43 Dimension of the proposed antenna

9.9.3 Reconfigurable Antenna for Millimetre-Wave Communication

5G is the promising solution to address the modern wireless network demands like higher data throughput and hence bandwidth. They also provide wide and unemployed bandwidth. The mm-wave band lies between 30 and 300 GHz frequency ranges. While using the higher frequency, the new challenges arise like an increase in patch loss and complexity of the system including antennas, filter, and amplifiers. The compact reconfigurable antenna with tunable radiation pattern is of great interest to maintain the user requirements in an atmosphere-dependent scenario.

Figure 9.43 shows a polarization reconfigurable antenna, consisting of square radiation patch, microstrip line, and two PIN diodes [153]. The proposed antenna can switch between RHCP and LHCP by changing the states of pin diodes. The antenna shows impedance bandwidth from 27.6 to 28.6 GHz. A good axial ration is also achieved between 27.65 and 28.35 GHz.

9.10 Future of Reconfigurable Antenna

The reconfigurable antennas have attractive features and provide flexibility in adjusting the functionality of the system, minimizing the overall system volume and circuit complexity. It is desired to use the reconfigurable antenna to increase the system capacity, spectrum, and energy efficiency. To make an antenna reconfigurable and change its three main properties (resonance frequency, radiation pattern, and polarization), different methods and novel design ideas have been proposed in the literature. However, there is still some imperfection, which adversely affects the performance of the reconfigurable antennas. These imperfections include large volume size, limited gain, and non-linear behaviour of RF switches, narrow bandwidth, complex impedance matching circuit, complicated biasing circuit, and finite overall performance.

Future research in this field will need to focus on the problem, which has a great impact on modern wireless communication systems. Since many antenna designs for advanced communication systems employ antenna array, including reconfigurable antenna array, metamaterial reconfigurable antenna array, and directional narrow beam antenna, hybrid (frequency, radiation pattern, and polarization) reconfigurable antenna will lead another important research direction for future endeavour.

9.11 Conclusion

This chapter starts with the brief history of reconfigurable antenna. The techniques and properties for the reconfiguration of an antenna were explained in detail. Some existing proposed reconfigurable antenna designs, methods, and their constraints are also discussed. In addition, the applications and the benefits of the reconfigurable antennas are highlighted.

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