A Comprehensive Review on Multiband Reconfigurable Antenna

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Abstract **—The advancement of wireless communication is markedly accountable from the past two decades. A variety of designs and techniques have been established in the domain of reconfigurable multiband antennas for different wireless services. Now a days, a high quality of communication with reduced size is required for new generation wireless system. A multiband reconfigurable functionality offers a flexible and high-performance design by single antenna only. A brief review on multiband antenna with different reconfigurable techniques is presented in this paper. Moreover, the new possibilities for future wireless communication system have been demonstrated. A reconfigurable system along with minimal interference level over the fixed or non-reconfigurable transceivers has been discussed in detail.**

Index Terms **—Multiband antenna, reconfigurable techniques, switching devices, group delay, VSWR, reflection coefficient, radiation pattern, feeding techniques**

I. Introduction

Wireless industry made a revolutionary remark from past few decades and the antenna has been proven to be a pioneering design at wireless platforms for enabling a fast and secure communication. Various communication standards have been developed for different applications. In recent years, reconfigurable multiband antenna has been deliberated as an utmost prevalent design widely used in many commercial, military, airborne communications, and radio applications. These novel techniques require more flexibility and multi-functionalities to support numerous wireless standards such as; Universal Mobile Telecommunications System (UMTS) (1885MHz-2200MHz), Ultra-Wide Band (UWB) (3.1GHz-10.6GHz), Bluetooth (2.480GHz), Worldwide Interoperability for Microwave Access (WiMAX) (3.3GHz-3.7GHz), Wireless Local Area Network (WLAN) (5.15GHz-5.825GHz), Wireless Fidelity (Wi-Fi) (2.4GHz-5GHz) etc. The antenna can select or reject signals at various frequencies at the front-end circuits in modern wireless systems [1]. The foremost challenge is to design configurable antenna with linear phase, low insertion loss, lightweight, small size, high selectivity, and lower cost due to the limitation of frequency spectrum. In order to overcome the limitations of single frequency band operations, the multiband antennas are used [2]. To improve the eminence of wireless services, reconfigurability has been introduced. Reconfigurable antenna can alter the operating frequencies, impedance bandwidth, radiation pattern and polarization separately as per the requirements [3], [4]. Numerous methods have been proposed to model the reconfigurable multiband antenna which comprises of dual-band, tri-band, quad bands and more for different wireless standards [5], [6]. The concept of reconfigurability was developed in USA in 1930. In a multifunctional communication system environment, it was a breakthrough for researchers because they were providing services in different frequency bands [7], [8]. Some switches and capacitive circuits can be used to modify the properties of design which includes frequency, radiation pattern and polarization.

A compact reconfigurable antenna is advantageous due to the property of functioning on multiband frequencies. Moreover, offering pre-filtering makes it further beneficial over fixed or non-reconfigurable transceivers [9]-[11]. Multiple bands can be corroborated simultaneously by wideband antenna at the cost of weak reception quality. In order to augment the switching capacities in bands, the multiband reconfigurable antenna is very promising design in current wireless applications [12]. The reconfigurability is classified in three categories according to its competence to change operating frequency, radiation pattern and polarization. A configuration that has the capability to modify its operating frequency is called frequency reconfiguration. The reconfigurable antenna in which radiation pattern can be altered in terms of direction, shape and gain is a radiation pattern reconfigurable antenna. Similarly, the configuration that can change its polarization (horizontal/vertical), left hand circular polarization (LHCP) to right hand circular polarization (RHCP) is known as polarization reconfigurable antenna [13].

II. Survey on Reconfigurable Antenna

A variety of constructive reconfiguration techniques have been projected in recent years for different wireless systems such as satellite, radar sensing and detection, multiple-input multiple-output and cognitive radio etc. A

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detailed discussion of different types of reconfigurable techniques has been demonstrated in this section. Moreover, reconfigurable antenna elements and arrays also have been discussed for future wireless research. The reconfigurable antenna can be classified based on different techniques for reconfiguration as shown in Fig. 1.

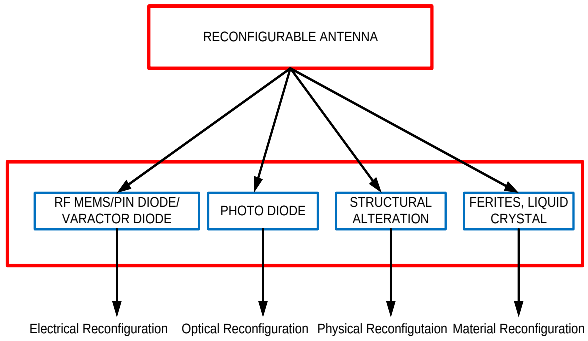


Fig. 1. Classification of reconfigurable antenna.

A. *Electrical Reconfiguration*

The Radio Frequency-Micro-Electro Mechanical system (RF-MEMS), PIN diodes and Varactor diode may be used as a switch for electrification of antenna system. The antennas with photoconductive switches are known as optically reconfigurable antennas and where reconfigurability is created by structural variation, those antennas are called physically reconfigurable antennas [13]. The reconfigurability in the antenna system can also be created using smart materials such as liquid crystals and ferrites. The switching technique is extensively used in novel communication system in which the electrical dimension of antenna system is amended by electronic switching. The variation in electrical length of antenna can modify three main parameters namely frequency, polarization, and radiation pattern [14]. The wireless data communication has two categories namely land and satellite. The land-based data communication is responsible for high error rates due to interference and unpredictable environments whereas in satellite-based data communication, the signal processing capacity is inadequate because of dependency on battery lifespan of the portable unit. The modern structure can support to overcome such limitations [15]. A detailed discussion for different reconfigurable antennas with their applications, advantages and limitations is reviewed in this article. Various techniques have been addressed in context of refining the physical and radiation properties. The electrical reconfiguration is most extensively used technique, where active elements such as MEMS switches, PIN and varactor diodes are key components to change the antenna characteristics. RF-MEMS switches offer low power degeneracies and low insertion losses. PIN diodes are responsible for faster switching speed and varactor diode offers impeccable tuning capability. But the states of these switches may cause deviation in radiation properties due to the biasing line distortion. The biasing circuits for PIN, varactor and MEMS switch are depicted in Fig. 2 [16].

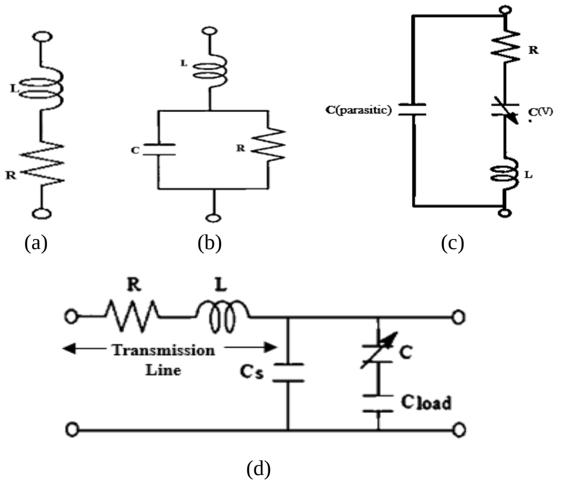


Fig. 2. Biasing network of PIN diode switch: (a) ON state, (b) OFF state, (c) Varactor, and (d) MEMS capacitive switch.

A reconfigurable antenna based on Multi-Input Multi-Output systems (MIMO) with MEMS switch has been demonstrated in 2004 [17]. It is compatible for categorizing two distinct frequencies; 4.1GHz and 6.4GHz. This antenna provides ten distinct operating modes. Reconfigurability has been accomplished by tuning the antenna aperture's magnitude. An electronically tunable antenna has been designed and presented in 2005, having a single-fed slot resonator [18]. Proposed structure consists of a series of four PIN diode switches for perfect tuning within the frequency range of 540MHz-950MHz. An input reflection coefficient (S_{11}) of –20dB and efficiency of 47% has been perceived which verifies the best impedance matching for the operating frequency band with precise gain of 11dBi.

A microstrip antenna with reconfiguration capabilities has been presented in 2005 [19]. A U-slot into a square patch is used, which is connected with a PIN diode and the frequency reconfiguration characteristic depends on switching states. The bandwidth of 3dB Circularly Polarized (CP) has been obtained at 35MHz and 40MHz by introducing PIN diodes in U-slot. A reconfigurable patch antenna for multi-standard systems with PIN switches has been proposed in 2005 [20]. An impedance bandwidth of 0.48% and 2.45% achieved at 1.89GHz and 2.37GHz, respectively.

An electronically tunable slot antenna, containing a slot resonator and a series of PIN diodes has been presented in 2005 [21]. An effective bandwidth of 1.7: 1 has been achieved and length of resonant slot has been optimized. The design has the proficiency to diverge at four discrete frequencies from 550MHz to 900MHz. An advanced hexagonal slot-loaded square Microstrip Patch Antenna (MPA) has been reported [22], having a single feed line and operable in dual frequency mode with dual polarization. After switching off the PIN diode within a slot, the resonance is achieved on 1.48GHz and 1.99GHz with frequency ratio of 1.34. The design provides a prodigious improvement in band width up to 3.3% and 4.27% for both the frequencies. The first resonant frequency shift is 105MHz in on state and a second resonant frequency shift is 60MHz in off state.

In 2006, six-state frequency reconfigurable antenna with band-pass filter is proposed [23]. The design provides the filter response with frequencies of 9GHz, 10GHz, and 11GHz. The range for wideband and narrowband has been achieved from 13.4% to 14.7% and 7.7% to 8.5% respectively. PIN diode switch was employed for the connection and isolation in transmission portion. The insertion loss of the filter has been estimated within the range of 1.74dB-1.92dB and evaluated gain is larger than 5dBi. A new technique has been introduced for designing a dual band reconfigurable slot antenna in 2006 [24]. A slot has been inserted in the antenna structure via lumped capacitor (or varactor) at selected location. This technique allows the antenna to be electronically tunable for dual frequency band (1.95GHz and 2.15GHz). The antenna includes a single varactor diode with capacitance of 2.2pF. The calculated resonant frequency has been altered from 1.8GHz to 1.95GHz and 2.15GHz to 3.22GHz respectively. The design provides significant radiation properties and reduced cross polarization degree with calculated efficiency of 70% and 85% for both bands correspondingly.

A novel multiband microstrip antenna has been demonstrated in 2007 [25]. It was printed on a hexagonal substrate of six-armed star shaped patch. The multi frequency operations were performed from 3GHz to 4.5GHz according to the switching. Furthermore, the design provides the wide band ranges i.e. 3.5GHz to 3.8GHz and 4.3GHz to 4.7GHz. An E-shaped patch antenna for wireless communication system which offers wide operational bandwidth has been presented [26]. Switching state (ON/OFF) is to change the operating frequency of proposed design. The covered operational frequency ranges of the proposed antenna are 9.2GHz to 15.0GHz and 7.5GHz to 10.7GHz.

A small reconfigurable antenna for the purpose of multi frequency band operations in mobile communication has been proposed in 2007 [27]. There are two excitation modes in this design: first mode is excited when operating switches are instigated in design which provides the truncated frequency about 900MHz and superior frequency band up to 1.8GHz. Similarly, when second mode is excited, the frequency bands of 900MHz and 2GHz are obtained. It is realized that the two different modes are responsible to cover five different services i.e. Global System for Mobile (GSM850 and GSM900), Digital Communication System (DCS), Personal Communication System (PCS), and UMTS bands with superlative efficiency more than 50%. A patch antenna using PIN diode switches was presented in 2008 [28]. The proposed design is applicable for multi-standard personal communication systems. Two different configurations are considered for dual-band function namely patch antenna with two switchable slots and a rectangular patch with a switchable parasitic element.

A novel antenna with conical-beam radiation for frequency reconfiguration has been reported in 2011 [29]. The design has TM02 mode-based configuration. In this design, the coplanar ring microstrip antenna and a few shorting strips are uniformly located on the perimeter of patch to deviate its resonating frequency. A microstrip slot antenna has been presented with frequency reconfiguration characteristics in 2012 [30]. The antenna is proficient to switch the frequency band for six different states, lies from 2.2GHz to 4.75GHz. To attain the frequency reconfigurability, a group of five RF-PIN diode switches are incorporated in the slot. The measured frequencies are shifted to the lower region with the average of 536MHz compared to the simulated frequencies. The average measured gain of 1.9dBi has been achieved with 33% reduction in size compared to conventional MSA. Apart from active elements (PIN diode, Varactor diode, MEMS etc.), some passive elements also have gained great attention in context of reconfigurability in modern wireless communication techniques. A reconfigurable reflect-array antenna reconfigured by passive and active components both has been presented [31]. The design consists of hollowed patches, which are identical in shape. A Surface mount capacitor (SMDC) has been encumbered in slots to examine the initial phase. In order to scan the beam, the value of capacitance has been adjusted. The patch components include varactor-diode, which leads to change in second phase. A new class of multifunctional antenna array has been reported [32]. The main objective of this design is to boost the spectral efficiency of existing system as well as future wireless network. The proposed antenna is modelled by combining four identical multi-functional reconfigurable antenna elements. The measurement of the prototype has been done in the frequency range 5.4GHz-5.6GHz and the peak gain value has found to be 24.3dBi, which is 2dBi to 3dBi higher than the standard patch array.

A small frequency reconfigurable antenna with RF-MEMS switch has been presented [33]. The design holds sharp frequency reconfigurability between two bands of 718MHz and 4960MHz. It is remarked that the system offers a wide bandwidth of 2.6% at 718MHz with reduced size. An innovative reconfigurable antenna with switchable slots has been anticipated [34]. The proposed design allows the various frequency bands by choosing the switching states of three switches (ON/OFF). The measured resonant bands of antenna are 2.46GHz, 3.59GHz, and 5.69GHz with gain values of 2.33dBi, 3.14dBi, and 2.89dBi respectively.

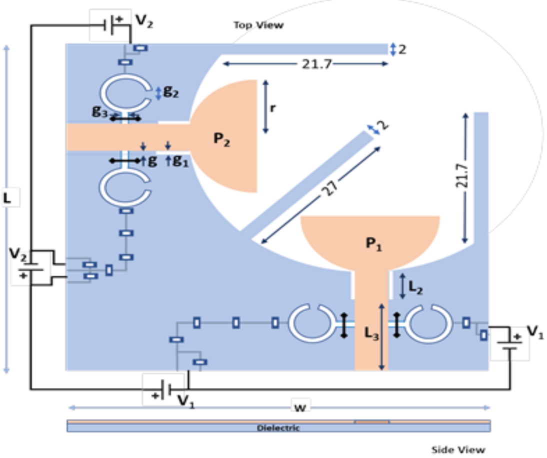


Fig. 3. Polarization diversity antenna.

The antenna having wideband (UWB) and narrowband (NB) switching capabilities for polarization diversity are shown in Fig. 3 [35]. The proposed design consists of two uniplanar ports and two open annular slots. In order to attain polarization diversity performance beyond UWB, the slots are excited orthogonally through identical coplanar waveguide feed line from the center. The UWB/NB switching can be realized by resonator-based filter. The Schottky Diode has been used for electronic control at the entrance of the slot. The frequency range for UWB is 2.9GHz to 11GHz and correspondingly for NB is 4.9GHz to 5.5GHz. The gain of antenna system has also been plotted which is varied from 3.2dBi to 6.5dBi for UWB and from 4.5dBi to 5.1dBi for NB respectively. A triple band reconfigurable antenna for WLAN and WiMAX bands has been analyzed [36].

A rectangular slot, a PIN diode, and a metamaterial (MTM) based ring structure has been introduced. The high average gain of 2.8dBi was achieved by this antenna. A novel reconfigurable antenna with folded slot has been presented in 2016. The fabrication process is performed on Polyethylene Terephthalate (PET) substrate which is flexible in nature. The design is reconfigured by PIN diode switch, which offers single and dual band features according switching states (ON/OFF). This inkjet-printing antenna is very promising for conformal applications such as WLAN, WiMAX etc. [37]. A compact UWB antenna with triple notch bands is proposed in 2016 [38]. A dual Elliptical Split Ring Resonator (ESRR) of distinct magnitudes has been etched in patch and two band-notched with range of 3GHz-3.7GHz and 5.125GHz–5.825GHz for WiMAX and WLAN are achieved, respectively. The design also offers the band notch property for 7.9GHz-8.4GHz by employing Step Impedance Resonator (SIR) near feed line. New technique for 5th generation reconfigurable wireless communication system has been presented in 2017. A partially reflective surface (PRS) antenna usually employs a source antenna with low directivity. PIN diodes have been used to create the reconfigurability for perfect tuning [39].

A dual band antenna with slot Active Frequency Selective Surface (AFSS) has been presented in 2017 which is operable in two frequency bands. The reconfigurability can be created by PIN diode switches. The designed antenna operating at 2.5GHz and 5.3GHz frequency bands has been fabricated and provides a low power and low cost structure [40]. An analysis of SIR based UWB antenna was introduced in 2017 [41]. Proposed antenna is dedicated to minimize potential interference between WLAN and UWB and it covers the notched band of 5.15GHz to 5.85GHz WLAN range. The experimental value of input reflection coefficient is less than −10dB with VSWR<2.

A reconfigurable phased antenna array configuration is designed for 5G mobile applications, which can be operated at 28 GHz frequency [42]. A passive slot antenna element has been introduced to generate the reconfiguration property. The proposed antenna provides considerable gain of 10dBi with 70% efficiency.

A dual band patch antenna, based on the characteristic mode analysis with frequency reconfigurability has been demonstrated in 2019. A slot with two varactor diodes for tuning lower band has been used. This design covers WLAN band, ranging from 2GHz to 5.8GHz [43]. The human Implants technology now a days is very emerging and research has been originated in some countries. A UWB antenna has been analyzed for human implants, which can provide a bandwidth of 1.5GHz for the antenna [44]. This wireless body area network (WBAN) is portable for human implant functions up to 4GHz. Moreover, the new trends for antenna system have been reviewed for both wide and narrow bands. A signal Analyzer is used to inspect dual port and multiport analysis for software radio peripheral [45].

All electrical switching techniques with its properties have been discussed above. A comparable study has been performed in context of switching. PIN diodes and Schottky diodes require fewer biasing lines, whereas MEMS switches are dedicated to realize the reconfigurability for low power and portable wireless standards. The overview of various projected antennas using distinct reconfiguration methodologies have been briefly listed in Table I. Some dominant constraints such as bandwidth and different reconfiguration modes have also been presented. Various designs have been summarized based on different switching methods and future challenges have been presented in Table II.

TABLE I: DESIGN SPECIFICATIONS AND KEY FEATURES OF PROPOSED ANTENNA UP TO NOW

References	Design Specifications	Advantages
Schaubert *et al*. [46], 1989	• Frequency and polarization reconfiguration are presented. • Percentage bandwidth of the microstrip antenna is 2% to 3% and provides a considerable immunity to interfering signals.	• Dedicated to mitigate the interference of signal
Liu *et al*. [47], 1997	• Compact reconfigurable antenna to deliver dual operating frequencies. • Radiation patch contains 2 slots of U-shape and rectangular shape.	• Exceptional impedance matching results in a wide impedance bandwidth • Additional slot provides extra current path.
Kolsrud *et al*. [48], 1998	• Antenna with Varactor diode of bias voltage from 0 V to 30V. • Measured tuning range at lower frequency is 14.5% or 300MHz upwards and at higher operating frequency is 11.5% or 450 MHz downwards.	• Very promising to achieve fast frequency tuning and high effective bandwidth.
Zhang *et al*. [49], 2005	• Novel fractal microstrip patch antenna with reconfigurable linear polarization in radiation patterns has been presented. • RF-MEMS switches used for reconfiguration.	• Input reflection coefficient • $S_{11} \leq$ -20 dB, for 10 GHz operational frequency.
Rajeev Kumar Kanth *et al*. [50], 2006	• Analysis of dual band fractal antenna dedicated for L and S bands. • Design is considered for satellite navigation and other telecommunication applications. • The gain of 4dBi and return loss of 10 dB with LHCP for both bands is achieved.	• L and S dual bands (2.9 GHz-3.2 GHz) are important for personal mobile satellite.

Fankem *et al*. [51], 2007	• Design of reconfigurable Printed Inverted F-Antenna (PIFA) with integrated RF-MEMS switches. • Proposed antenna works on five bands GSM900, Global Positioning System (GPS1575), GSM1800, PCS1900 and UMTS2100. • PIFA is feasible for low and high bands i.e. for lower band the impedance bandwidth matched up to -6dB from 748MHz - 912MHz	• Excellent electrical and radiation characteristics. • RF-MEMS switch provides additional advantages. • Reduced size up to 50%.
Weily *et al*. [52], 2008	• Partially reflective surface high-gain design sideways frequency reconfigurability is proposed. • Effective frequency is shifted from 5.2GHz to 5.95GHz when the bias voltage is varied from 6.49V to 18.5V. • Measured gain of reconfigurable antenna is varied from 10dBi to 16.4dBi with tuning limit of 13.5% over 5.2GHz to 5.95GHz.	• Provides high directivity and gain. • Wide bandwidth and easy to fabricate.
J. Costantine et al. [53],2009	• An innovative reconfigurable antenna model with rotatory slot. • Graph model has been introduced to control the slot rotations. • Stable radiation patterns are achieved by the algorithm commonly used in FPGA.	• The graph model provides Environment to realize a complex model in easiest way.
Perruisseau-Carrier *et al*. [54], 2010	• Antenna with wide bandwidth reconfigurable/rejection characteristics. • Mixing sets of varactor diodes with patch of antenna, tuning ratios have been achieved up to 2 at the design frequency. • Considering tuning capacitances of 0.1 pF - 2.0 pF range, frequency tuning limit lies between 1.859 GHz to 3.672 GHz.	• Reflection coefficient less than -10dB achieved. • Offers superb filtering performance.
Sanchez-Escuderos *et al*. [55], 2011	• Reconfigurable slot-array antenna with RF-MEMS switch. • Isolation of 12 dB between two states of switch has been obtained.	• Radiation efficiency is high (34% and 96% for On/OFF states) • Good isolation between two switching states
Abutarboush *et al*. [56], 2012	• Multiband reconfigurable antenna with C-Slot has been proposed. • Overall dimension of antenna system, including ground plane is (50mm×50mm×1.57mm). • System functions in two twin-band and one wideband mode. • Antenna upholds the frequency range of 5 GHz to 7 GHz by using two PIN diodes.	• C-slot provides a persistence gain (around 4.9dBi). • High Impedance bandwidth and 30% reduced size as compare to conventional design.
Chen, Gang *et al*. [57], 2012	• Folded slot frequency-reconfigurable antenna along with two modes of operation for two resonant frequencies has been presented. • Effective frequencies are 3.29 GHz and 5.2 GHz for mode1, and 2.36 GHz and 5.7 GHz for mode 2.	• No need of typical bias network or any capacitor. • Simple fabrication steps and multifrequency operations
J. Kumar *et al*. [58], 2016	• Frequency E-shaped patch antenna for medical applications. • PIN diode to create reconfigurability and operable for two frequency states: 2.03 GHz–2.28 GHz in multiband and 300 MHz–645 MHz in single band.	• Promising for various implant methodologies in medical field. • Additional filter improves the impedance characteristics.
Anatoliy Batmanov *et al*. [59], 2017	• UWB antenna using single notched configuration with octagonal shape patch. • Practicable for band range from 3.1 GHz to 12 GHz, for Cognitive Radio applications.	• Reduces interference by meandered slot and parasitic strip (WiMAX & WLAN).
A. Desai et al. [60], 2018	• Design of hexagonal fractal antenna with defected ground plane fed by CPW for wireless applications. • The resonant frequencies of 3.79 GHz and 5.5 GHz with measured S_{11} of -25.02 dB and -26.03 dB respectively are achieved.	• Large bandwidth is achieved by DGS. • Superb input impedance matching and multi-frequency performance.
A.A. Abdul Hameed *et al.* [61], 2019	• Low profile CR sensing antenna is proposed. • Two PIN diodes are used for reconfigurability. • Mutual coupling between sensing and antenna is less than -16dB.	• Beneficial for multiple wideband CR applications with different bandwidths.
Pradyunma K. Patra *et al.* [62], 2019	• Improved MIMO UWB, E-shape antenna with 50 Ω step fed. • Two inverted Γ shaped stubs in the ground plane are used.	• Low-cost and dimension is reduced by 33%. • High isolation (−20 dB).
Hassan Umair *et al*. [63], 2020	• MTM star-slot planar fed UWB antenna. • Provides a range of 4 GHz to 16.2 GHz and maximum gain of 8 dBi at 9.2 GHz.	• High gain and unidirectional radiation pattern.
Anees Abbas *et al*. [64], 2020	• Analysis of UWB antenna with a rectangular notch using electromagnetic bandgap (EBG) structures. • Bandwidth from 3.1 GHz – 12.5 GHz for S_{11} < -10 with notch band from 5 GHz – 6 GHz.	• Very compact in size and provide stable gain and radiation patterns. • By EBG, notch band is shifted to X-band.

TABLE II: COMPARATIVE REPRESENTATION OF VARIOUS PROPOSED ANTENNA STRUCTURES WITH CHALLENGES

Ref.	Antenna Specifications	Switches used	Limitations
[65] [66]	• Yagi-Uda antenna with single port • Microstrip Patch Antenna with Stub-Loaded	• 12-Varactor diodes • 4-Varactor diodes	• Very high ohmic losses because 1 MΩ resistors are used to bias 12 diodes. • Low quality factor, MEMS switches proposed for tuning purpose.
[67] [68] [69] [70]	• 4 port Microstrip with switchable multiband radiators • Microstrip antenna for UWB applications • C-Shaped Circular Patch Antenna • Microstrip with circular slot	• 4 RF-MEMS switches • 4 RF-MEMS switches • 2 RF-MEMS switches • 2 RF-MEMS switches	• Need filters to remove noise and poor isolation between switches. • Polarization reconfigurable (vertical/horizontal) • Operating only in fixed frequency bands. • Pattern reconfigurable and low bandwidth.
[71] [72]	• Monopole antenna with two microstrip fed-line on identical substrate • Rectangular ring slot patch antenna through one port	• 2-electronic switches • 3-electronic switches	• Suppression of coupling is difficult which occurs on multiple antennas set on identical substrate. • Speedy switching between UWB and NB accomplished with more complexity.

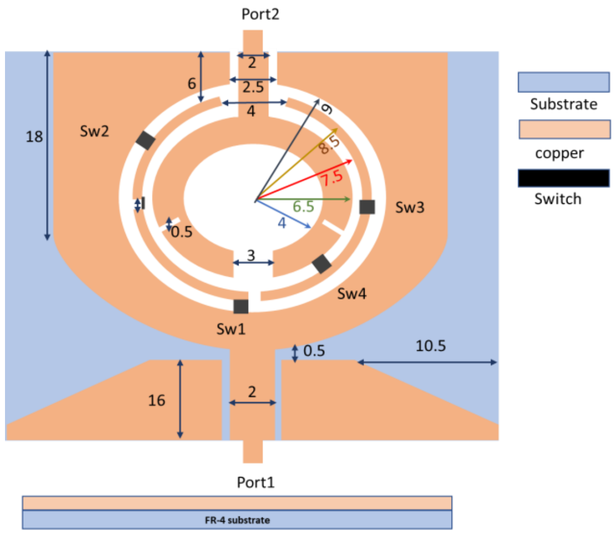


Fig. 4. Reconfigurable antenna using optical switch

B. Optical Reconfiguration-based Switching

Optical technology is extremely considerable in high capacity wireless applications and can deal with integrated UWB and NB cognitive radio applications. The electrical front-ends of such regimes are being progressed at large scale. An optically controlled reconfigurable antenna is shown in Fig. 4 [73].

The reconfiguration is created by four conducting silicon switches. When light illuminates on switch, it acts as short circuit and conduction takes place. It will be OFF when there is no beam of light. The switch acts as an insulator in OFF state. By joining distinct slender ring parts and optically controlled switch, the structure of inner antenna can be improved. The four reconfigurable frequency bands are 5.8GHz to 6.8GHz, 6.7GHz to 7.3GHz, 7.0GHz to 8.4GHz and 7.9GHz to 9.2GHz, which are dedicated to acquire the UWB. The gain for UWB is from (2.6dBi to 4.1dBi) and for NB from (0.1dBi to 4.5dBi) for all possible bands. A frequency reconfigurable antenna with a photoconductive silicon switch has been presented in 2014 [74]. The proposed microstrip patch antenna with stub is dedicated for validating the switching ratio along with photo-conductance, which provides the frequency switching with very low optical power (less than 60 mW). The antenna is fabricated on glass epoxy substrate.

A planar rectangular antenna array with optical reconfigurability has been presented in [75]. Photoconductive switches have been used to prevent the isolated biasing networks and complexity. The proposed design offers frequency reconfiguration with switching ratio of 10-50 MHz with the operational optical power of 50 mW. An advanced optically controlled antenna has been investigated for fifth generation broadband network based on Slotted Waveguide Antenna Array (SWAA). The proposed system has the switching capabilities for frequency range 28 GHz - 39 GHz, which is anticipated for future 5G mobile networks [76]. The results indicate transmission on 16-QAM and 32-QAM with improved SNR of 22.3 dB (on state of switch).

C. Reconfigurable Antenna Using Physical Angular Alteration

The mechanical proficiencies have significant advantages in context of antenna geometry, offering an enormous frequency shift apart from electrical switching approaches. But the designing of such antenna is a key challenge for those having actuation mechanism and to maintain the other characteristics with substantial structural changes. An antenna system having a rectangular patch with microstrip fed-line is shown in Fig. 5 [77]. The ground plane structure of antenna is divided in three segments i.e. a moving plane and two fixed planes. The movable ground plane is measured by two actuators that permits perpendicular movement and tilting position. The actuators control system is based on pulse width modulation, which is lined by Arduino board.

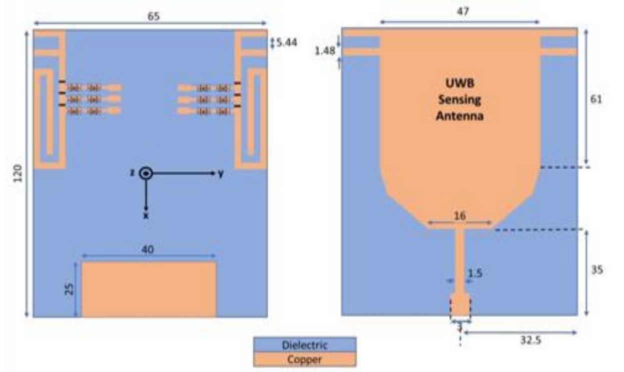
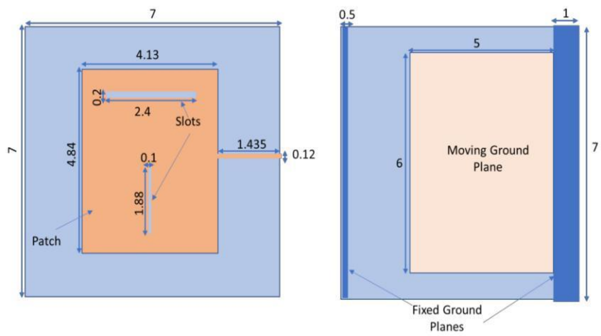


Fig. 5. MIMO Antenna for cognitive radio.



(a) (b)

Fig. 6. Communicating antenna: (a) top view and (b) bottom view.

The design for cognitive radio consists of two antennas in which the first one is utilized for channel detection and second one is employed for transferring information. A printed monopole antenna has been fabricated for sensing, which has the position out of the plane of a reconfigurable antenna at some height below the surface of patch. The communication antenna with rectangular patch is shown in Fig. 6 [78]. The dimensions of patch are (4.13cm×4.85cm). Two rectangular slots are cut on patch of dimensions (2.4cm×0.2 cm) and (1.88cm×0.1cm). The site of detecting antenna supports an improved isolation communicating antenna. Dimensions of sensing wideband antenna on ground plane are (4.7cm×0.75cm) and fed by a strip line width of 0.4 cm. The radiating monopole patch has an altered shape of 3.75cm length and 2.79cm width.

A novel mechanically reconfigurable microstrip antenna dedicated for wireless sensor network (WSN), WLAN and LTE2500 has been presented. The antenna is located on a dielectric slab with four end-to-end cavities and these cavities are addressed as binary bits (24 combinations) [79]. The proposed design covers the frequency band 2400 MHz to 3000 MHz excluding some nibbles. Moreover, the prototype can be used as RFID based system. A compact mechanically controlled reconfigurable microstrip patch antennas for wireless sensor networks is demonstrated [80]. By changing the dielectric properties, reconfigurability has been attained, which is operable among the frequency bands from 2442 MHz to 2716MHz. Several cavities have been filled by using dielectric strips of different permittivity. The proposed antenna is pertinent for wireless fluid level sensor and IoT with less power degeneracy.

D. Reconfigurable Antenna Based on Material Change

By changing the material properties of design, perfect tuning at the discrete frequency ranges is possible. It is perceived that relative permittivity (ϵ_r) and permeability (μ_r) of a ferroelectric material can be altered by employing the static electric field and static magnetic field respectively. The variation in ϵ_r and μ_r is responsible for effective electrical length of an antenna, which produce the operating frequency shift. It is very convenient to reduce the antenna size by increasing the values of the ϵ_r and μ_r of substrate materials. Apart from the complexity of bias structure, another drawback of standard ferroelectric and ferrite bulk materials is high conductivity which causes relentlessly reduction in efficiency of antenna.

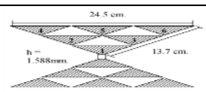
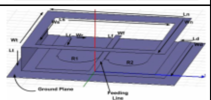
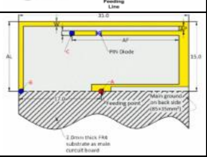
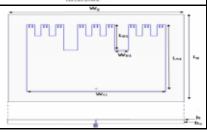
A material based reconfigurable antenna structure has been presented to realize the adaptive design for evolving communication system [81]. The design consists of a reconfigurable axial mode helical antenna and an alloy spring actuator. The actuator is accountable to alter the height of antenna. The measured and simulated results have been described for different helix heights of proposed antenna (40 mm-90 mm). It is stated that virtuous impedance matching is achieved from 4GHz to 4.5GHz for all sweep points of the conical helix. The maximum radius with 6 turns of conical helix is 18mm with the radius ratio of 0.55 and the variation in height is from 50mm to 90mm which concludes that the practical matching for a wideband is approximately 3GHz. Similarly, the helix pattern at 3GHz is established with the modification in height from 40 mm to 95mm for cylindrical helix. A novel technique for reconfigurable antenna has been introduced in [82], having phase-change materials feature. The smart material Vanadium Dioxide (VO_2) has been used to design the antenna, which is capable of mitigating the resistivity of the material. It shows the solid-to-solid phase transition at 68^0C, which is expedient for RF-front ends.

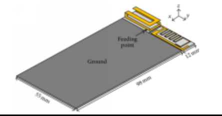
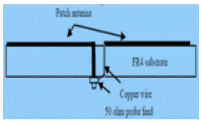
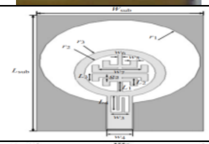
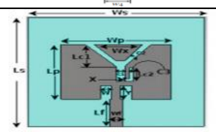
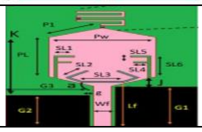
A reconfigurable antenna with Phase-change material (VO_2) have been presented to increase the switching proficiencies [83]. Two reconfigurable antennas have been used in analysis with small and thin film of phase change material to amend the antennas resonant frequency. The rapid transition of the VO2 (microseconds) is accountable for future reconfigurable applications, for instance; ultrafast reflect arrays, reconfigurable radomes etc.

III. Survey on Multiband Antenna

A compact multiband antenna is essential for fifth generation mobile communication services. Now a days, the progressive steps are being developed extensively in context of improving communications capacity. The researchers are focusing to develop compact, high gain and robust design of multiband antennas. These designs provide multifunctional and flexible environment for long- and short-range applications [84].

TABLE III: Multiband Antennas with Different Dimensions and Specifications

Ref.	Structure	Design specifications	Outcomes/Applications
[85] (2004)		• Compact antenna suitable for mobile phone handsets and for higher bandwidth. • Dimension is (28.5mm×30mm×5.5mm).	• Triple band antenna compatible with the GSM/DCS/PCS systems. • Relative bandwidth for lower bands (876 MHz - 972 MHz) is 10.4%. • For higher band (3.1616 MHz-2003 MHz), relative bandwidth is 21.4%.
[86] (2005)		• Antenna design by neural networks. • Multilayer perceptron used to locate bands at different reconfiguration conditions.	• Reduces complexity by numerical methods in reconfigurable design.
[87] (2009)		• Compact multiband antenna • Inserted a slot on the top patch for multiband features. • Dimension is (70mm×70mm×1.5mm).	• Impedance bandwidth at 1.2 GHz, 1.6 GHz, 2.4 GHz, and 2.6 GHz with gain 4.2dBi, 1dBi, 5dBi and 2dBi respectively.
[88] (2011)		• Reconfigurable multiband antenna for mobile terminals. • Planar inverted-E antenna (PIEA) with a PIN diode switch for reconfigurability. • Dimension is (3.5cm×10cm×0.2cm).	• Covers GSM / DCS / PCS / UMTS / WiMAX/ WLAN etc. • Covers Time Division Duplex Long Term Evolution (TDLTE)/ Industrial, Scientific and Medical frequency band (ISM)/China Mobile Multimedia Broadcasting (CMMB)
[89] (2013)		• Multi band fractal antennas for spectrum sensing in cognitive radio system with E-shape radiation patch. • Dimension is (45mm×55mm×2mm)	• Covers the bands GSM (820 MHz- 1070 MHz), UMTS (1750 GHz-2150 GHz) and LTE (2340 MHz-2600 MHz). • Measured gain is around 5dBi- 5.7dBi.

[90] (2014)		• Multiband antenna consisting a meandered PIFA. • Additional branch line for wide bandwidth and folded loop antenna. • Dimension is (55mm×110mm×5) mm).	• Cover the hepta-band LTE/GSM/UMTS operations. • For low and high frequencies, bandwidth is 169 MHz and 1030 MHz, respectively.
[91] (2015)		• Multiband antenna with C-shaped patch. • Dimension is (90mm × 25 mm×1.6mm).	• Single dipole operated at 1.23 GHz for GPS application on off state with gain 13dBi. • Dual-band frequency performed at 0.89 GHz and 2.45 GHz for Radio Frequency Identification (RFID) applications at ON state with gain 12dBi and 13.9dBi.
[92] (2015)		• Multiband antenna with monopole patch. • Two slots and a meandering strip on the top. • Dimension is (40mm × 24mm×1.5mm).	• Operate at 860 MHz –1040 MHz, 1705 MHz–2428 MHz and 2500 MHz–2710MHz. • Bandwidths cover GSM900, DCS, PCS, UMTS, LTE2500, and LTE's low frequency band.
[93] (2019)		• Dual band antenna with Coplanar Waveguide (CPW) feed. • Used a T-shaped resonator inside circular slot for operation. • Dimension is (32mm×24mm×0.8 mm).	• Antenna covers range of WiMAX (3.1GHz–4.5 GHz) and X-band (10.3 GHz–11.7 GHz). • Gain for both bands are 14dBi and 13.98dBi respectively.
[94] (2019)		• Multiband MPA with two slots U and V. • Ring slot on ground plane to cover patch from back and line separation in ground plane. • Dimension of antenna is (40mm×40mm×1.6mm).	• Used in IEEE 802.15.1 (2.402 GHz–480 GHz), TDLTE (2.2 GHz–2.5 GHz) and X-band for satellite communication systems (XSCS) (7.25 GHz–8.43GHz).
[95] (2020)		• Frequency and pattern hybrid reconfigurable antenna with PIN diode switches. • Fabricated on flexible polyimide substrate and F and U-shaped slot in radiation patch. • Dimension of antenna is (43mm×28mm×0.2mm).	• Covers the frequencies for LTE (2.3 GHz-3.8 GHz), Wi-Fi (4.5 GHz-5.1 GHz), WLAN (6.3 GHz-6.8 GHz) and fixed satellite applications. • Peak gain is 9dBi and efficiency is beyond 74%.
[96] (2020)		• Reconfigurable bandwidth multiband antenna for vehicular communication system with circular ring structure. • Fabricated on liquid crystal polymer (LCP) substrate • Radome paint effects incorporated on signal. • Dimension of antenna is (40mm x 30mm x 0.1 mm)	• Applicable for GSM-1900 (1850-1990 MHz), LTE (1.9 GHz-2.025 GHz), UMTS (1920 GHz-2170 MHz), Mobile Satellite Service (1980 MHz-2010 MHz), WLAN (5.710 GHz-5.835 GHz). • Used in dedicated short-range communications (DSRC) (5.850 GHz-5.925 GHz).

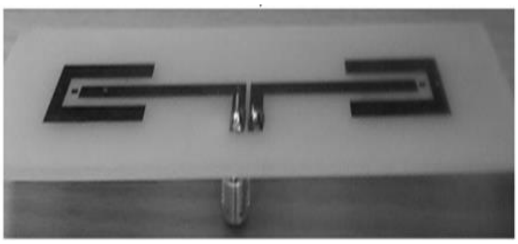


Fig. 7. Prototype of multiband antenna(C-shaped).

The design with different reconfiguration techniques cover a big range of frequency bands for instance: dual, triple, hepta-bands, and some advanced wideband applications. A compact C-shaped multiband antenna specifically used in mobile communication is shown in Fig. 7 [91]. A few multiband antennas for various applications are described in Table III.

In recent years, reconfigurable antennas are progressively being meandered in modern radar imaging technology, which requires high-performance SAR systems with excellent imaging capabilities. The radio frequency interference in SAR is a key challenge now a days [97]. Various mitigation techniques have been used to minimize radio frequency interference. Notch and LMS filtering mitigation techniques are widely used for expeditious processing and good imaging quality. A 3-D millimeter wave synthetic aperture radar (SAR) technology has been presented by L. H. Nguyen *et al.* for perfect imaging from any distance [98]. Moreover, the low cost multiband antennas for radar imaging applications are highly enviable to realize the necessity of future wireless telecommunication services.

IV. Conclusion

The reconfigurable antennas with numerous methodologies for novel wireless system have been realized and discussed in this review. Each configuration has its particular facts and faults in context of performance. It is concluded that the size reduction and bandwidth enhancement are the main challenges for upcoming communication system. Several techniques have been demonstrated to improve main constraints further. An extensive section of research is restricted for higher frequencies instead of lower frequencies. Some novel approaches for a precise design in wireless technology have been described. From the above survey, it is observed that both the wideband and narrowband reconfigurable antennas with small size and high-quality factor are obligatory for future wireless applications for both higher and lower frequencies. A detailed summary of above discussion is concluded in Table IV. The reconfigurable antennas with multifunction and elevated data rate are very promising for advanced wireless communication technology due to their inherent advantages. The future wireless system have often procured the interest in array based configuration, massive MIMO based models for 5th generation mobile applications and wireless body area network (WBAN).

TABLE IV: ADVANTAGES AND LIMITATIONS OF DIFFERENT RECONFIGURATION TECHNIQUES

Reconfiguration techniques	**Advantages**	**Disadvantages**
Electrical Reconfiguration	• Ease of design • Cost effective • Low power degeneracies	• Complex structure • Need biasing (active/passive)
Optical reconfiguration	• Biasing network is not required • No harmonic variations	• Requires initiation device for switching • Less reliable • Lossy behaviour
Material based reconfiguration	• Simple configuration • Lighter weight	• High sensitivity • Low efficiency • Unfrequented
Physical reconfiguration	• No Biasing required • Low implementation cost	• Slow response • Less flexible • Requires power source • Tunability limitations

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors have analyzed the paper and approved the final version.

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