A Review on Reconfigurable Antennas for Wireless Communication Systems

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Abstract: –Reconfigurable antennas have the great utility in smart and adaptive. The reconfigurable characteristic offer many advantages in wireless applications such as fourth generation (4G) and fifth generation (5G) mobile terminals. A reconfigurable antenna needs to have an adequate number of active elements for the reconfiguration of antenna characteristics. These high-quality active elements increase the cost and biasing complexity of the networks to control the circuitry. The current distribution in the radiating patch is responsible of antenna's characteristics, which can be change through changing the current flow in the patch. To change the current distribution in radiating patch the active element (switches) are required such as MEMS switch, varactor diode and p-i-n diodes. Therefore, we have presented a review on the reconfigurable antennas for advance wireless terminals, which are recently proposed by the other authors.
Keywords: 4G, 5G, CR, MIMO, reconfigurable antenna, switches, UWB, WiMAX and WLAN.

1. INTRODUCTION

A wireless system may reduce the complexity, size and cost if the front-end circuitry parameters are reconfigurable such as frequency, pattern and polarization. In the recent year, the reconfigurable antennas are very helpful to improve the performance up to maximum level of a radio frequency (RF) system [1, 2]. This kind of antennas can facilitate the future and advance generation of wireless communication and mobilesystems [3]. By using other techniques the parameters can be achieved with the help of active elements such as switches or capacitor [4, 5]. However, the number of reconfigurable parameters depend on the number of active element employed [6, 7].

The switches such as RF-MEMS (Radio Frequency – Microelectromachanical systems), varactor diodes, PIN diodes and well as the optically activated switches can be used to change antenna characteristics [8–10]. A high switching speed has a great advantage to change the antennas operation fast. The ranging of RF-MEMS switches lies between 1–200 ns, which is normally low for most applications [8]. An antenna (which is embedded with a varactor diode) can have wide tuning range at the cost of very high nonlinearity [9]. While, a PIN diodes can be used in reconfigurable antenna system designs due to its fast switching (1–100 ns), which helps fast dynamic reconfiguration [10]. In this review article we have study the kinds of reconfigurable antennas with single and multiple reconfiguration characteristics for wireless systems.

The organization of this paper is as follows:

Part 2: Single parameter reconfiguration
Part 3: Multiple parameter reconfiguration
Part 4: Conclusions

2. ANTENNAS WITH A SINGLE RECONFIGURABLECHARACTERISTIC

The frequency, radiation pattern and polarization switching are the different operations to achieve the reconfiguration in the antenna system through changing the size and shape of antenna radiators. In this section, we have studied the different single reconfigurable parameters.

2.1. Frequency-Reconfiguration

In terms of fundamental characteristics the FRA design requires lot of attention because it can move from one frequency band to another frequency band dynamically or continuously in a stated frequency range, and also the limitation of space in modern wireless devices such as smart phones and tablets [11–20]. The techniques which are useful to achieve the reconfiguration of antenna system;

1- PIN diodes: To tune the electrical length of antenna radiator is the most common method [11–13].
2- Varactor diode: To tune the operation band such as; wideband to narrowband or vice-versa [14, 15].
3- Matching Network: To set the resonance frequency [16, 17].
4- Other methods: Embedded a shorting post on the antenna configuration or by changing the input-impedance [18, 19].

Hence, the operational spectrum of an antenna can be switched to the desired frequency range by using the many ways.

A FRA configuration is shown in Figure 1 [20]. The varactor is loaded on the meander-line slot to tune the operation band of the antenna. As illustrated, the designed structure is based on a composite right/left-handed transmission line (CRLH-TL). The CRLH-TL is having a shunt capacitance/inductance and series capacitance/inductance. The operating frequency range is from 4.13to 4.50 GHz at 0–36 V which might be suitable for 5G base applications with good frequency-reconfigurable characteristics.

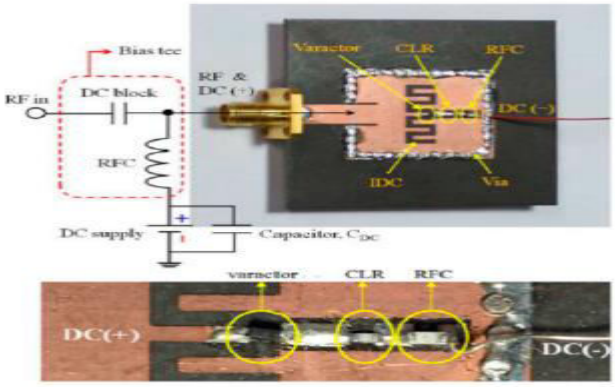

Figure 1. Fabricated prototype of antenna

The feed line contains a matching-network or reconfigurable-filter so that the structure can be useful to change the operational bandwidth from narrowband to wideband or vice-versa [21–23]. The modification in ground plane, especially for patch or monopole antennas has been used [24]. The proposed structure is shown in Figure 2. A rotated F-shaped slot is embedded in rectangular radiation patch, which is connected to a microstrip feed-line. To controls the current flow in the radiation patch a 2 PIN diodes is introduced in the center of the slot. The impedance bandwidth is achieved from 22% to 78%, which is very useful for various wireless services. In addition, the Narrowband/Wideband reconfiguration characteristic is used to avoid the interference between the wideband services and other wireless systems such as 4G, WLAN, WiMAX, and satellite communication [25]. This is enhance the flexibility of the antenna system, which makes suitable for multi-mode wireless communications.

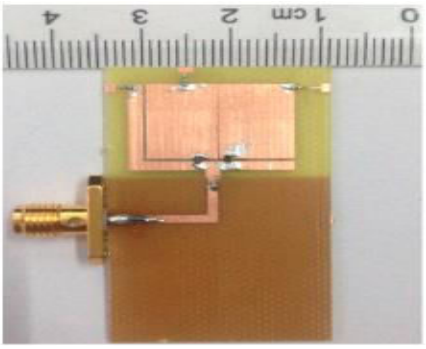

Figure 2. Bandwidth-reconfigurable antenna

2.2. Pattern-Reconfigurable Antennas

The surveillance and tracking applications are required different directivities at the same operating frequency, which can be fulfil by the pattern reconfigurable antennas [26, 27]. Generally, the array theory is used to design the structures to produce pattern diversity for reconfigurable characteristics [28, 29]. An antenna is designed on Rogers 4350B substrate with 4 identical arc dipoles along with feeding system, shown in Figure 3. The antenna end-fire radiation pattern can be steered with a 90-degree by changing the states of the diodes to cover all directions. The cover frequency range is 2.3−3.2 GHz [30].

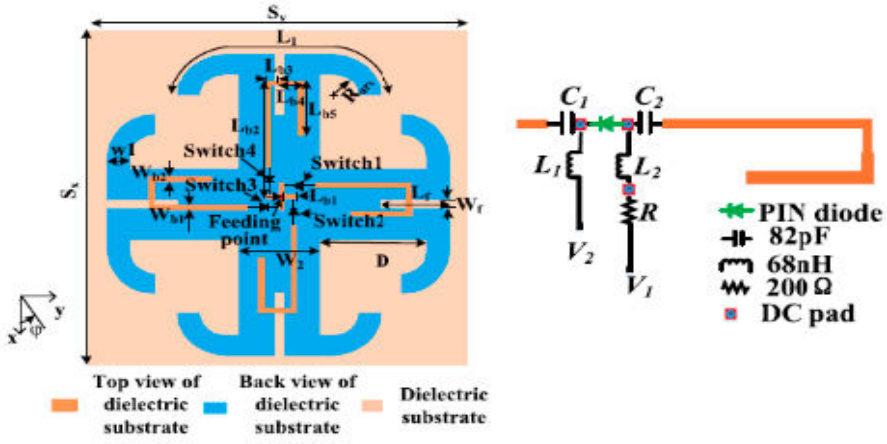

Figure 3. Antenna configuration

The field distribution in the substrate of antenna has been changed with the help of shorting capacitor, which plays the role to change the direction of antenna radiation patterns [31–33]. A phased array pattern reconfigurable antenna structure has been proposed for 5G mobile applications at 28 GHz [34]. The pattern reconfigurable antenna has also been used in MIMO wireless system to reduce noise and to improve the system performance [35].

2.3. Polarization-Reconfigurable Antennas

The polarization reconfigurable antennas can be switched to different modes and also offer exceptional multipath fading reduction [36]. The switching between RHCP and LHCP at a desired frequency is the most concerned in the PRAs [37], although linear polarization (vertical or horizontal modes) is also studied [38, 39]. The most popular methods to achieve the polarization-reconfigurability are truncated corners, slot, slit and parasitic structures along with active elements embedding in the main radiator [40, 41]. The active structures like meta-surfaces and feeding networks along with some other techniques, such as using reconfigurable external polarizers or phase shifters can also provide polarization reconfigurability [42, 43].

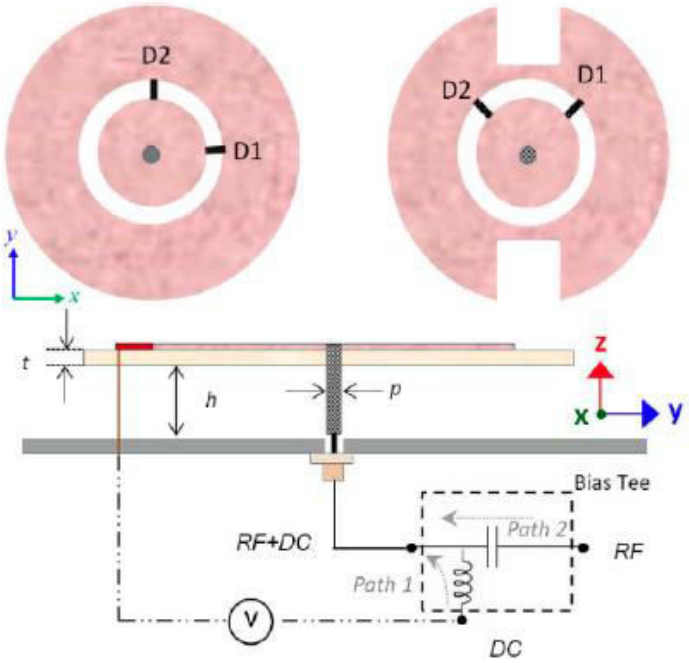

Figure 4. Schematic of antenna structure

A C-shaped slot reconfigurable antenna for 4G applications is shown in Figure 4. The operating frequency range is 2.2−2.8 GHz with polarization reconfigurability [44]. It consist a circular radiation patch with two diodes across the concentric circular slot. The antenna can be applicable for 5G wireless communications because it is capable to switch between vertical and horizontal linear polarizations (VP/HP) modes as well as between LHCP and RHCP circularly polarized

modes. The two compact size antennas with polarization reconfigurable characteristics have been reported and investigated for 5G wireless systems [45, 46].

3. MULTIPLE PARAMETER RECONFIGURATIONIN ANTENNA

Two or more features perform independently in single antenna is called multiple reconfigurable antennas; as given bellow

1. Pattern and Frequency
2. Polarization and Frequency
3. Pattern and polarization
4. Frequency, pattern and polarization

3.1. Frequency and Radiation Pattern Reconfigurable Antennas

The radiation pattern and frequency comes in this category [47]. The radiation pattern of an antenna can be reconfigurable for broadside, end-fire and omnidirectional modes, which may help to enhance the system performance, minimization of noise and save energy of the system [48]. The minimization of interference between the wireless services the frequency tuning is very useful and it is also used to reduce the requirement of number of the antennas [49-58]. The active elements such as varactors or PIN diodes are used to achieve the frequency switching [50–54]. The current distribution in the radiating patch of an antenna has a vital role in pattern reconfiguration. The slot or slit structure is used to alteration the current distribution of the antenna, which helps to steer the direction of the antenna radiation pattern [55-58].

A semi-circular back-to-back F antenna is presented in Figure 6. The proposed structure consists a radiator patch with four identical elements, which helps to operate the antenna at three different frequency bands [56]. In 2015, a new design of antenna with circular aperture has been proposed [55]. The circular aperture has 6radiators symmetrically with 12 parasitic elements, which help to get frequency and radiation pattern. The switching states of diodes are responsible to achieve broadband, WLAN, Zigbee and satellite-digital multimedia broadcasting (S-DMB) services with the 45^0 steps steering capability of radiation pattern.

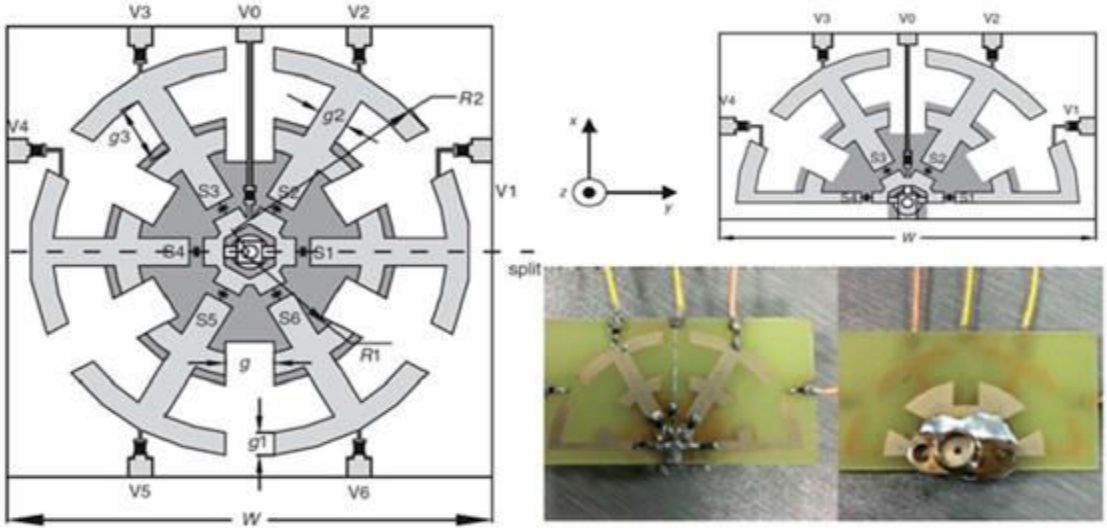

Figure 6. Configuration of proposed antenna system

3.2. Frequency and Polarization Reconfigurable Antennas

The reconfigurable combination of frequency and polarization is very useful for imaging, sensing, tracking and radar applications [60]. The frequency reconfiguration plays a role of making the efficient use of the available spectrum and the polarization diversity is helpful to reduce multipath fading effects and enhance the channel capacity. This combination is very interesting so that a number of designs have been proposed [61]. The electromagnetic band gap (EBG) or meta-surface structure is the important method to achieve the re-configurability in antenna system by using the switches on top of the antenna resonator [60–63]. However, for achieving frequency and polarization re-configurability the most common methods are by embedding the active elements such as varactor diodes and PIN diodes [64–67]. A patch antenna with stub-loaded to achieve the frequency and polarization agility has been proposed in 2015 [65]; shown in Figure 7. The twelve stubs are loaded at the four edges of the main radiator. The frequency can be tuned from 2.4 to 3.4 GHz with diverse polarization, which makes it best suitable for multi-mode 4G/5G communication systems.

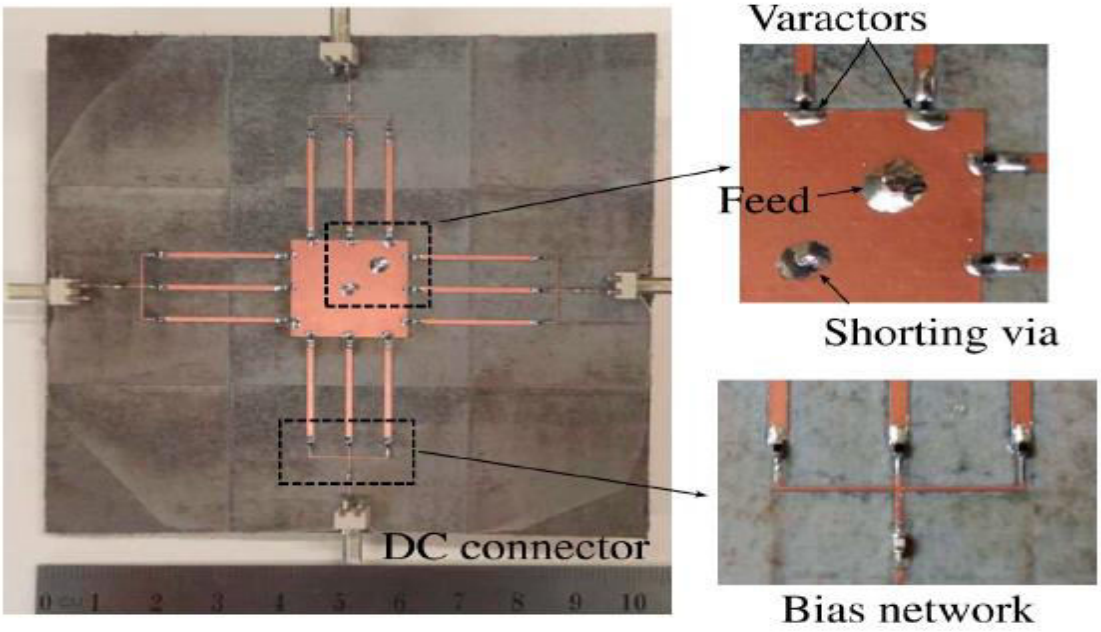

Figure 7. Configuration of antenna system

3.3. Radiation Pattern and Polarization Reconfigurable Antennas

This combination is very helpful to increase the system efficiency in the form of radiation coverage and polarization mismatching. To satisfy the system needs the radiation pattern re-configurability is very helpful such as improve channel capacity without increasing a radiator's volume [68-74].

In 2014, an omnidirectional microstrip-fed patch antenna with a switchable polarization and radiation pattern is introduced [68]. The shared ground plane and at a corner a pair of back-to-back coupled patches fed is used in the designed structure. In this structure, the phase shifting

technique is used to achieve the re-configurability between high degree of polarization and radiation pattern. In 2015, a new design of antenna with switchable radiation patterns and polarization diversity is also proposed [69]. The proposed design consists the parasitic elements around the main radiator and configurability that depends on the states of the PIN diodes. A PIFA with an inverted F-shaped parasitic structure for pattern and polarization diversity is proposed [70]. The pattern and polarization reconfigurable properties are achieved in the frequency range 2.357–2.562 GHz by using one diode. Another reconfigurable antenna design with switchable radiation pattern and polarization diversity (2.45–2.65 GHz) is also proposed [81]. The structure has three substrate disks as the radiator, feeding and switching. The four plastic screws have been used to support the substrates. The switchable radiation beams for broadside and conical circular polarized modes have been achieved.

Figure 8. The fabricated prototype of pattern and polarization reconfigurable antenna

Figure 8 shows the fabricated prototype of low profile reconfigurable quadrifilar helical antenna with a switchable feeding network has been proposed [73] at 0.9 GHz. The proposed structure has capability to switch the four different modes with polarization and radiation pattern reconfiguration by using diodes. A square patch radiator with four coupled parasitic structures has been proposed in 2018, which is fed by a coaxial cable [74]. The antenna provides three different modes for polarization and pattern diversity at single frequency.

3.4. Frequency, Radiation Pattern and Polarization Reconfigurable Antennas

There is only one design, which has been proposed in 2014 [75]. It shows independently three-parameter reconfiguration frequency, radiation pattern and polarization. Another design of frequency, radiation pattern and polarization reconfigurable antenna has been proposed in 2017 [76]. This design has the limitations in terms of tuning, which is unable to provide simultaneously independent reconfiguration unlike the design has been proposed in 2014 [75]. This is a major research gap, even though a much hard challenge to design an antenna with the

flexibility to reconfigure all its fundamental properties in terms of frequency, radiation pattern and polarization.

Figure 9 shows the antenna schematics and the prototype [75]. It consists a patch radiator and a parasitic pixel surface of 66 pixels loaded by 60 PIN diodes. This switched-grid pixel surface helps to get the re-configurability in terms of frequency, radiation pattern and polarization simultaneously. The different configurations of switches help to tune the frequency operation from 2.4 to 3 GHz and the radiation pattern can steered between ±30. It is also capable to get LHCP/RHCP and LP polarization switching, which makes it very suitable for different mobile and wireless communication system.

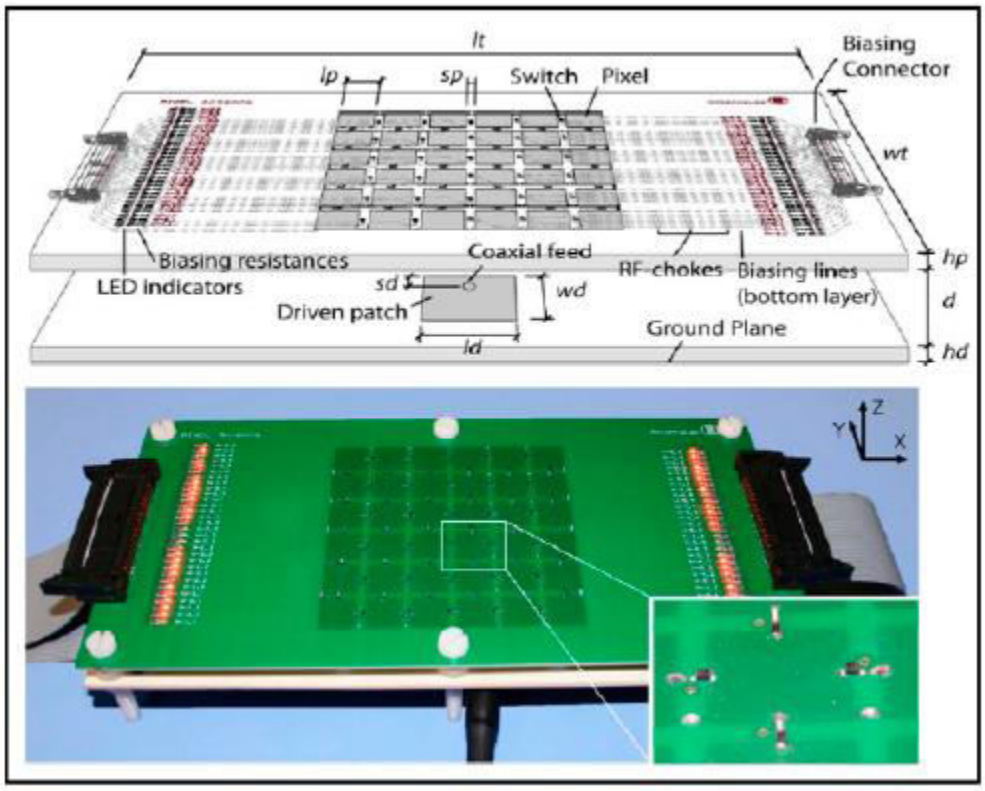

Figure 9. Schematic of the multi-functional reconfigurable antenna

Table 1 and table 2 reflect a comparative study of recently proposed reconfigurable antennas in term of antenna specifications and fundamental characteristics such as; reconfiguration type, number of switches used, operation frequency and the overall size.

Table 1

Comparative summary of reconfigurable antennas proposed.

References	**Reconfiguration characteristics combination**	**Types of Switches used**	**Operating Frequency (GHz)**	**No. of Switches used**	**Antenna Aperture (mm^2)**

[48]	Frequency/Band width	PIN/Varactor	3.9–4.82	3	25 × 75
[59]	Frequency/Radiation Pattern	Varactor Diode	2.15/2.25/ 2.38	2	151.5 × 160.9
[62]	Frequency/Radiation Pattern	PIN-Diode	3.6/3.95	2	30 × 40
[69]	Frequency/Polarization	varactor Diode	1–1.6	112	88 × 114
[81]	Radiation Pattern /Polarization	PIN-Diode	5	36	78 × 78
[82]	Radiation Pattern /Polarization	PIN-Diode	0.9	32	81 × 81
[85]	Frequency/Radiation Pattern/Polarization	PIN-Diode	2.4–3	60	31 × 31
[74]	Frequency/Polarization	PIN-Diode	1.9–2.7	2	40 × 70
[76]	Frequency/Polarization	varactor Diode	2–3.1	1	100 × 100

Table 2
The design specifications and key features of the proposed antenna

References	**Design Specifications and features**
Schaubert et. al. [77]. 1989	1- A frequency and polarization reconfiguration 2- The instantaneous percentage bandwidth is 2 to 3%. 3- The switching frequencies over a wide range
Liu et. al. [78], 1997	1- A frequency reconfiguration 2- The radiation patch has two slots, one is U-shape and another is rectangular shape 3- Dual operating frequencies
Kolsrud et. al.[79], 1998	1- The varactor diode has been used for switching with the variation of bias voltage from 0 to 30 V 2- The measured tuning range (2.065 GHz to 2.365 GHz) at the lower frequency is 14.5% and at the higher operating frequency is 11.5% (3.955 GHz to 3.505 GHz)
Ali, Mohammod et. al. [80], 2000	1- An integrated planar inverted-F (PIFA) antenna 2- This antenna gives the matched input impedance around 2.45 GHz

	3- The antenna resonant resistance is also varied from 3112 Ω to 43.7 Ω
Yang, Fan et. al. [81], 2002	1- The frequency, bandwidth and polarization diversity 2- The axial ratio at 4.64 GHz is 3% CP bandwidth for both RHCP and LHCP patterns 3- The axial ratio are 2.9 dB and 1.6 dB at 4.0 GHz and 4.37 GHz when the switch is ON and OFF respectively
Shynu, S. V et. al. [82], 2004	1- Frequency reconfigurable 2- The covered bandwidth of 2.82% and 2.42%, at 1.2 and 1.4 GHz respectively 3- The size reduction of antenna has been achieved up to 72.21% and 46.81%
Cetiner, Bedri A. et. al. [83], 2005	1- A reconfigurable spiral antenna for MIMO systems 2- The average half power beam width (HPBW) of the antenna is 105^0 3- The antenna radiation is almost circularly polarized with axial ratio of 0.9 dB and the gain 5.3 dB 4- The circularly polarized bandwidth with the axial ratio ≤ 3 dB is 11% and gain variation 4.9 dB
Zhang et. al. [84], 2005	1- A reconfigurable novel fractal microstrip patch antenna 2- Shows linear polarization 3- The controlling depends on RF-MEMS switches
Peroulis et al. [85], 2005	1- A resonant slot structure loaded with a series of PIN diodes 2- The variation between the minimum and maximum in measured E-plane pattern is 3 - 4 dB 3- The effective bandwidth is 1.7: 1 4- The prototype of antenna is capable to radiate at four resonant frequencies (from 550 MHz to 900 MHz)
Ali, Mohammod et. al. [86], 2007	1- Frequency reconfiguration 2- The upper frequency with a broadside pattern, the antenna shows the 7.5 dBi gain and 15.8% bandwidth whither at lower frequency 3- 7.3% bandwidth and 3.9 dBi peak gain
Fankem et. al. [87], 2007	1- A frequency reconfigurable planar inverted-F antenna (PIFA) 2- Works on five bands GSM900, GPS1575, GSM1800, PCS1900 and UMTS2100
Weily et. al. [88], 2008	1- A partially reflective surface (PRS) high-gain antenna with frequency reconfigurable feature 2- The reflection phase of each cell has controlled by the bias voltage of varactor diodes 3- The measured gain varied from 10 to 16.4 dBi with the tuning range of 13.5% over 5.2 GHz to 5.95 GHz
Perruisseau-Carrier et. al. [89], 2010	1- An antenna which is having a wide bandwidth with reconfigurable/rejection characteristics.

	2- By considering the tuning capacitances 0.1 - 2.0 pF range the frequency tuning range lies between 1.859 GHz to 3.672 GHz 3- The reliable measurement has been done between 2.0 GHz to 4.25 GHz and it is observed that the measured efficiency is slightly lower, which remains in between 50% to 70%.
Sanchez-Escuderos et. al. [90], 2011	1- A reconfigurable slot-array antenna by using RF-MEMS 2- The isolation between two states of the switch is 12 dB 3- The radiation efficiencies are 36% and 93% in the ON and OFF state respectively
Abutarboush, Hattan et. al. [91], 2012	1- A reconfigurable wideband and multiband C-Slot with dual-patch element patch antenna 2- The overall size of the antenna system, including ground plane is 50×50×1.57 mm3 3- The two employed parallel C-Slots on the patch elements are used to perturb the surface current paths for excitation of the dual-band and the wideband modes 4- The antenna is covering the frequency range 5 GHz to 7 GHz by using two PIN diodes 5- The impedance bandwidth of 33.52% and the measured gain range has been obtained 3.72-4.92 dBi
Chen, Gang et. al. [92], 2012	1- A novel folded slot frequency-reconfigurable antenna which is having two modes of operation with two resonant frequencies 2- The measured resonant frequencies and peak gain are: Mode1 — 3.29 GHz, 5.2 GHz — 5.22 dBi and 5.4 dBi Mode 2. — 2.36 GHz and 5.7 GHz for — 4.45 dBi and 4.9 dBi
Zohur, Abdul et al. [93], 2013	1- An electrically small frequency reconfigurable antenna 2- Frequency reconfigurability between two bands of 718 MHz and 4960 MHz 3- The reconfigurability has been obtained by using a single RF-MEMS switch 4- Antenna having a wide measured bandwidth of 2.6% at 718 MHz with suitable size reduction

4. CONCLUSIONS

An intensive review of frequency reconfigurable antennas with single and multiple reconfiguration features has been presented in this article. Moreover, some more techniques were used to improve the design parameters and size reduction methods were categorically presented. As the high frequency designs were preferable choice of research, therefore, low frequency designs attracted less attention. In view of aforesaid, the low frequencyreconfigurable antenna

design including geometrical parameters, suitable for wireless applications has been thoroughly reviewed in this paper. In addition, the methods and design requirements to achieve the simultaneous and flexible reconfiguration, pattern reconfiguration and polarization characteristics, have also been presented in this article.

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