ISSN 2229-5518

# Design and performance issues of Microstrip Antennas

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**Abstract**— In recent years, microstrip antennas are playing an important role in wireless communication systems because of their many advantages like light weight, low profile, low cost, easy integration with planar structure and easy fabrication. So, it is very much essential to know all the aspects of microstrip antennas. The main objective of this paper is to discuss the design and performance issues of microstrip antennas. The design issues include microstrip antenna dimensions, feeding techniques and various polarization mechanisms whereas the performance issues include gain enhancement, bandwidth issues and reconfigurable microstrip antennas. This paper is also aimed to introduce few applications of microstrip antennas like Wi-Fi, Wi-MAX, RF energy harvesting, Cognitive radio, GSM, Radar and ultra-wide band. Microstrip antennas are also having disadvantages like low gain and low efficieny.

**Index Terms**— active patch, cognitive radio, feeding techniques, gain enhancement, impedance bandwidth, polarization, reconfigurable patch, ultra-wide bands.

## 1 Introduction

AN Antenna is a sensor and transducer that converts electrical signals into electromagnetic waves and electromagnetic waves into electrical signals. In modern wireless communication systems an antenna with low cost, small size, easy fabrication with good performance is required. For those systems microstrip antennas are the best because of their enormous advantages. Microstrip antennas also known as patch antennas. This paper completely explains the design and performance issues of patch antennas along with their applications. In this paper, initially we focus on the design and performance issues of microstrip antennas.

## 2 Design issues of patch antennas

In this section, we present the design issues of microstrip antennas. As discussed earlier, the design issues include antenna dimensions, feeding techniques and various polarization mechanisms. Here, we present the dimensions of a patch antenna.

### 2.1 Antenna dimensions

Basic patch antenna consists of two good conducting layers separated by a dielectric substrate of thickness (h) as shown in Fig 1. Upper conducting layer is known as radiating patch or active patch whereas the bottom layer is referred as ground patch. The good conducting material may be copper, gold or aluminium. The active patch may take various shapes like square, rectangular, circular, elliptical or triangular. Different shapes are having different advantages, but most of the times circular and rectangular active patches are preferred [1]. Generally, the microstrip antenna dimensions are expressed in terms of mathematical equations. Dimensions of an active patch play a vital role on antenna performance. Here, we focus on the dimensions of a rectangular active patch [2-5].

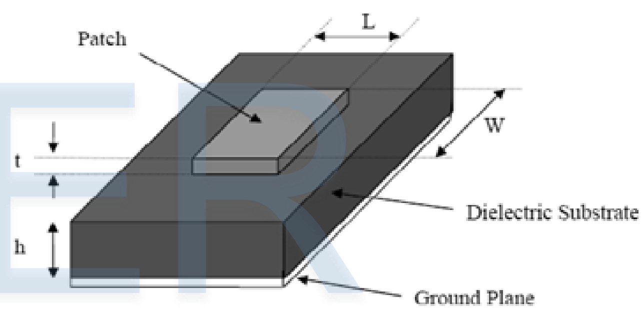


Fig 1: Basic rectangular microstrip antenna.

Basic rectangular active patch is having length (L), width (W) and thickness (t) as shown in Fig 1. Standard thickness of the active patch is 0.35μm. However, it may be a different value, but must be as small as when compared with the free space wavelength ($\lambda_o$).

i.e. t << $\lambda_o$.

Width (W) of the radiating patch is given by the equation (1).

$$W = \frac{c}{2f_o}\sqrt{\frac{\varepsilon_r + 1}{2}}, \qquad (1)$$

Where, $f_o$ is the resonant frequency, $\varepsilon_r$ is the dielectric constant or relative permittivity and c is the velocity of light in free space.

Effective permittivity or effective dielectric constant of the dielectric substrate when W/h > 1, is given by the equation (2).

$$\varepsilon_{\text{reff}} = \left[\frac{\varepsilon_r + 1}{2}\right] + \left[\frac{\varepsilon_r - 1}{2}\right]\sqrt{\left[1 + \frac{10h}{W}\right]}. \qquad (2)$$

Length of the active patch (L), which is more responsible for better antenna performance generally lies between $\lambda_o/3$ and $\lambda_o/2$. However, it is given by the equation (3).

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ISSN 2229-5518

$$L = \frac{c}{2f_o\sqrt{\varepsilon_{\text{reff}}}} - 2\Delta l, \qquad (3)$$

Where, Δl or ΔL is the extended line length on both sides of the active patch due to the effect of fringing fields [6].

$$\frac{\Delta L}{h} = 0.412\left[\frac{(\varepsilon_{\text{reff}}+0.3)}{(\varepsilon_{\text{reff}}+0.3)}\right]\left[\frac{\omega/h+0.264}{\omega/h+0.8}\right]. \qquad (4)$$

To obtain the dimensions of a rectangular active patch very quickly a link given in [7] can also be followed. In this link, dimensions of the active patch can be achieved by substituting the known values like $\varepsilon_r$, h and resonant frequency ($f_o$). Once we got the dimensions of an active patch it is possible to calculate the width (Ws) and lengths (Ls) of the dielectric substrate by using equations (5) and (6). Here, 'W' and 'L' are width and lengths of the active patch respectively.

$$Ws=W+6h \qquad (5)$$

$$Ls=L+6h \qquad (6)$$

However, antennas may also resonate at same frequencies with dimensions which are not matching with these calculations. But, the antennas resonate exactly at the particular operating frequency with these calculations. Basically, microstrip antennas primarily radiate by the virtue of fringing fields between the patch edge and the ground plane as shown in Fig 2.

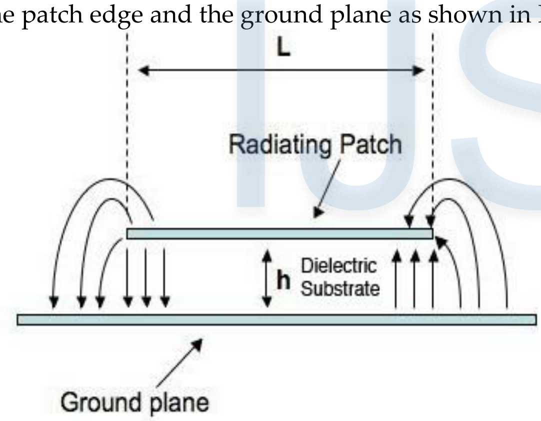


Fig 2: Fringing fields in patch antenna [8].

To have better performance in terms of radiation or bandwidth, we need a dielectric substrate with low dielectric constant ($\varepsilon_r$) and more thickness (h). Generally, the value of $\varepsilon_r$ lies between 2.2 to 12.

i.e. $2.2 \le \varepsilon_r \le 12$.

If the value of $\varepsilon_r$ is small, then we get good radiation from the antenna. If it is high, then the fields are more tightly contained in the substrate which results in less radiation. The dielectric substrate with high $\varepsilon_r$ is desirable in microwave circuitry to minimize undesired radiation and coupling [9]. As discussed earlier, the value of substrate thickness (h) must be as high as possible to obtain high efficiency and high bandwidth. But, if we increase the height of substrate it may degrade antenna pattern and polarization characteristics. The value of substrate thickness is like $0.003\lambda_o \le h \le 0.05\lambda_o$ [10].

Ground patch is with good conducting material takes the dimensions of the dielectric substrate. However, it may be partial or full ground with slots according to the requirement.

The patch antennas are having disadvantages like low efficiency, low power handling capacity, high Q-factor, poor polarzization purity, poor scan performance, spurious feed radiation and very narrow bandwidth.

## 2.2 Feeding techniques

In the design of microstrip antennas, it is necessary to connect the active patch with ground patch by using various techniques. These techniques are called feeding techniques. In fact, the scheme of feeding technique also plays an important role on antenna performance. There are various feeding techniques applied to the patch antennas. The most popular feeding techniques [11, 12] are microstrip line [13, 14], coaxial probe [5], aperture coupling and proximity coupling.

Among the above feeding techniques microstrip line feeding is very simple and easy for fabrication [10]. There are different microstrip line feeding techniques presented in [14], out of them the microstrip line with inset feeding shown in Fig 3 is widely used. The main advantage of using this mechanism is that, impedance matching can be done easily by adjusting the position of inset feed [1, 13]. According to the standard relations discussed in [1], dimensions of the microstrip line width and length can be understand by the links mentioned in [15]. In the first link of [15], 'w' and $\lambda/4$ are the width and the lengths of microstrip line for proper impedance matching.

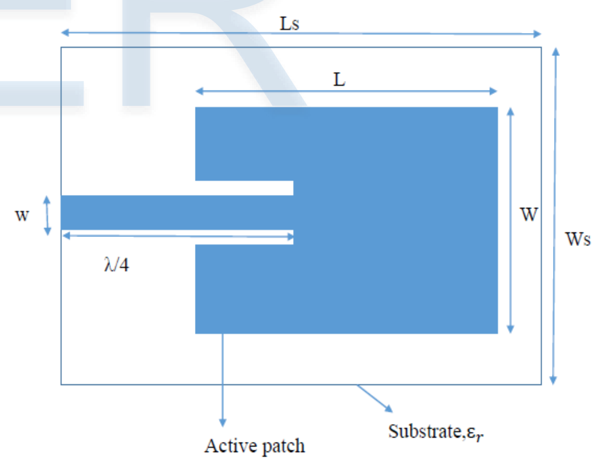


Fig 3: Microstrip antenna with inset feeding.

Basically, the microstrip line with inset feeding introduces a physical notch which causes a junction capacitance. The capacitance and the notch influence the resonant frequency by 1%.

## 2.3 Various Polarization mechanisms

Polarization is defined as the propagation or orientation of the electric flux lines in an electromagnetic field. Basically, electromagnetic waves propagate in three different polarizations. They are linear, circular and elliptical polarizations [16]. By applying conventional feedings to the rectangular and circular patches we can obtain linear polarization [17, 18]. A linearly polarized patch antenna with co-axial feeding is shown in Fig 4.

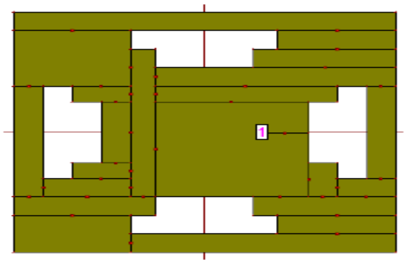

Fig 4: Proposed linearly polarized patch antenna with Co-axial feed [17].

We can obtain circular and elliptical polarizations by modifying the designs or by using different feedings. Generally, circular polarization to an antenna can be achieved when two orthogonal modes are excited with a phase difference of 90 degrees. It can be done by adjusting the dimensions of the patch with single or two [1, 19] or more feeds. Phase difference of 90 degrees is obtained by using 90 degree power dividers or hybrids as shown in Fig 5.

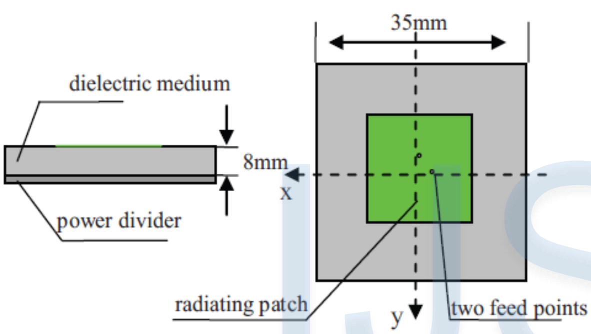


Fig 5: Circularly polarized patch antenna with two feedings [19].

Sometimes, slits on the active patch with single feed also plays an important role in obtaining circular polarization [20-23]. In some situations normal antenna designs can also yield circular polarization [24].

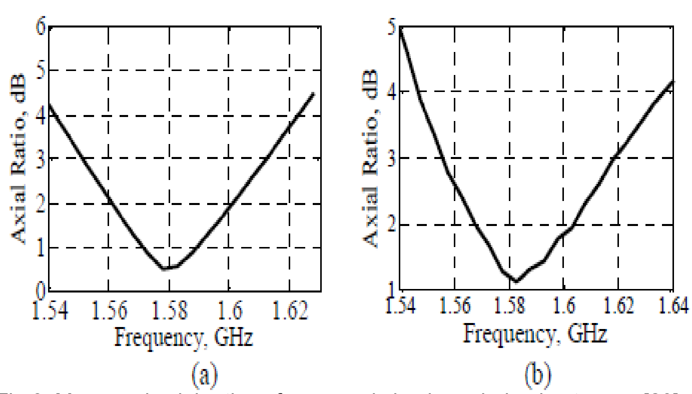


Fig 6: Measured axial ratios of proposed circular polarized antennas [20].

Microstrip antenna model for an elliptical polarization is discussed in [25]. In software simulations, there is one parameter called axial ratio through which the type of polarization is identified. Axial ratio is the ratio of orthogonal components of an electric field. The axial ratio is unity (0 dB) for circular polarization, because the orthogonal components are equal in magnitude and having a phase difference of ±90 degrees. The axial ratio for an elliptical polarization is larger than 1 (> 0 dB). For a perfect linear polarization the axial ratio is infinite [26].

## 3 Performance Issues

As mentioned above, the performance issues include gain enhancement, bandwidth issues and reconfigurable patch antennas. Initially, we present the issues related to the gain enhancement.

### 3.1 Gain enhancement

Enhancing the gain of a microstrip antenna is a complex job. However, it can be increased to some level by introducing different designs.

First one is, by introducing multilayer substrates in the design of a patch antenna as shown in Fig 7 [27, 28]. In this method, we need to use different dielectric materials with different or similar heights. Air can also be used as a dielectric substrate.

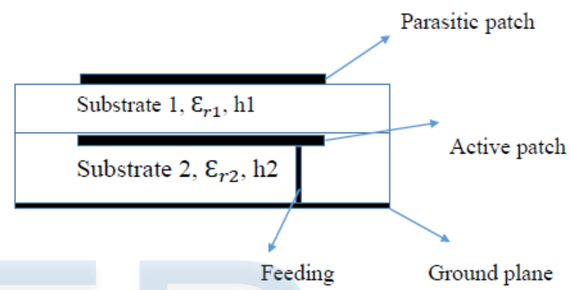


Fig 7: Two level substrate microstrip antenna.

Second one is, by integrating electromagnetic band gap (EBG) structures [29-31] within the microstrip antennas [32]. By using EBG structures in the patch antenna, we can reduce surface wave effects. The reduction in surface wave effects result in the improvement of the gain. Combination of slots and with or without the integration of EBG structures can also be used for enhancing the gain [33]. EBG designs are also used to enhance efficiency [34].

Third one is, by the proper selection of substrate relative permittivity and thickness [35, 36]. We need a substrate with low relative permittivity and small thickness for achieving improved gain.

### 3.2 Bandwidth issues

There are various bandwidths related to the antenna performance. They are impedance or return loss bandwidth, directivity bandwidth, gain bandwidth, efficiency bandwidth, polarization bandwidth and axial ratio bandwidth. Most of the times we consider impedance bandwidth of a patch antenna.

The main disadvantage of a patch antenna is narrow bandwidth. However, in terms of impedance bandwidth we can obtain bandwidth in Giga hertz ranges. By using patch antennas we can achieve very narrow bands [23, 37] as well as ultra-wide bands [38-40]. There are some key points to obtain ultra-wide bands [41]. Round edges and round shapes lead to smoother current flow, which results to ultra-wide band characteristics [42-44]. Partial ground planes and full ground planes with specially designed slots play a key role in obtaining UWB behavior [45, 46]. However, we can obtain ultra-wide band characteristics without round shapes and partial grounds [47-50], but the above key points give success to obtain wide bands. In recent years, UWB applications are becoming very popular because of high data rate over short distances, low power consumption, high secure and high reliable communication solutions.

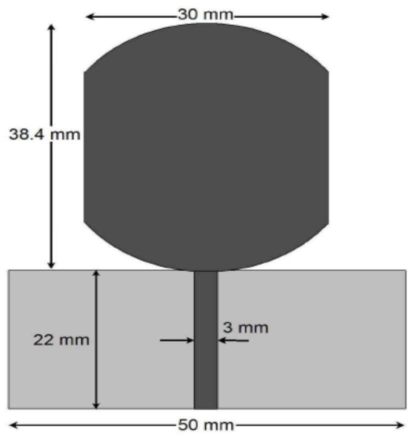


Fig 8: Proposed UWB antenna [38].

Basically, the UWB range approved by FCC in 2002 (3.1GHz to 10.6GHz) covers the frequencies of Wi-Fi as well as Wi-MAX bands. While designing patch antennas if we want to avoid interference between these bands and UWB bands, we need to design UWB antennas with band notch characteristics. To perform band rejection function we need to introduce some specially designed slots onto the active patch. These slots can act as band notched or band rejection functions. The dimensions of the slots or strips depend upon the rejection bands which we want to reject [51, 52]. At the desired frequency, the length of the strip is about half or quarter of the guided wavelength.

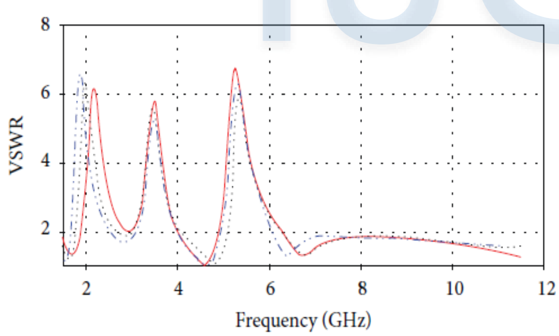


Fig 9: VSWR vs. frequency plot of the proposed UWB antenna with rejection bands [51].

### 3.3 Reconfigurable patch antennas

In modern wireless communication systems, an antenna with variable characteristics is required. For those applications reconfigurable antennas are having huge demand. Patch antennas can be designed as reconfigurable in which the performance characteristics of the designed antenna will change according to the reconfiguration of the design. There are basically four types of reconfigurable antennas [53] as shown in Fig 10. The performance characteristics may be frequency or radiation or polarization or any combination of this. Due to the reconfiguration, if resonant frequency is changing then the concerned antenna is known as frequency reconfigurable antenna. Similarly, if polarization is changing, then the antenna is known as polarization reconfigurable antenna.

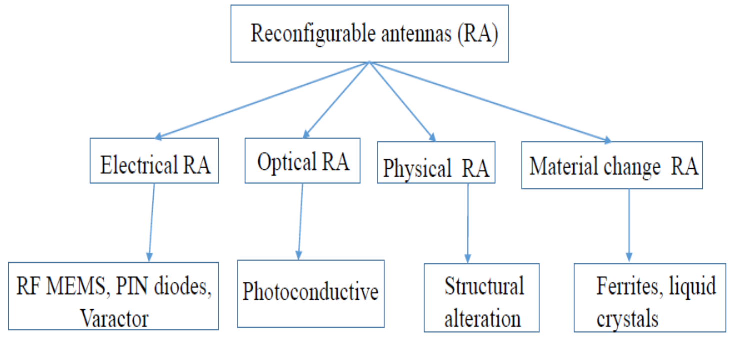


Fig 10: Types of reconfigurable antennas [53].

There are many ways to reconfigure the design. Some of them are done by introducing switches like PIN diodes [54-56], varactor diodes [57], RF-MEMS switches [58] or by altering the structure of the design [59] or by using materials like ferrites or liquid crystals as substrate material. Another way of doing reconfiguration is by introducing switches of photoconductive elements [60].

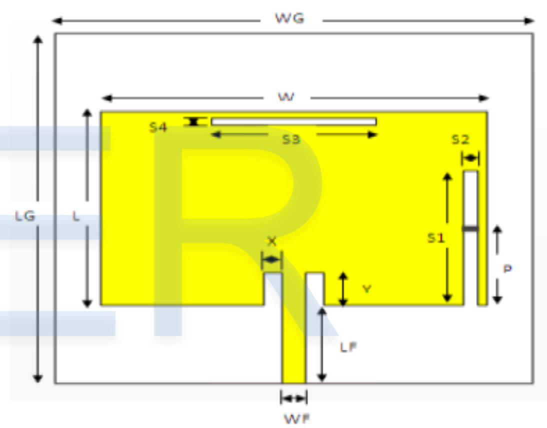


Fig 11: Proposed reconfigurable microstrip antenna with PIN diodes [54].

In case of electrical reconfigurable antennas, reconfigurability is achieved by making switches ON and OFF [61]. Similarly, in case of optical reconfigurable antennas, the photoconductive switches made ON and OFF by exposing them to a laser light of proper wavelength. In physical or structural reconfigurable antennas, the physical structure of the active patch changes according to the requirement of performance characteristics. In material change reconfigurable antennas case, dielectric substrates are fabricated by using smart materials like ferrites or liquid crystals. The advantage of using these materials is that, the substrate relative permittivity and permeability can be varied by various methods. Once the substrate properties are varying means reconfigurability is achieved.

The main advantages of the reconfigurable antennas are fast tuning, low cost, time and space saving. However, they are having disadvantages like power consumption, non-linear effects of switches, interference and losses. Moreover, these antennas require biasing networks for activation or deactivation of the switching elements which makes antenna design complex.

Patch antennas can also be designed in folded models so that they are useful in structures like flexible electronic systems [62].

ISSN 2229-5518

## 4. Applications and Softwares for Simulation

In this section, we discuss various applications and softwares used for microstrip antennas.

### 4.1 Applications

Because of enormous advantages of patch antennas, they are widely used in many applications like Laptops, mobiles (for GSM [63-65], Wi-Fi [66, 67], GPS [68], Bluetooth [69] and Wi-MAX [70, 71]), ultra-wide Band [38-52], Satellite communication, RF energy harvesting [72-75], MIMO, Cognitive radio [76-78], Radio frequency identification (RFID)[79], radar, body centric communication and so on.

We can model microstrip antenna designs for single as well as multiband operations. For example, we can design a microstrip antenna for Wi-Fi application as well as for Wi-Fi, Wi-MAX and GSM (multi bands) applications as shown in Figures 12 and 13.

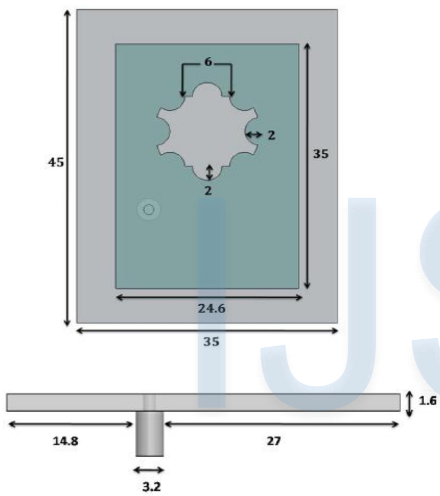


Fig 12: Proposed antenna for GSM, Wi-Fi and Wi-MAX applications [71].

All over the world, Wi-Fi applications cover two frequency bands. First one is 2.4GHz band (2.401GHz-2.484GHz) [80] and second one is 5GHz band [81]. There are almost five bands for Wi-MAX applications. Those are 2.3GHz, 2.5GHz, 3.3GHz, 3.5GHz and 5.8GHz bands [82, 83].

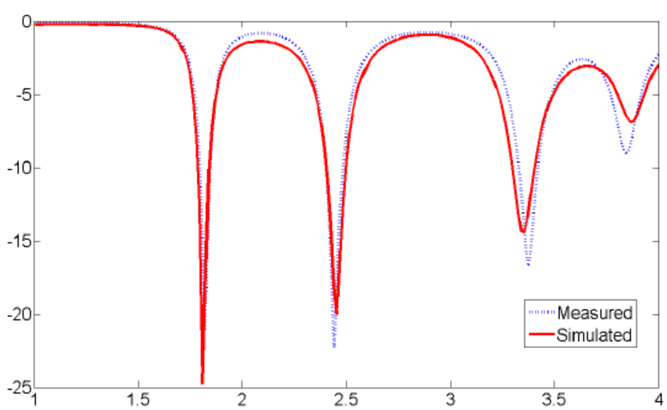


Fig 13: Simulated and measured return loss of proposed GSM, Wi-Fi and Wi-MAX antenna [71].

Main idea of RF energy harvesting is to save RF energy from radio environment. The harvested energy can be used for small voltage electronic devices. Initially, to sense the RF energy from the radio environment we need antennas like patches with ultra-wide band characteristics. However, narrow band antennas can also be used, but it depends upon the frequency bands which we are going to sense. For example, to sense GSM 900 frequencies we need an antenna with narrow band characteristics.

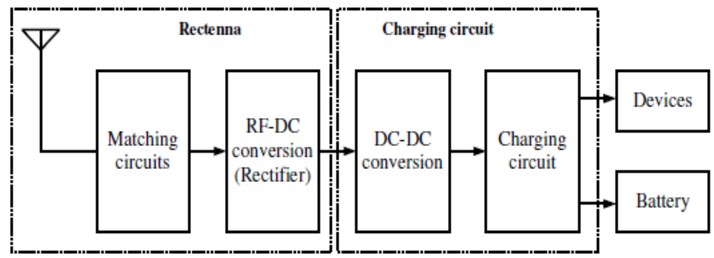


Fig 14: System of RF energy harvesting for electronic devices [74].

In order to enhance the performance characteristics of wireless communication systems multiple input multiple output systems are employed. The MIMO systems uses multiple antennas at transmitting and receiving ends to increase the system coverage, QoS, capacity, and spectral efficiency. Because of their enormous advantages, microstrip antennas are widely used in MIMO applications.

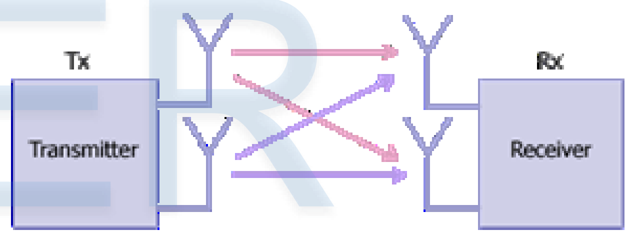


Fig 15: MIMO system.

Cognitive radio is a radio in which the licensed spectrum (utilized by primary user) is utilized by unlicensed user (secondary user) when the channel is free. In this application, we need an UWB antenna to detect or to sense the spectrum hole (free channel) and another reconfigurable NB antenna for communication as shown in Fig 16.

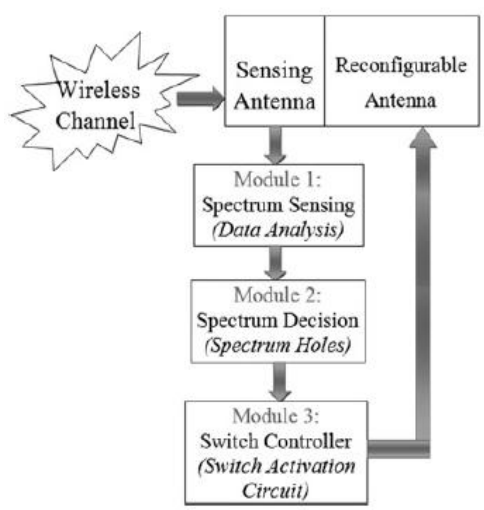


Fig 16: Working flow of Cognitive radio system [84].

However, it is possible to integrate UWB and NB antennas into one antenna so that it is useful for spectrum sensing as well as for communication [85-87]. The integrated UWB and NB antennas are designed in such a way that the mutual coupling between them must be as low as possible.

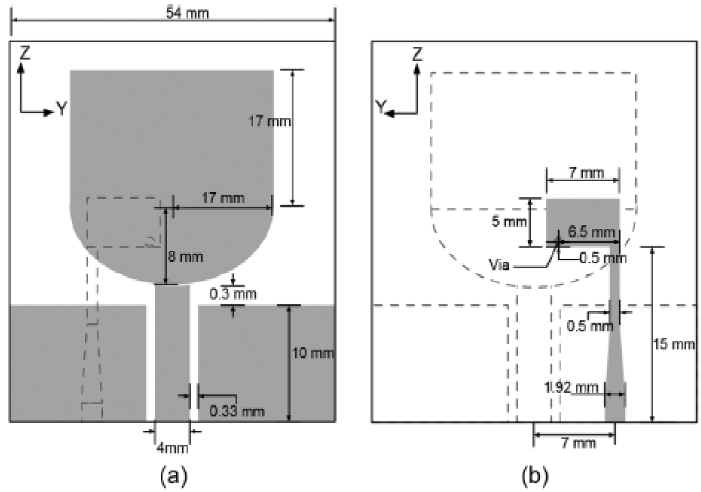


Fig 17: Proposed dual port Integrated UWB and reconfigurable NB antenna for cognitive radio (a) Top view (b) Bottom view [85].

For UWB as well as NB applications microstrip antennas are extensively used because of their wide advantages.

### 4.2 Softwares for simulation

- HFSS.
- FEKO.
- ADS.
- AWR.
- IE3D.
- CST- Microwave studio.
- Antenna Magus.
- AN-SOF.
- 4NEC2.
- MATLAB.

## 5. Present and Future Scope

Nowadays, reconfigurable antennas are dominating because of their huge advantages. But, they also require additional hardware for activation and deactivation of switches. Sometimes, they need different voltage levels. In future, multiport antennas may play an important role because they support multiband and multiple applications. If we are able to achieve better isolation between the ports, then multiport antennas become the best solution for space, time and cost.

## 6. Conclusion

In this paper, we focus on the basic and important concepts of microstrip antennas. This paper also presents the gain enhancement techniques and reconfigurable antenna types. We also discuss the current research applications of microstrip antennas. Finally, we can say that this paper covers all the aspects of microstrip antennas.

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