Chapter-11

Radio Frequency Antennas and the Idea of Antenna Operating Characteristics Reconfiguration

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This article provides a brief description of various conventional radio frequency antennas and their uses on widely spanned wireless networks. The work also focuses on the issue of multi standard accessibility of a single antenna using reconfigurable antenna techniques. It is an approche to summarize some of the reconfigurable antenna techniques namely electrically controlled, optically controlled, mechanically controlled and smart metarial based reconfiguration techniques. An encapsulated idea of these techniques, their pros and cons are also discussed. This chapter also focuses on the major advantages of reconfigurable antennas over conventional antennas and their potential utilizations in wireless communications.

1. INTRODUCTION:

It has always been crucial to be accessed to the information grid in a fast moving and digital world. The exponential growth of importance of being

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connected necessitates implementation of infrastructures, capable of supporting the growing streams of data that crosses the new generation networks. These new implementations should be capable of adopt itself according to the demands of the grid. Besides the technical specifications, an environment friendly mind-set has been introduced into the scenario, which includes investigations for a light, low-profile, energy efficient, and self-sufficient devices and components. The eco-friendly concept also includes the uses of materials, which are less hazardous to the environment.

The range of wireless communication technologies that have emerged in the last two decades is immense. And nowadays the tendency is to study new methods of integration and interoperability between devices. There are such a large number of frameworks that uses an antenna, for example, cellular phones, spacecraft, wireless phones, radars, etc. Fig. 1 shows a generic smartphone, a very common wireless communication device nowadays, and lists some of the different radio frequency systems it has to aggregate in itself.

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GSM/ GPRS
UMTS
LTE
WiMAX
WLAN
GPS
Bluetooth
DVB/NFC etc.

Fig. 1: A generic smart phone and list wireless standards present in it (Image Source: http://www.digitphones.co.uk)

In order to access these wireless channels, each of the communication device requires a transducer whichtransducer, which can convert the electrical signals to electromagnetic waves. In this aspect an antenna is basically used to serve the purpose [1]. An antenna can work as both transmitter and receiver and physically composed of one or more conductors or sometimes with dielectric materials. In transmission mode, an electric current oscillating at radio frequency supplied to the antenna terminals by and radio transmitter, and the antenna radiates the energy from the current as electromagnetic waves [2]. In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals that is applied to a receiver to be amplified.

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2. TYPES OF CONVENTIONAL ANTENNAS:

Originating from Heinrich Hertz in 1888, radio frequency antennas have gone through tremendous developments resulting in different types of antennas. These include helical antennas, parabolic antennas, planar antennas, wire antennas, horns and many more [3]. Most of the practical antennas fallsfall into six broad categories namely

2.1 Dipole antenna:

A basic dipole antenna is made up of two conductors, usually metal rods or wires arranged symmetrically. The most common type of dipole antenna half-wave dipoles, consists of two resonant elements of quarter wavelength long [4]. For many other more complicated directional antennas, the half-wave dipoles are also used a building block. Some of commercial directional dipole antennas are

2.1.1 Yagi-Uda:

The antenna is made up of a series of half wave dipole elements in a line, which contains a single driven element and multiple parasitic elements. Driven element is a part of the antenna, which is electrical, connected to the transmitter, whereas there is no electrical link between the parasitic elements. Yagi-Uda can accommodate HF, VHF, and UHF frequencies and is highly directional and high gain antenna with a narrow bandwidth. Most common use are rooftop television antennas are point-to-point communication links [5].

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Figure 2: A Yagi-Uda antenna (Image Source: https://en.wikipedia.org/wiki/Yagi%E2%80%93Uda_antenna)

2.1.2 Log-periodic dipole :

These antennas are similar to the Yagi-Uda in appearance, this consists of many dipole elements with gradually increasing lengths, all connected to the transmission line with alternating polarity. It is a directional antenna with a wide bandwidth although its gain is much less than a Yagi. Use as a rooftop television antenna [6].

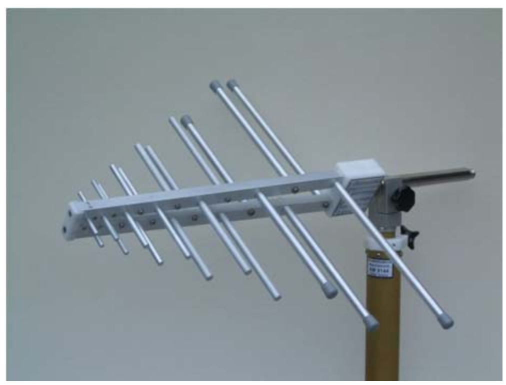

Figure 3: A Log-periodic dipole antenna (Image Source: https://en.wikipedia.org/wiki/Log-periodic_antenna)

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2.1.3 Turnstile:

The antenna consists of two dipole antennas mounted at right angles and are fed with a phase difference of 90°. This antenna radiates in all directions. Used for receiving signals from satellites [7, 8].

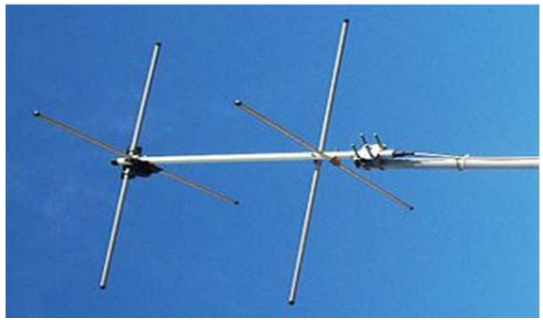

Figure 4: A Turnstile antenna (Image Source: https://en.wikipedia.org/wiki/Turnstile)

2.1.4 Corner reflector:

It is a UHF frequency directive antenna with moderate gain. The antenna consists of a dipole mounted in front of two reflective metal screens joined at an angle, usually 90°. Used as a rooftop UHF television antenna and for point-to-point data links [9].

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Figure 5: A Corner reflector antenna (Image Source: https://en.wikipedia.org/wiki/Corner_reflector)

2.1.5 Patch (microstrip):

It is a planar type of antenna with elements consisting of metal sheets mounted over a ground plane. Their easy fabrication using PCB techniques and edge of integration to other devices and instruments have made them popular in modern wireless devices. Often used in arrays [10, 11].

Figure 6: A microstrip patch antenna (Image Source: http://www.mcv-microwave.com/patch-antenna.html)

2.2 Monopole antenna:

Monopole antennas are single conductor antennas which contains conductors such as a metal rod, mounted over the ground or ground plane (conducting sheet) [12]. The most common form monopole antenna is the quarter-wave monopole which length is one-quarter of a wavelength and mounted over a ground plane. Radiation pattern of monopoles is omnidirectional and are used for broad coverage of an area.

2.2.1 Whip:

The antenna is made up of a flexible rod with telescoping segments. They are used on mobile and portable radios [13].

(a) **(b)**

Fig. 7: (a) ***Whip and (b)*** **Rubber Ducky antenna**
(Image Source: http://www.banggood.com,
http://www.scannermaster.com)

2.2.2 Rubber Ducky:

Most common antenna used on portable two way radios and cordless phones due to its compactness, consists of an electrically short wire helix [14].

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2.2.3 Inverted F:

In this antenna, a monopole antenna is placed parallel to a ground plane and grounded at one end. The antenna fed point is located at an intermediate point away from the grounded end. The name Inverted F Antenna come from antenna structure as it somewhat resembles an inverted F [15].

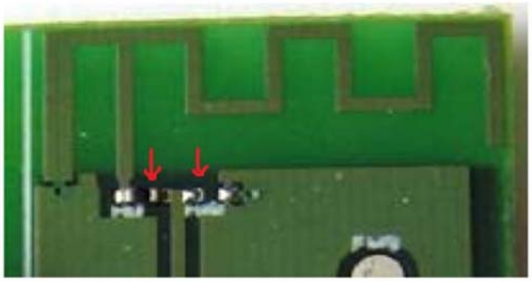

Figure 8: Inverted F antenna (Image Source: https://e2e.ti.com/support/wireless_connectivity)

2.2.4 Umbrella:

It is a very large wire transmitting antennas consisting of a central mast radiator tower attached at the top to multiple wires extending out radially from the mast to ground, like a tent or umbrella, insulated at the ends. Used for long range military communications [16].

Figure 9: Umbrella antenna (Image Source: https://www.alibaba.com/product-detail)

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2.3 Array antenna:

Array antennas are combinations of multiple antennas serving as a single antenna. Typically, identical dipoles are used as driven elements in order to give increased gain over that of single dipole.

2.3.1 Collinear:

It is a high gain omnidirectional antenna consisting of a number of dipoles in a vertical line. Used as base station antennas [17].

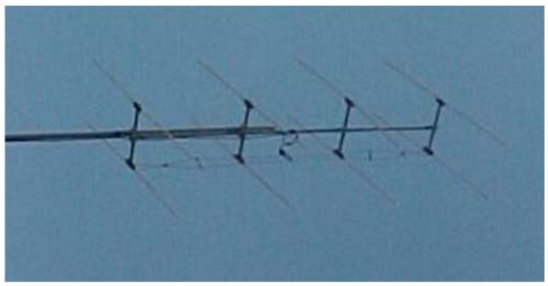

Figure 10: Collinear array antenna (Image Source: http://pe2bz.philpem.me.uk)

2.3.2 Reflective array:

It is a two-dimensional array of dipoles mounted in front of a flat reflecting screen. Mainly used as radar and UHF television antennas [18].

(a) (b)

Figure 11: (a) Reflective array antenna (b) Phased array antenna (Image Source: http://ema-lab.aut.ac.ir, http://defence-blog.com)

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2.3.3 Phased array:

The array consists of multiple dipoles in a two-dimensional array with controllable phase shifters. It is an electronically steerable high gain antenna used at UHF and microwave frequencies, which beam can be instantly pointed in any direction over a wide angle in front of the antenna. Mostly used for military applications [19].

2.3.4 Microstrip:

is microstrip line fed an array of patch antennas on a substrate. It can achieve large gains in compact space and more popular due to the ease of fabrication [20].

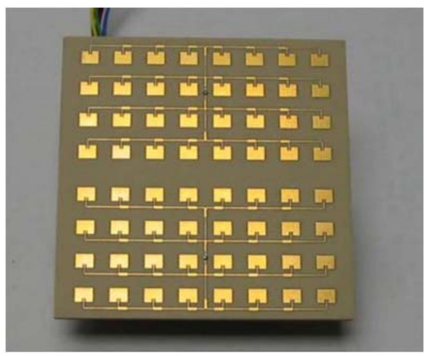

Figure 12: Microstrip array antenna (Image Source: http://radarandlaserforum.com/showthread.php)

2.4 Aperture antenna:

Generally, these are three-dimensional antennas and are the leading type of directional antennas used at microwave frequencies and above. These type of antennas are constructed by placing a small dipole or loop feed antenna inside a comparatively large three-dimensional guiding structure and an

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aperture to emit the radio waves. The non-resonant behaviour of the antenna make it broadband antenna [3, 21].

2.4.1 Parabolic:

At microwave frequencies, it is the most widely used high gain antenna consists of a feed antenna at the focus of dish-shaped metal parabolic reflector. Used for radar antennas, point-to-point data links, satellite communication, and radio telescopes [22].

2.4.2 Horn:

They are one of the simple antennas consists of a flaring metal horn with an attached waveguide. Used in radar guns, radiometers and parabolic dishes as feed antennas [23].

Figure 14: Horn antenna (Image Source: http://www.ecmicrowave.com)

2.4.3 Slot:

These are normally slot cut waveguides with one or more slots and operated in microwave frequency range. Used as UHF broadcast antennas and marine radar antennas [24].

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(a) (b)

Figure 15: (a) Slot antenna (b) Dielectric resonator antenna (Image Source: http://croatia-microwave.blogspot.in, http://www.eleceng.adelaide.edu.au)

2.4.4 Dielectric resonator:

It consists of waveguide aperture excited small ball or puck-shaped piece of dielectric material and used at millimeter wave frequencies [25].

2.5 Loop antenna:

In loop antennas a loop of conducting wire is used as radiator. Circumference of loop is equal to wavelength or integer multiple of the wavelength of resonant frequency. Loop antenna operates similarly to the half-wave dipole. They are used as receiving antennas at low frequencies [3].

2.5.1 Ferrite (loopstick):

These types of antennas are constructed by winding a conducting wire around a ferrite core. These are used to receive lower frequency broadcastings in most consumer amplitude modulated radios [26].

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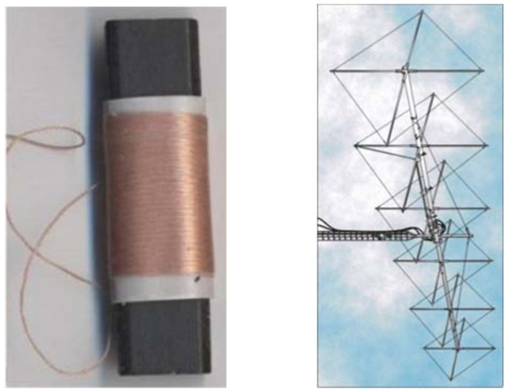

(a) (b)

Figure 16: (a) Ferrite antenna (b) Quad antenna (Image Source: http://www.discovercircuits.com, http://www.lightningantennas.com)

2.5.2 Quad:

Multiple wire loops in a line are used to construct the antenna. One of the loops is functioning as the driven element, and the others as parasitic elements. In shortwave communication these antennas are used as a directional antenna on the HF bands [27].

2.6 Travelling wave antenna:

Travelling wave antennas are another type of non-resonant antenna and inherently they are broadband antennas. Typically, these are multiple wavelengths wire antennas. Unlike the resonant antennas the voltage and current waves travel in one direction, instead of bouncing back and forth to form standing waves as in resonant antennas [21].

2.6.1 Random wire:

These antennas are made up of a random length of wire. Normally they are strung outdoors between supports or in a zigzag pattern along walls in indoors and are connected to a receiver at one end. This type of antennas are used to receive shortwave radio [21].

2.6.2 Beverage:

These are the simplest traveling wave antenna having unidirectional radiation pattern. They are constructed by suspending a straight wire ranging from one to several wavelengths long near the ground, which are connected to a receiver at one end. A resistor equal to its characteristic impedance terminates the other end. It is used for reception of skywaves reflected off the ionosphere in long distance shortwave communication [21].

2.6.3 Rhombic:

It is a type of antenna having four equal wire sections, which is shaped like a rhombus. A balanced feed line placed at one of the acute corners feeds the antenna. A resistor equal to the characteristic resistance of the antenna is connected to the two sides. These antennas are used for sky wave communication on shortwave bands [21].

2.6.4 Helical (axial mode):

These antennas are made up of a wire shaped in the form of a helix, which is mounted above a reflecting screen. It is a circularly polarized antenna with omnidirectional radiation pattern. It is used for communication with satellites and animal tracking transmitters at VHF and UHF frequencies, due to its circularly polarized radiation characteristics. It is insensitive to the relative orientation of the antennas [21].

2.6.5 Leaky wave:

These are microwave antennas, which consist of a waveguide or coaxial cable with a slot, or apertures cut in it. Due to these cuts, the antenna can radiates continuously along its length [21].

3. ANTENNA CHARACTERISTICS:

A number of performance measures which a user would be concerned with in selecting or designing an antenna for a particular application characterizes antennas. Chief among these relate to the directional characteristics (as depicted in the antenna's radiation pattern) and the resulting gain [21].

3.1 Input Impedance:

The input impedance of the antenna plays an important role in antenna performance. The impedance of the radio, the antenna and the transmission cable connecting them must be the same for an efficient transfer of energy. A mismatch results in losses of energy. For any mismatch, an impedance matching circuit is required to reduce the losses. Typically transceivers and their transmission lines are designed for 50 Ω impedance [3].

3.2 Return loss:

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It is a logarithmic ratio between the power reflected by the antenna to the power that is fed into the antenna from the transmission line and measured in dB. The return loss is another way of expressing mismatch [3].

3.3 Bandwidth:

The bandwidth of an antenna is the range of frequencies over which the antenna can operate effectively. The antenna bandwidth expressed in terms of frequency and a particular antenna should exhibit an SWR less than 2:1 its bandwidth. The bandwidth can be described in terms of percentage of the center frequency of the band also [3].

$$BW = 100\times (HF - LF)/ CF$$

Where, HF is the highest frequency in the band,

LF is the lowest frequency in the band,

FC is the center frequency in the band.

3.4 Directivity and Gain:

Directivity is a fundamental antenna parameter. It tells us the ability of an antenna to radiate or energy in a particular direction in transmitting mode, or to receive energy from a particular direction receiving mode. The directivity of an antenna is the ratio of the maximum power density to its average value over a sphere as observed in the far field of an antenna. Depending upon utility antennas could have high directivity as well as omni-directional radiations [3].

Gain is another key performance parameter of antenna and it is a combination of directivity and efficiency. In case of transmitting antenna gain describe how effectively the antenna can convert electrical energy into

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radio waves in a specified direction and for receiving antenna it gives the conversion effectiveness of radio waves into electrical energy [3].

Gain is always measured as a comparison to a standard antenna and it describes how much power is transmitted or received in the direction of peak radiation to that of an isotropic or half dipole source. Gain is not a quantity whichquantity, which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dBi. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dBd [3].

3.5 Radiation Pattern:

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two-dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format [3].

3.6 Beam width:

An antenna's beam width is usually understood to mean the half-power beam width. The peak radiation intensity is found and then the points on either side of the peak, which represent half the power of the peak intensity, are located. The angular distance between the half power points is defined as the beam width. Half the power expressed in decibels is —3dB, so the half power beam width is sometimes referred to as the 3dB beam width. Both horizontal and vertical beam widths are usually considered [3].

4. RECONFIGURABLE ANTENNAS: A NEW FRONTIER

Introduction of various wireless standards in a single handheld devices has made the situation more challenging as along with the antenna characteristics there is other parameters viz. large operational bandwidth, stable radiation characteristics throughout the bandwidth, isolations between different frequency bands, easy integration, low profile etc., which are also crucial for overall device performance. Normally, due to their easy fabrication and compact design planar antennas have gained much intention as handheld device antenna. Typically, in order to accommodate different wireless standards in a single device more than one antenna is used as their bandwidth is limited, but this approach has negative impact on the antenna size. Large number of antennas increases the overall device size and complicacy, which is not desirable. Uses of a wide band antenna could cut the no of antennas required but unable to reduce the system complexity, as sophisticated filters are required to filter undesired frequency bands offered by the wide band antennas. Another potential solution of this problem is reconfiburable antennas. Reconfigurable antennas are a type of antenna, which can alter antenna-operating frequency, radiation characteristics and polarization according to requirements. Infect, reconfigurability has become an important and desirable feature of modern radio frequency systems.

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Reconfigurable antennas can address complex system requirements by adapting to changes in environmental conditions or system requirements. As mention above reconfigurable antennas can alter antenna operating frequency, radiation characteristics and polarization, designing of reconfigurable antenna takes three challenging questions [28].

1. Which antenna operating characteristics i.e. frequency, radiation pattern or polarization needs to be altered?
2. How to arrange the antenna radiating elements to achieve the desired alternation?
3. Which technique would be most suitable for reconfiguration?

Based on the first question reconfigurable antennas can be classified into four different categories [28].

- Category 1: A radiating structure which is able to change its operating frequency between different frequency bands is called frequency reconfigurable antenna
- Category 2: A radiating structure that is able to tune its radiation pattern is called radiation pattern reconfigurable antenna. For this category, the antenna radiation pattern changes in terms of shape, direction, or gain.
- Category 3: A radiating structure that can change its polarization is called polarization reconfigurable antenna. In this case, the antenna can change, for example, from vertical to left-hand circular polarization.

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Category 4: This category is a combination of the previous three categories. For example, one can achieve a frequency reconfigurable antenna with polarization diversity at the same time.

In order to achieves these four categories of reconfigurabiltiy, there are four major techniques which includes,

1. Electrical reconfiguration
2. Optical reconfiguration
3. Material based reconfiguration
4. Mechanical reconfiguration

4.1 Electrically reconfigurable antennas:

An electrically reconfigurable antenna technique relies on the redistribution of the surface currents by altering the antenna radiating structure topology electronic by using switching components (RF-MEMs, PIN diodes, or varactors [29]). It is the integration of switches into the antenna structure, which makes it easier to reach the desired reconfigurable functionality. The ease of integration of electrical switching elements into the antenna structure has attracted antenna researchers to this type of reconfigurable antennas despite the numerous issues regarding such reconfiguration technique including the nonlinearity effects of switches, and the interference, losses, and negative effect of the biasing lines used to control the state of the switching components on the antenna radiation pattern and other characteristics.

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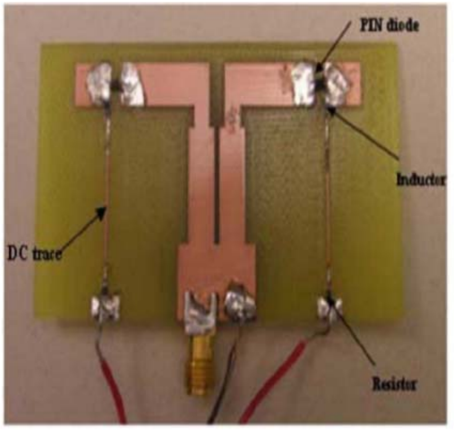

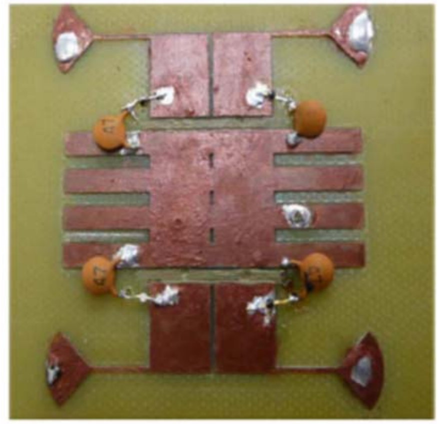

(a) **(b)**

Figure 17: Electrically reconfigurable antenna (a) using PIN diodes (b) using varactor diodes (Image Source: [29])

4.2 Optically reconfigurable antennas:

An optical reconfigurable technique involves incident of light of suitable wavelength normally lasers on a semiconductor material (silicon, gallium arsenide). This will excites electrons from the valence to the conduction band and thus creating a conductive connection. Reconfiguring the antenna characteristics by integrating optically controllable switch offers the advantages of the linear behavior of optical switches, non-requirement of biasing lines. However, their lossy aspect and complicated activation mechanism of such switches are the main concerns [30].

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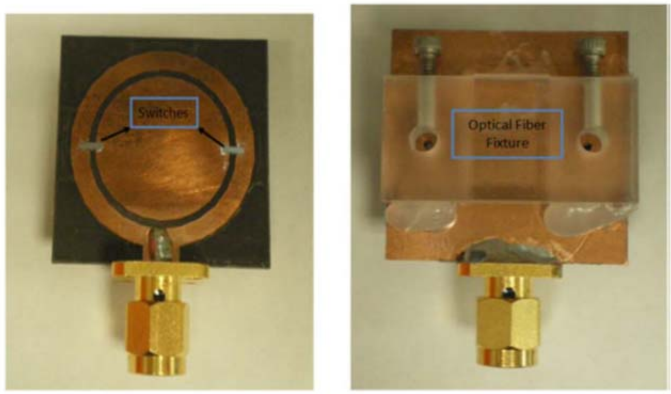

Figure 18: Optically reconfigurable antenna (Image Source: [30])

4.3 Mechanically reconfigurable antennas:

This technique involves the physical altering of antenna radiating structure. The tuning of the antenna is achieved by structural changes of the antenna radiating parts by means of actuators. The major advantage of this technique is that it does not depend on any switching mechanisms, biasing lines, or optical fiber/laser diode integration. However, the technique also possesses the disadvantages bulk actuators and limitations of physical contacts [31].

Figure 19: Mechanically reconfigurable antenna (Image Source: [31])

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4.4 Reconfigurable antennas based on smart materials:

It is also possible to make reconfigurable antennas based on the tunable substrate matrials. The antenna operational characteristics can be altered by changing the relative electric permittivity or magnetic permeability of the substrate material. Normally, materials such as liquid crystals or ferrites are used as tunable substrate materials. The substrate material is tuned by applying suitable external voltage or external magnetic field to alter the dielectric constant/ permittivity or permeability of the substrate material [32, 33].

5. APPLICATIONS:

The uses of reconfigurable antennas on today's high-end communication network are immense. They are needed to cover various widely spanned wireless standards. Uses of reconfigurable antennas instead of multiple antennas can effectively reduce the size and cost of hand held devices. In cognitive radio, environment reconfigurable antennas can use to improve the spectrum efficiency. Radiation pattern and polarization reconfigurable antennas are effectively used in multiple input multiple output channels and satellite communications [28].

6. CONCLUSION AND FUTURE OF RECONFIGURABLE ANTENNAS:

In this literature, a detailed study about the different types of conventional antennas and reconfigurable antennas are presented. The study is based on various conventional antennas, their applications and issue of

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reconfigurable antennas. The study also focuses on different reconfiguration techniques, which are used to achieve required reconfigurability. Based on reconfigurable techniques, reconfigurable antennas were mainly divided into electrically, optically, mechanically, and smart-material-based tunable structures. Different uses of reconfigurable antennas for cognitive radios, satellite communications, etc. are also discussed. With the ability to alter the antenna operational characteristics, reconfigurable antennas have the potential to act according to the environment. Based on next generation communication protocols, implementations of reconfigurable antennas will helps in the efficient uses of different frequency bands and radiation pattern and polarization reconfigurability offer data communication into a targeted area more securely. MIMO channels equipped with reconfigurable antennas will improve the channel capacity along with the increase in efficiency of such channels and reduce their costs. In space communications, reconfigurable antennas have also found their potential utility as deployable antennas. Along with these applications, reconfigurable antennas have found the most interesting utilization in handheld devices, which makes the access of various wireless standards using a single antenna quite easy and thereby making the system simple and compact.

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