# DESIGN OF BAND RECONFIGURABLE UWB MICROSTRIP PATCH ANTENNA FOR COGNITIVE RADIO APPLICATION

***A Project report submitted in partial fulfillment of the requirements for***

***the award of the degree of***

**BACHELOR OF TECHNOLOGY**

**IN**

**ELECTRONICS AND COMMUNICATION ENGINEERING**

**Submitted by**

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Sangivalasa, Bheemili Mandal, Visakhapatnam dist. A.P

(2021-2022)

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## CERTIFICATE

This is to certify that the project report entitled " **DESIGN OF BAND RECONFIGURABLE UWB MICROSTRIP PATCH ANTENNA FOR COGNITIVE RADIO APPLICATION** submitted by in partial fulfilment of the requirements for the award of the degree of **Bachelor of Engineering K.SINDHUJA (318126512083), CH.LALITHA DEVI (319126512L12), D.SATYA SUSHMA (318126512071), B.MOTHILAL (318126512069), T.RAJESH (318126512109)** in **Electronics and Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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# ABSTRACT

The contemporary communication antennas require Ultra-Wide Band (UWB) spectrum coverage for cost-effectiveness and efficient operation. Re-configurability is the requirement of present communication systems. The project proposes a broadband sensing ultra-wide band Cognitive Radio (CR) antenna in the frequency range of 3.8 to 11.1 GHz with a broad radiational pattern. The structure of octagonal shaped patch antenna is proposed with UWB characteristics. The rectangular coplanar ground plane structure can be modified by incorporating two symmetrical horizontal T-shaped structures to increase the impedance bandwidth. Two PIN diodes are implanted to achieve frequency reconfiguration with impedance matching at 6.8GHz, 7.5GHz, 10.6GHz, and 11,1GHz. FCC UWB characteristics can be obtained by making suitable changes in the geometry of the ground plane. Four cases of switching of two PIN diodes give S11 minima at different operating bandwidths in the UWB range. The switches must be incorporated to convert a narrowband antenna into a broadband spectrum antenna. The proposed antenna can be used for cognitive radio applications in C - band, X - band.

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# Chapter-1

# Microstrip Patch Antenna

In this chapter, an introduction of Microstrip Patch Antenna is followed by its advantages and disadvantages and also feeding techniques were discussed. Finally, Microstrip Patch Antenna analysis theory is discussed. Working mechanism is also discussed.

## 1.1 Introduction

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric which has a ground plane on the other side as shown in Figure 1.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and feed lines are usually photo etched on the dielectric substrate.

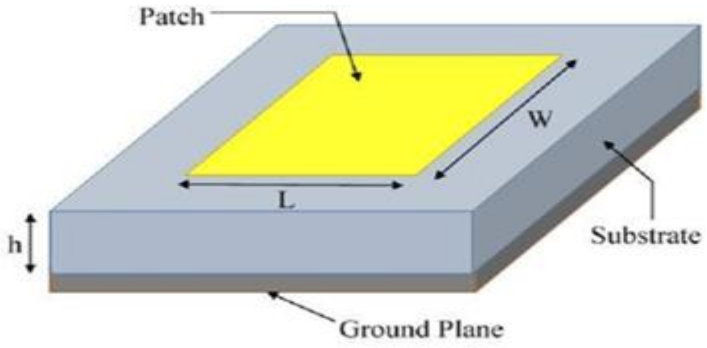


Figure 1.1 Structure of a Microstrip Patch Antenna

In order to simplify analysis or performance prediction, the patch is generally square, rectangular, dipole, circular, triangular, elliptical, disc sector, circular ring, ring sector are shown in Figure 1.2.

For rectangular patch, the length L of the patch is generally $0.3333\lambda_o < L < 0.5\lambda_o$ where $\lambda_o$ is free space wavelength. The patch is very thin such that $t << \lambda_o$ where t is the thickness of the patch. The height h of the dielectric substrate is generally $0.003\lambda_o < h < 0.05\lambda_o$. The dielectric constant of the substrate($\varepsilon_r$) is in the range $2.2 < \varepsilon_r < 12$.

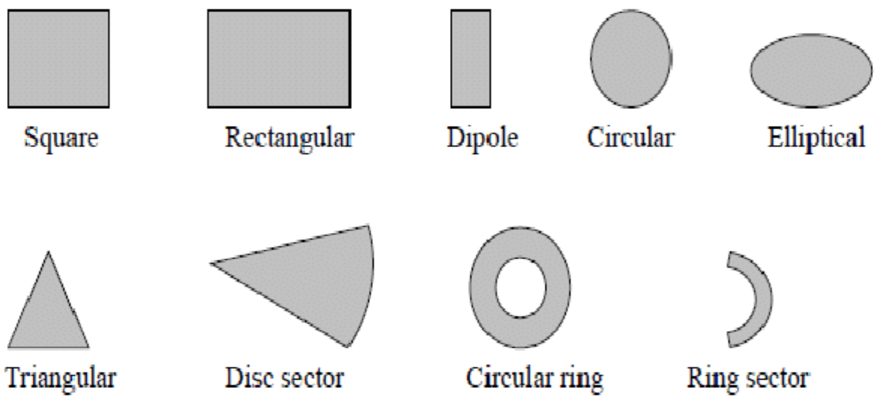


Figure 1.2 Common shapes of microstrip patch antenna

Microstrip patch antenna radiate because of fringing fields between patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is required since this provides better efficiency, larger bandwidth and better radiation. However such configuration leads to a larger antenna size. In order to compact Microstrip Patch Antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth.

## 1.2 FR4 Substrate

"FR" stands for flame/fire retardant. FR-4 is a designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods and printed circuit boards. It is a composite material composed of fibre glass clot an epoxy resin binder that is flame resistant. FR-4 glass epoxy is famous and flexible high-pressure thermoset plastic laminate material with high strength to weight ratios.

If the material has to be flame or fire retardant, there are certain requirements to be fulfilled for the material to be certified as FR. The FR4 substrate is manufactured by compressing an epoxy resin at high pressure and a glass fibre mat is embedded within the structure. The glass fibre gives strength to the substrate and increases the dielectric constant of the composite material. The weave is generally more densely packed in one direction and so material is anisotropic with small variation in dielectric constant in different planes. At microwave frequencies, the bulk dielectric constant value is similar to value at 1MHz, decreasing slightly at frequencies above GHz.

The microstrip patch antenna design depends upon substrate thickness. The thick substrates with low dielectric constants are required one to obtan the larger bandwidth and higher efficiency due to loosely bound fringing fields. While thin substrates with large dielectric constants reduce overall size of antenna, due to high loss tangents thin substrates are less efficient that results with narrow bandwidth. Therefore substrate plays an important role while designing an antenna.

## 1.3 FR4 Advantages and Disadvantages

Microstrip patch antenna are increasing in popularity for use in wireless applications due to their low-profile structure. They are compatible for embedded antennas in wireless devices such as cellular phones, etc…

### 1.3.1 Advantages

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal face.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both linear and circular polarisation.
- Can be easily integrated with microwave integrated circuits.
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

### 1.3.2 Disadvantages

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor and fire radiator except tapered slot antennas
- Low power handling capacity
- Surface wave excitation

Microstrip patch antennas have a high antenna quality factor(Q). Q represents losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as thickness increases , an increasing fraction of the total power delivered by source goes into a surface wave.

## 1.4 Feeding Techniques

Microstrip patch antenna can be fed by variety of methods. These methods can be classified into 2 types-contacting and non-contacting. In contacting method, the RF power is fed directly to the radiating patch using a connecting element such as microstrip line. In non-contacting method, electromagnetic field coupling is done to transfer power between microstrip line and radiating patch. The four most feeding techniques used are microstrip line, coaxial probe (both are contacting methods), aperture coupling and proximity coupling(both are non-contacting methods) .

### 1.4.1 Microstrip line feed

In this type of feeding technique, the conducting strip is directly connected to the edge of the microstrip patch as shown in Figure 1.3. The conducting strip is smaller in width as compared to patch and this kind of feed arrangement has advantage that the feed can be etched on same substrate to provide planar structure.

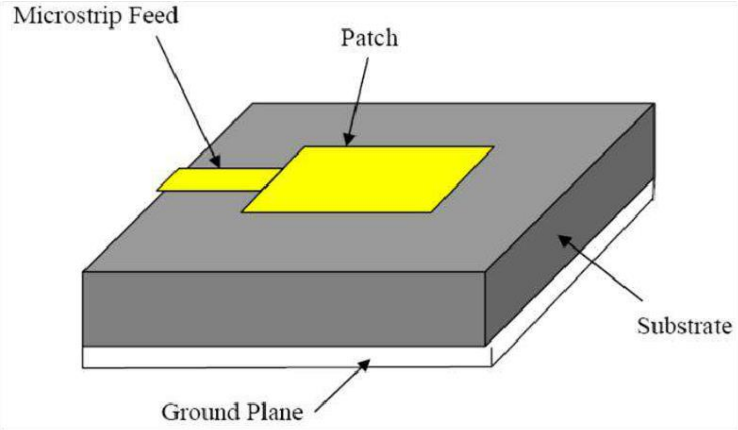


**Figure 1.3** Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme since it provides case of fabrication and simplicity in modelling as well as impedance matching. However, as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

### 1.4.2 Coaxial feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 1.4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

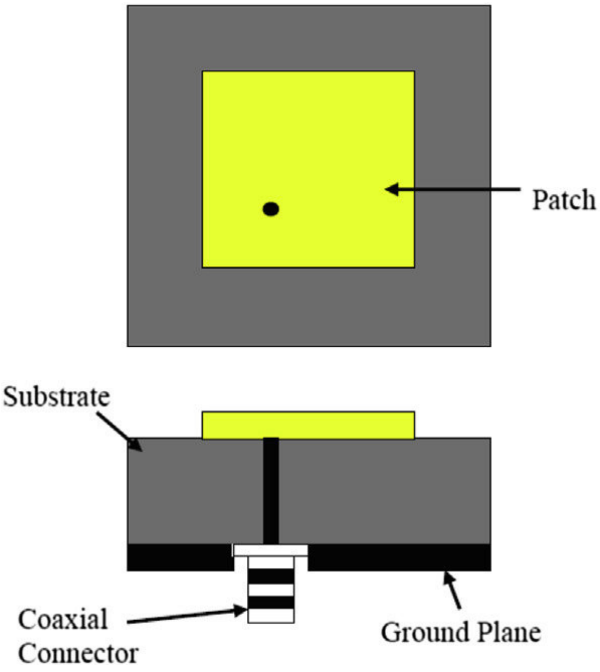


**Figure 1.4** Probe Feed rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates. Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these problems.

### 1.4.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 1.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

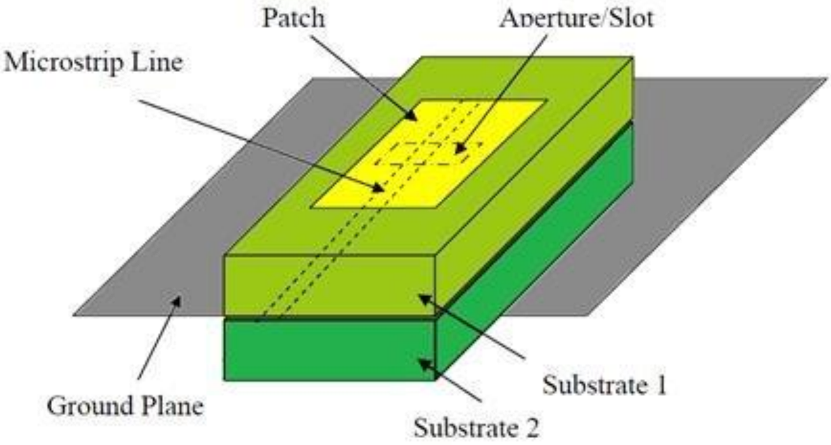


**Figure 1.5** Aperture Coupled Feed

The coupling aperture is usually centred under the patch, leading to lower cross- polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

### 1.4.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 1.6, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) , due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

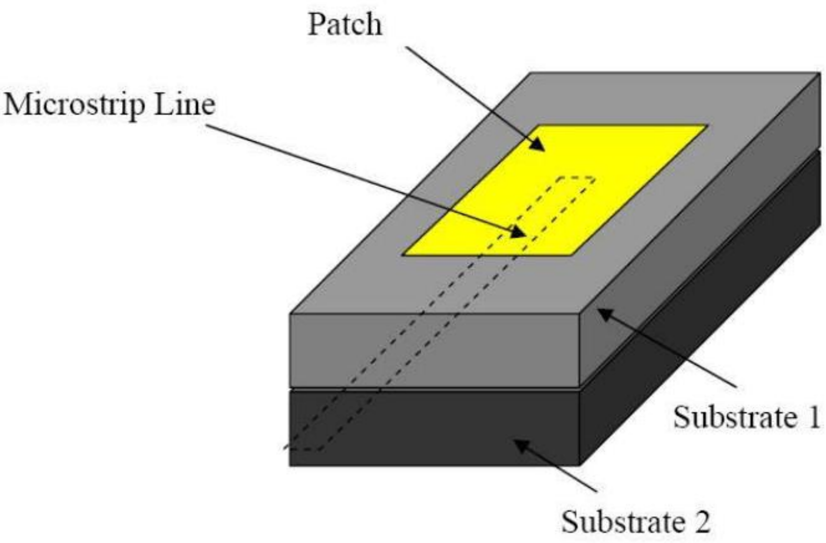


**Figure 1.6** Proximity Coupled Feed

Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, thereis an increase in the overall thickness of the antenna. Table 1.1 below summarizes the characteristics of the different feed techniques.

**Table 1.1** Comparing the different feed techniques

| **Characteristics** | **Microstrip Line Feed** | **Coaxial Feed** | **Aperture Coupled Feed** | **Proximity Coupled Feed** |
|---|---|---|---|---|
| Spurious feed radiation | More | More | Less | Minimum |
| Reliability | Better | Poor due to soldering | Good | Good |
| Ease of fabrication | Easy | Soldering and drilling needed | Alignment required | Alignment required |
| Impedance Matching | Easy | Easy | Easy | Easy |
| Bandwidth(achieved with impedance matching) | 2-5% | 2-5% | 2-5% | 13% |

## 1.4.5 Methods of Analysis

There are many methods of analysis for microstrip antennas. The most popular models are the transmission model and cavity model and full wave (which include primarily integrations/methods). The transmission line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling. Compared to transmission line model, the cavity model is more accurate at the same time more complex. However it gives also physical insight and is rather difficult to model coupling, although it has been used successfully. In general, when applied properly, the full wave models are accurate, very versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However they are the most complex models and usually give less physical insight. In this section we will cover the transmission-line model only.

### 1.4.5.1 Rectangular Patch Antenna

The rectangular microstrip patch is by far the most widely used configuration. It is very easy to analyse using both the transmission-line and cavity models, which are most accurate for thin substrates. We begin with the transmission-line model because it is easier to illustrate.

#### 1.4.5.1.1 Transmission Line Model

The transmission line model treated rectangular microstrip as a part of transmission line as the rectangular microstrip antenna consists two radiating slots, transmission line modeller presents each radiating slots by an equivalent admittance which are separated by a distance equal to the length. The resistive part of them represents the radiation loss from each slot. At the resonance the reactive part of the input impedance cancelled out and the input impedance become pure resistive Transmission line model consider the elects of various parameters described below.

#### a. Fringing Field

The fringing field in rectangular microstrip antenna as shown in Fig.1.7, arises from the radiating edges shown in the figure below. Fringing field are mainly depends on the dielectric constant and length L to height h ratio. Since in most of the cases the L/h ratio is <<1 therefore the fringing fields are less.

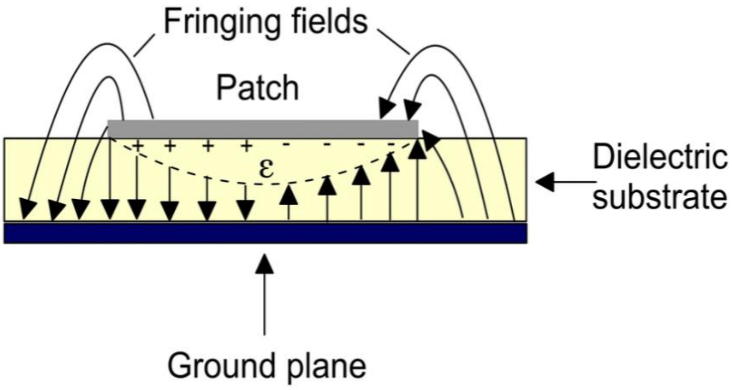


**Figure 1.7** Fringing Field Effect

Higher dielectric constant substrate leads to bounded electric fields more enclosed in the substrate as used in the microstrip lines. While the lower dielectric constants substrates results in loosely bounded electric fields means they will go more further from the patch. Lesser the dielectric constant material used in substrate more bowed the fringing fields. We know that the fringing fields are responsible for the radiations from microstrip antenna. Therefore, lower dielectric constants more the fringing fields and more the radiation leads to better efficiency and better antenna performance. From figure fringing field lines are not only enclosed in substrate but also further out in the air. As the field lines travel in substrate and air also we must calculate an Effective Dielectric constant by taking the air also in account as shown in Fig 1.8

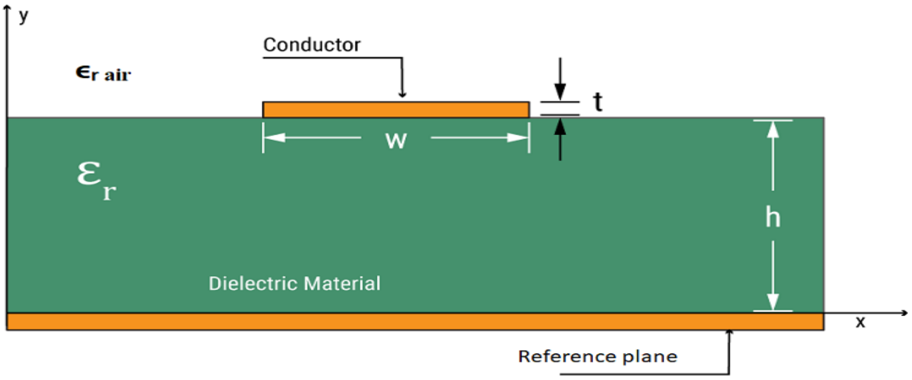


**Figure 1.8** Effective Dielectric Constant

The effective dielectric constant is a dielectric constant of the material for which the antenna characteristics are same as for the real one. The range of effective dielectric constant varies from 1>Ereff<Er. In most cases the Ereff value is close Er. If the air is used as a substrate then the effective dielectric constant is equal to dielectric constant Ereff=Er. The Ereff is also depends on frequency. As the operating frequency increases the value of effective dielectric constant reaches to the real value of dielectric material used. Fig. 1.9 below showing the variation of effective dielectric constant with the frequency below.

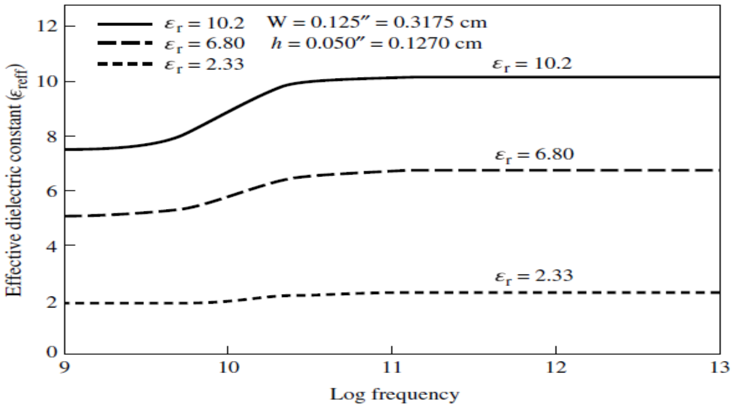


**Figure 1.9** Effective dielectric constant vs Frequency

For the lower frequency the effective dielectric constant does not varies but as the frequency increases the effective dielectric constant approaches towards the actual dielectric constant of substrate material.

The Ereff for W/h>I can be given by equation 1.1

$$E_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\,\frac{h}{w}\right]^{-1/2} \text{ ............1.}$$

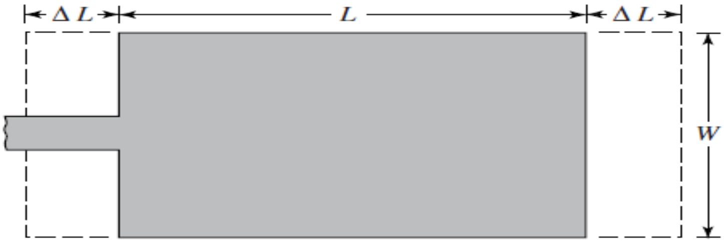
## Effective length, Resonant Frequency, and Effective Width:

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. Where the dimensions of the patch along its length have been extended on each end by a distance delta L, which is a function of the effective dielectric constant Ereff and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is given by equation 1.2.

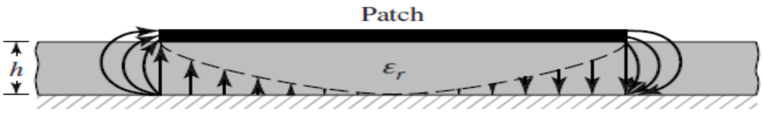
$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

…………..1.2

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch as shown in Fig. 1.10.



(a) Top view



(b) Side view

**Figure 1.10** Length Extension

This delta L value mainly depends on the effective dielectric constant and the width to height ratio. Due to this length extension length of patch is about 0.48lambda rather than 0.5lambda. Therefore, to get the actual physical length of the patch equal to lambda/2. we have considered the extension on both the ends and that is, the length of the patch is given by equation 1.3.

$$L = L_{eff} - 2\Delta L \quad \ldots\ldots\ldots\ldots 1.3$$

As we know for dominant mode the length of the patch is equal to lambda/2 therefore the $L_{eff}$ is given by equation 1.4.

$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon eff}} \quad \ldots\ldots\ldots\ldots 1.4$$

Where C is the velocity of light in free space and f, is the resonance frequency for which antenna is to be design. For the dominant mode TM010 there is no fringing fields along the width therefore there is no need to consider the effective dielectric constant. Width of the patch can be calculated by this formula is given by equation 1.5.

$$W = \frac{c}{2fo\sqrt{\frac{\varepsilon r+1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots 1.5$$

For the dominant mode TM010 the antenna resonates (without taking fringing into account) at the frequency given by the equation 1.6.

$$f_{10} = \frac{c}{\sqrt{\varepsilon r}}\left(\frac{1}{2L}\right) \quad \ldots\ldots\ldots\ldots\ldots 1.6$$

and when considering the effective length and effective dielectric constant the antenna will radiate at the frequency.

### 1.4.5.2 Circular Microstrip Antenna

Circular patch is the second most widely used geometry for the microstrip patch antenna. As in rectangular microstrip antenna we have two degree of freedom (length and width) to control the antenna characteristics, here we have only radius of circular patch. A circular microstrip antenna is shown in the Fig.1.11 below.

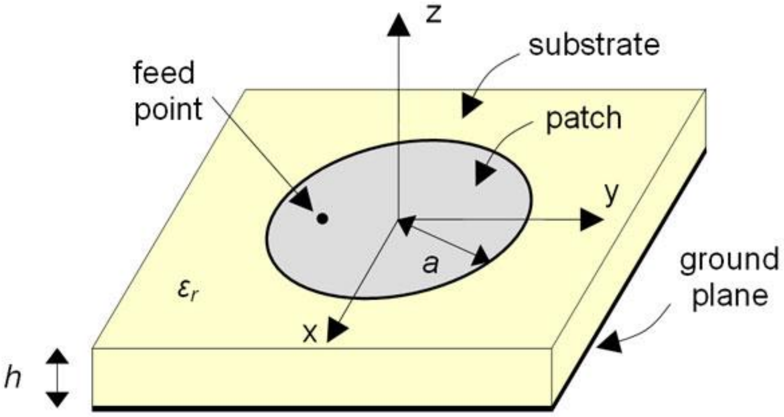


**Figure 1.11** Circular Patch Antenna

# Chapter-2

# Reconfigurable Antenna

## 2.1 Introduction

Antennas are necessary and critical components of communication and radar systems. Nine different types of antennas have proliferated during the past 50 years in both wireless communication and radar systems. These nine varieties include dipoles, monopoles. loop antennas, slot/horn antennas, reflector antennas. Microstrip antennas, log periodic antennas, helical antennas, dielectric/lens antennas and frequency-independent antennas, Each category possesses inherent benefits and detriments that make them more or less suitable for particular applications. When faced with new system design guidelines as starting points to develop new structures that often produce acceptable results.

Making antennas reconfigurable so that their behaviour can adapt with changing system requirement or environmental conditions can ameliorate or eliminate these restrictions and provide additional levels of functionality for any system. The reconfigurable antennas have a capacity to change an individual radiator's fundamental operating characteristics through electrical, mechanical or other means.

## 2.2 Necessity of Reconfigurability

Let us consider two general application areas, single-element scenarios and array scenarios, In single element scenarios an antenna used in portable wireless vices, such as a cellular telephone, a personal digital assistant, or a laptop computer. Single antennas typically used in these devices are monopole or microstrip antenna based and may or may not have multiple-frequency capabilities. Moreover, the portable device is often used in unpredictable and/or harsh electromagnetic conditions, resulting in antenna performance that is certainly less than optimal. Antenna reconfigurability in such a situation could provide numerous advantages. If the antenna's radiation pattern could be changed, it could be redirected toward the access point and use less power for transmission, resulting in a significant savings in battery power. The antennas are mostly used in array configuration, feed structures with power dividers/combiners and phase shifters. This restriction comes from mutual coupling effect on one hand, appearance on grating lobe on other hand. Many of these established applications assume that the antenna element pattern is fixed, all of the elements are identical, and the elements lie on a periodic grid.

There are several antenna structures that are suitable for implementation of reconfigurable antennas, Among them microstrip patch antennas are very attractive structures for various types of reconfigurable antennas, all such antennas are usually equipped with switches that are controlled by DC bias signals. Upon toggling the switch between on and off states, the antenna can be reconfigured. The following section describes the design procedure of microstrip patch antenna types presented and different feed types used in this dissertation.

## 2.3 Types of Reconfigurable Antenna

Reconfigurable antenna has an ability to change any one of the antenna parameter (operating frequency, radiation pattern and polarization) without effecting the remaining parameters. Based on the antenna parameter that is dynamically adjusted, the reconfigurable antennas are classified into four types. They

### 2.3.1 Frequency Reconfigurable Antenna

Frequency reconfigurable antennas can adjust their frequency of operation dynamically. They are particularly useful in situations where several communications systems converge because the multiple antennas required can be replaced by a single reconfigurable antenna. Frequency reconfiguration is generally achieved by physical or electrical modifications to the antenna dimensions using RF switches, impedance loading or tunable materials.

These antennas can be developed by two mechanisms, electrical or mechanical. The electrical mechanism employs discrete tuning and continuous tuning methods. Discrete tuning can be achieved by radio frequency (RF) switches and continuous tuning can be achieved by varactor diodes. The mechanical mechanism employs the impedance loading tunable materials such as liquid crystals to achieve the frequency reconfiguration.

### 2.3.2 Radiation Pattern Reconfigurable Antenna

Radiation pattern reconfigurability is based on the intentional modification of the spherical distribution of the radiation pattern. Pattern reconfigurable antennas are usually designed using movable/rotatable structures or switchable and reactively-loaded parasitic elements.

### 2.3.3 Polarisation Reconfigurable Antenna

These antennas use switching between different polarizations, i.e. from linear polarization to left hand circular polarization (LHCP) and right hand circular polarization (RHCP), using multi modes structures. To reduce the polarization mismatch, losses in portable devices, switching between horizontal, vertical and circular polarizations are needed.

## 2.4 Switchable Devices used for reconfiguration

In order to demonstrate the reconfigurable antennas, various effective implementation techniques have been proposed to be used in different wireless systems such as satellite, multiple-input multiple-output (MIMO) and cognitive ratio communications, which are classified as below:

- Electrical reconfiguration
- Optical reconfiguration
- Physical reconfiguration
- Reconfigurable antennas with smart materials

The most common technique is electrical reconfiguration, which uses active elements such as positive intrinsic-negative (PIN) diodes, varactors and radiofrequency micro-electromechanical system (RFMEMS) switches. Compared to RFMEMS switches, PIN diodes have acceptable performance and a low price. Another technique is called optical reconfiguration, which relies on photoconductive switching elements. The antenna reconfigurable characteristic can also be implemented by altering the structure of the antenna this is called the mechanical reconfiguration method. The antenna can be also reconfigured using smart materials in the antenna configuration.

### 2.4.1 Electrical Reconfiguration

In this type of reconfiguration method, the antenna characteristics are changed using electronic switching components such as PIN diodes, varactors or MEMS. Using these switches, the antenna structure can be reconfigured, which causes the redistribution of the surface current and alters the antenna's fundamental characteristics in terms of frequency, radiation pattern and polarization. The implementation of such a reconfigurable antenna with switching elements is easy and has received lots of attention in research. Next, different methods along with some examples of electrically reconfigurable antennas to obtain the corresponding reconfigurability function with their own advantages and disadvantages using PIN diodes, varactors or MEMS switches are described.

### 2.4.2 PIN Diodes

A PIN diode is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. The wide intrinsic region makes the PIN diode an fast switch, photo detectors, and high voltage power electronics applications. PIN diodes are widely used as the switching components in different wireless systems.The PIN diode needs a high tuning speed, a high bias current in the ON-state and a high power-handling capacity. it is very reliable and extremely low-cost which makes it a good choice for the reconfiguration technique. The Pin Diode model is shown in Fig 2.1.

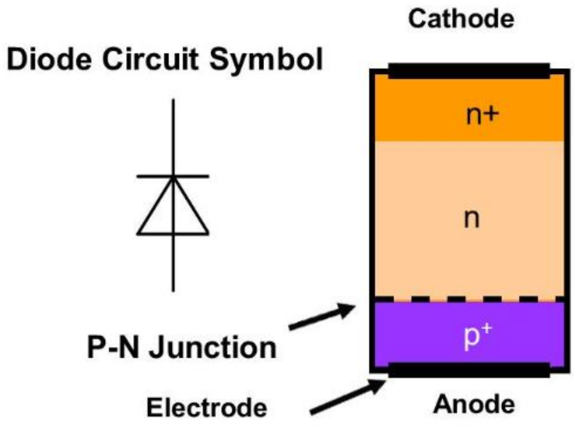


**Figure 2.1** PIN Diode

### 2.4.3 Varactor Diodes

Varactors are used as voltage-controlled capacitors. By changing the voltage levels of the varactor, its capacitance changes, which leads to tune the antenna performance. Usage of varactors in reconfigurable designs helps to achieve the frequency tuning function. The varactor is nonlinear with a low dynamic range. It also requires a complex bias circuitry. When compared with other active elements such as a PIN diode or MEMS, it has a small current flow and continuous tuning characteristics. Voltage-controlled oscillators have many applications such as Phase-locked loops are used for the frequency synthesizers that tune many radios, television sets, and cellular telephones. The Fig 2.2 shows the structure of the Varactor Diode.

The equation for capacitance is:

$$C = (\varepsilon_r\varepsilon_o)A/d$$

C is the capacitance in Farads
A is the area of each plate measured in square meters
Er is the relative permittivity of the insulator
Eo is the permittivity of free space
d is the separation between the plates in meters.

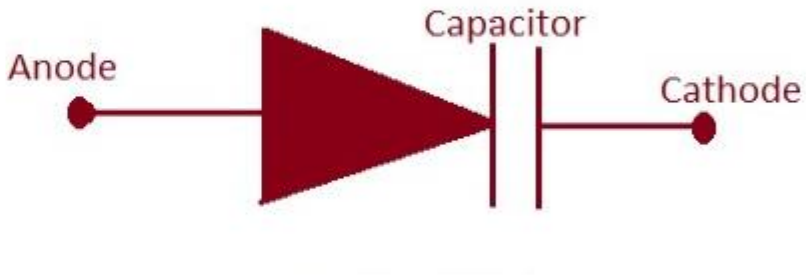


**Figure 2.2** Varactor Diode

### 2.4.4 MEMS

Reconfigurable antennas with MEMS switches are more interested for research. MEMS switches are devices which operate by the use of mechanical movement to achieve a short or open circuit in RF circuits. MEMS switches can be designed in different configurations based on signal path, the required force for mechanical movement can be obtained by different mechanisms for actuation such as electrostatic and magnetostatic.

RFMEMS switches that are able to handle up to 20 W. These have applications in radar system, network analyser, satellite communication systems and base stations. An RFMEMS shunt switch is a type of MEMS switch, It is a series switch, which consists of a suspended movable thin metal bridge over the centre conductor. MEMS switches for RF applications operate through short and open circuits to transmit signals. The Fig 2.3 represents the MEMS structure.

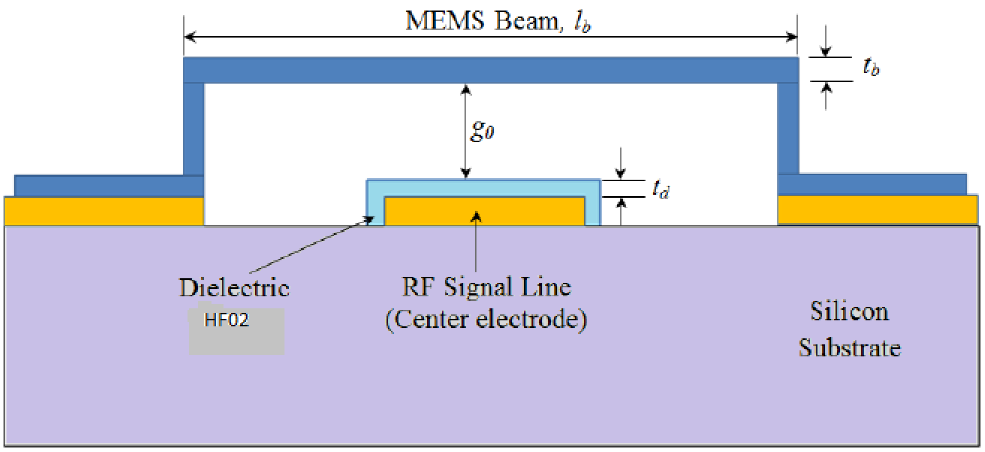


**Figure 2.3** MEMS

### 2.4.5 Optical Reconfiguration

This is based on the use of photoconductive switches, made of a semiconductor material In optical reconfiguration, the photoconductive switches need for metallic wires, and bias lines are used which provide less interference and high isolation compared to electrical switches. In addition, they exhibit extremely fast switching speeds, switching in nanoseconds. Using photoconductive switches allows one to optically control an antenna's operational bandwidths and radiation pattern. In an optically reconfigurable antenna is proposed for cognitive radio applications.

### 2.4.6 Mechanical Reconfiguration

In mechanical reconfiguration, the main radiator of the antenna can be reconfigured mechanically to provide different characteristics. In contrast to other reconfiguration techniques with the switches, this type of reconfigurable antenna does need active element integration, biasing systems. The performance flexibility of this type of antenna is limited, and it is difficult to provide multi-function reconfigurable characteristics. In a reconfigurable antenna is proposed that uses a liquid metal to mechanically reconfigure its performance. By changing the size of channel filling, the operation frequency and impedance bandwidth of the proposed mechanically reconfigurable antenna can be easily tuned for different frequencies. The performance flexibility of this type of antenna is limited, and it is difficult to provide multi-function reconfigurable characteristics. In a reconfigurable antenna is proposed that uses a liquid metal to mechanically reconfigure its performance.

### 2.4.7 Reconfigurable Antennas with Smart Materials

Reconfigurable antennas with smart materials are new area of research, In this type of reconfiguration technique, the characteristics of the antennas can be reconfigured by pumping fluid into a hollow placed behind the antenna to change the characteristics of the substrate in terms of relative electric permittivity or magnetic permeability. In a broadband polarization reconfigurable antenna is proposed. The antenna utilizes two water arms and is mounted above a large ground plane for unidirectional radiation. Two water channels are mounted above the ground plane to generate different polarizations. By controlling the water flow along the water channels, the polarization of the antenna can be switched between right-hand and left-hand circular polarizations. The antenna operation band covers a frequency range of 1.2-1.84 GHz.

## 2.5 Advantages

Reconfigurable antennas have several advantages when compared to multi-band/wideband antennas or multiple antennas. Some of them are

1. Ability to support more than one wireless standard

a) Minimizes cost

b) Minimizes space requirement

c) Allows easier integration.

d) Good isolation between different wireless standards.

2. Lower front-end complexity

a) No need for front-end filtering

b) Good out-of-band rejection

3. Multifunctional capabilities

a) Act as a single element or as an array

b) Provide narrow band or wideband operation

e) Provide narrow band or wideband operation

4. Best candidate for software defined radio

a) Capability to adapt and learn

b) Automated via a microcontroller or a field programmable gate array (FPGA).

## 2.6 Applications

The reconfigurable antennas are applicable in situations where the operating requirements of a communication system change over time. Major applications of the reconfigurable antenna are

### 1. Wireless equipment's:

In wireless equipment's where several communication systems will converge and integration of multiple antennas are used. Instead of using multiple single-function antennas, a single frequency reconfigurable antenna can accommodate the multiple requirements. This is a very attractive approach for actual wireless equipment which integrate multiple communication systems, as depicted in Fig 2.1, and would lead to significant size reductions, which is of utmost importance in portable and compact devices.

### 2. Cognitive Radio:

Frequency reconfigurable antennas play a key role is cognitive radio (CR). Cognitive radio transceivers sense the spectrum usage and the channel characteristics to dynamically select the operating frequency band according to specific performance metrics as illustrated in Fig. 2.2. Cognitive radio can benefit from frequency reconfigurable antennas because of the capability to tune the operating frequency over the required frequency range.

## 3. SAR level reduction:

Pattern reconfigurable antenna is used to reduce the specific absorption rate (SAR) in the personal wireless devices as shown in Fig 2.3. When the radiation from the wireless devices are travelling into the user's body, in that situation the pattern reconfigurable antenna changes its pattern to other direction rather than in the direction of the body and it reduce the power dissipation in the user's body.

## 4. Portable devices:

Due to the variable orientations in the portable devices, the polarization of the transmitter and the receiver are not in align which in turn degrades the performance of the device. In this situation, the polarization reconfigurable antenna is useful in order to improve the performance of the portable devices.

Some other interesting applications of reconfigurable antennas are

- In line of sight condition when mobile devices are moving To mitigate in-hand and out-band interference
- Adaptive MIMO systems
- Space applications

## 2.7 Design Equations and Procedure for designing the antenna

The three important parameters while designing the antenna are

1. Operating Frequency (f)

2. Dielectric Constant (ε)

3. Substrate Thickness (h)

By using above three parameters, the dimensions of an antenna can be determined by using the below equations

Width of the patch(W) is given by equation (1.5)

The Length of patch (L) is given by equation (1.3)

Where $L_{eff}$ is the effective length of the patch

$E_{eff}$ is the effective dielectric constant

The effective length of the patch ($L_{eff}$) is given by equation (1.4)

Where C is the velocity of light in free space

f is the resonant frequency for which case is to be design

The effective dielectric constant ($\varepsilon_{eff}$) is given by equation (1.1)

# Chapter-3

# HFSS

## 3.1 Introduction

HFSS (High Frequency Structure Simulator) uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra, and the entire collection of tetrahedron is called mesh A solution is found for the fields within the finite elements are interrelated so that Maxwell's equations are satisfied across inter-clement boundaries Yielding a field solution for the entire, original, structure. Once the field solution has been found, the generalized S-matrix solution is determined.

Ansys HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high frequency electronic products such as antennas, antenna arrays, RF or microwave components, high speed interconnects, filters, connectors, IC packages and printed circuit boards Engineers worldwide use Ansys HFSS to design high-frequency, high-speed electronics found in communications systems, radar systems, advanced driver assistance systems (ADAS), satellites, internet-of-things (IoT) products and other high-speed RF and digital devices.

HFSS (High Frequency Structure Simulator) employs versatile solvers and an intuitive GUI to give you unparalleled performance plus deep insight into all your 3D EM problems. Through integration with Ansys thermal, structural and fluid dynamics tools, HFSS provides a powerful and complete multi physics analysis of electronic products, ensuring their thermal and structural reliability. HFSS is synonymous with gold standard accuracy and reliability for tackling 3D EM challenges by virtue of its automatic adaptive meshing technique and sophisticated solvers, which can be accelerated through high performance computing (HPC) technology.

The Ansys HFSS simulation suite consists of a comprehensive set of solvers to address diverse electromagnetic problems ranging in detail and scale from passive IC components to extremely large scale EM analyses such as automotive radar scenes for ADAS systems. Its reliable automatic adaptive mesh refinement lets you focus on the design instead of spending time determining and creating the best mesh. This automation and guaranteed accuracy differentiate HFSS from I other EM simulators, which require manual user control and multiple solutions to ensure that the generated mesh is suitable and accurate. With Ansys HFSS, the physics defines the mesh rather than the mesh defining the physics Ansys HFSS is the premier EM tool for R&D and virtual design prototyping. It reduces design cycle time and boosts your product's reliability and performance. Beat the competition and capture your market with Ansys HFSS.

## 3.2 Requirements

- HFSS consume huge memory if fine result is needed.
- 300M+ Memory and 400M+ processor is recommended.

- Personal Laptop with 8GB RAM and 1.7G processor.

## 3.3 Features

- Computes s-parameters and full-wave fields for arbitrarily shaped 3D passive structures.
- Powerful drawing capabilities to simplify design entry.
- Field solving engine with accuracy-driven adaptive solutions.
- Powerful post-processor for unprecedented insight into electrical performance.
- Advanced materials.
- Model Library-including spiral inductors.
- Model half, quarter, or octet symmetry.
- Calculate far-field patterns.
- Wideband fast frequency sweep.
- Create parameterized cross section models- 2D models.

## 3.4 Simulation Workflow

The Fig 3.1 shows the design process in HFSS. There are 6 main steps to creating and solving a proper HFSS simulation. They are:

### 3.4.1 Creating model

The initial task in creating an HFSS model consists of the creation of the physical model that a user wishes to analyze. This model creation can be done within HFSS using the 3D modeler. The 3D modeler is fully parametric and will allow a user to create a structure that is variable with regard to geometric dimensions and material properties. A parametric structure, therefore, is very useful when final dimensions are not known or design is to be "tuned." Alternatively, a user can import 3D structures from mechanical drawing packages, such as Solid Works, Pro E or AutoCAD. However, imported structures do not retain any history of how they were created, so they will not be parameterizable upon import If parameterization of the structure is desired, a user will need to manually modify the imported geometry so that parameterization is possible.

When using HFSS, a user must initially specify what type of solution HFSS needs to calculate. There are three types of solutions available:

1. Driven Modal

2. Driven Terminal

3. Eigen mode

The difference between driven modal and driven terminal is that, simulations that use the driven modal solution type yield S-matrix solutions where as the driven terminal expressed in terms of the incident and reflected powers of waveguide modes. The eigen mode solver will provide results in terms of eigen modes or resonances of a given structure. This solver will provide the frequency of the resonances as well as the fields at a particular resonance.

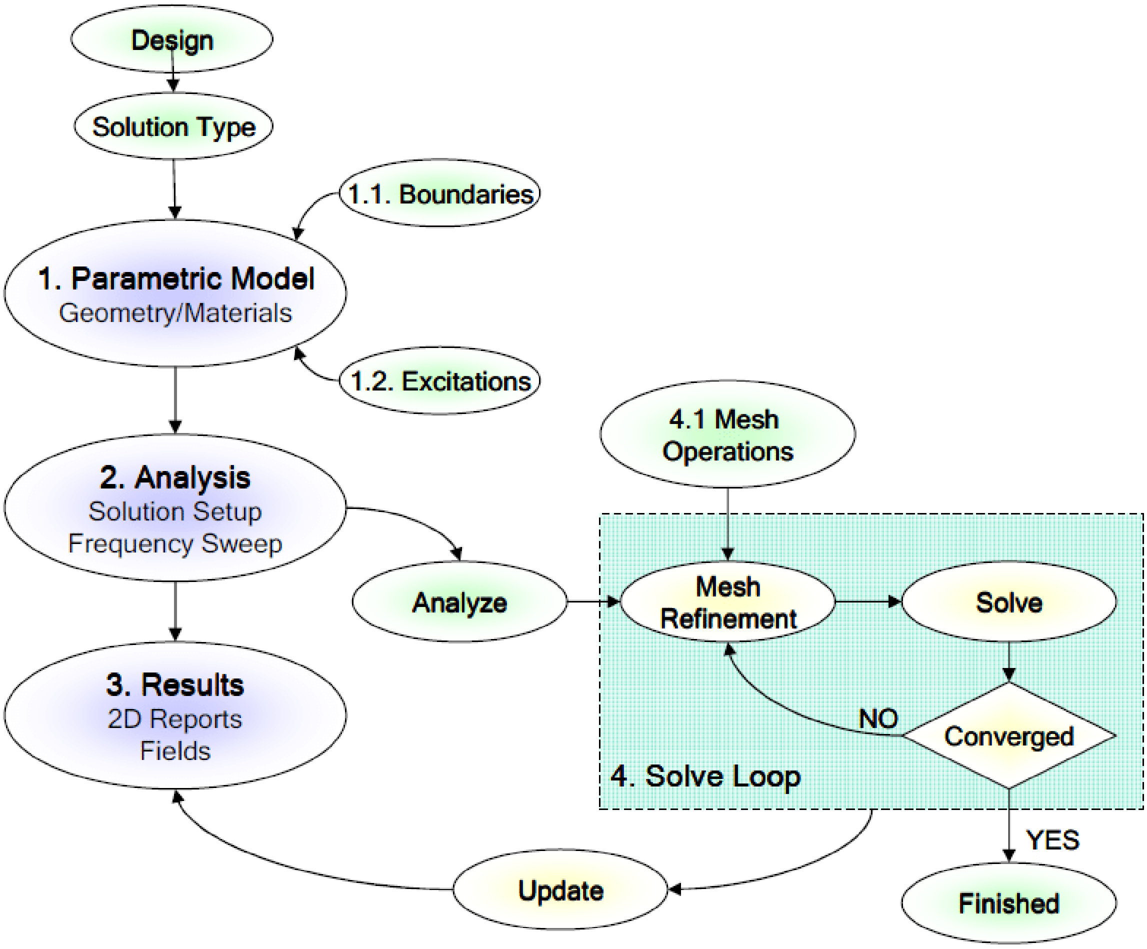


**Figure 3.1** Simulation Workflow of HFSS

### 3.4.2 Assign Boundaries

The assignment of "boundaries" generally is done next. Boundaries are applied to specifically created 2D (sheet) objects or specific surfaces of 3D objects. Boundaries have a direct impact on the solutions that HFSS therefore, users are encouraged to closely review the section on Boundaries in this document.

There are twelve boundaries available within HFSS. Boundaries are applied to specifically created 2D sheet surfaces of 3D objects. The twelve boundaries are:

1. Perfect Electric Conductor (PEC): default HFSS boundary fully encloses the solution space and creates closed model.

2. Radiation: used to create an open model

3. Perfectly Matched layer(PML): used to create an open model and preferred for antenna simulations.

4. Finite Conductivity: allows creation of single layer conductors.

5. Layered Impedance: allows creation of multilayer conductors thin dielectrics.

6. Impedance: allows creation of ohm per square material layers.

7. Lumped RLC: allows creation of ideal lumped components.

8. Symmetry used to enforce a symmetry boundary

9. Master: Used in conjunction with Slave Boundary to model infinitely large repeating array structure.

10. Slave: Used in conjunction with Master Boundary to model large infinitely repeating array structures.

11. Screening Impedance: allows creation of large screens or grids.

12. Perfect H: allows creation of a symmetry plane.

### 3.4.3 Assign Excitations:

After the boundaries have been the excitations (or ports) should be applied. As with boundaries, the excitations have a direct impact on the quality of the that HFSS will yield for a given model. Because of are again encouraged to closely review the section on excitations in this document. While the proper creation and use of excitations is important to obtaining the most accurate.

HFSS results, there are several convenient rules of thumb that a user can follow.

### 3.4.4 Set up the Solution:

Once boundness and excitations have been created, the neat step is to create a solution setup. During this step a user will select a solution frequency, the desired convergence criteria, the maximum number of adaptive steps to perform a frequency band over which solutions are desired, and the particular solution and frequency sweep methodology to use.

### 3.4.5 Solve:

When the initial four steps have been completed by an HFSS user,, the model is now ready to be analyzed. The time required for an analysis highly dependent upon the model geometry, the solution frequency, and available compute resources. A Solution can take from a few seconds to the time needed to get a coffee, to an overnight run. It is often beneficial to use the remote solve capability of HFSS to send a particular simulation run to another computer that is local to the user's site. This will free up the user's PC so it can be used to perform other work.

### 3.4.6 Post-process the results:

Once the solution has finished, a user can post-process the results Post processing of results can be as simple as examining the S-parameters of the device modelled or plotting the fields in and around the structure Users can also can the far fields created by an antenna. In essence, any field quantity or S.YZ parameter can be plotted in the post-processor. Additionally, if a parameterized model has been analyzed, families of curves can be created.

In this chapter, we have discussed the methodology and High Frequency Structure Simulator. HFSS is used to simulate the proposed antennas. The antenna designing steps with HFSS has been elaborated step by step.

## 3.5 Methodology

Symmetry techniques are always helpful to improve the output. Accurate symmetry exhibits better results. So, we have implemented symmetrical cutting while designing the antenna structures. Antenna may have the impedance loss because of improper impedance matching. and this can be overcome by using parameter sweep technique which is also helpful to find the position of the feed point for best impedance matching. While designing the antenna, the cutting either on the fractal shape, patch or ground plane should be done in the appropriate way that it should reduce the cost as well as enhance the bandwidth. Manufacturing cost will get less, as it depends on the material used. The antenna performance also depends on the height and dielectric constant of the substrate.

## 3.6 Simulation tool used

HFSS The Ansys/Ansoft HFSS (High Frequency Structure Simulator) Version 13 is used for designing and simulating the designed antenna. It is a standard simulation tool used for 3D full wave EM field simulation and is mainly for the high frequency design. It was introduced in the year 1990.

This tool is a combination of simulation, automation, visualization, and solid modelling. This software can be used to accurately solve the three-dimensional electromagnetic problems. This software offers art solver (multiple state) technologies i.e. it uses Finite Element Method (FEM), brilliant graphics and adaptive meshing to provide us superior performance and also provide proper understanding to the problems. User has option to select the solver as per their simulation requirement.

## 3.7 Designing steps of an Antenna

1. Create the substrate first.

2. Assign the dimensions to the substrate.

3. Assign the material to substrate.

4. Than create the Patch and assign the dimensions to the patch.

5. Assign the boundary to patch.

6. In the Next Step, create the Feed Line and assign dimensions to the feed line.

7. Than unite the feed line.

8. After this, create the Ground Plane.

9. Than Create the Excitation Port to provide the electromagnetic energy to the antenna.

10. After this, create the radiation box and assign the radiation boundary to the radiation box.

## 3.8 Steps for Simulating and Analysing the results of Antenna

1. To analyse the different parameters of designed antenna, the analysis setup is created first and desired solution frequency is assigned.

2. After assigning the solution frequency, the next step is to add the frequency sweep which is used to generate the solution frequency across the frequency ranges.

3. Than far field radiation setup is used to analyse the gain and radiation pattern of designed antenna.

4. After this, antenna is validated, analysed band report is created

## 3.9Applications

- Antennas
    - Microwave transiting Waveguide components
    - RF filters
    - Three-dimensional discontinuities
    - Passive circuit elements

- After the simulation, the layout design is generated by using the AutoCAD software. This software is used to create the mask, and this mask is printed on the transparent sheet. Than photolithography process is used to fabricate the desired antenna. Once the antenna is fabricated, it can be tested on the VNA to measure the antenna parameters like reflection coefficient, VSWR, etc.

# Chapter-4

# Reconfigurable Antenna Design

## 4.1 Introduction

As wireless communication technology advances, the demand for numerous wireless services in a single device has grown, dramatically and Traditional antennas are no longer capable of meeting this new wireless communication system's needs. To meet the demands, an antenna that can change its direction features depending on the needs is being built. One such antenna is a reconfigurable antenna. Antennas with reconfigurable behaviour can modify their behaviour according to their needs. Frequency reconfigurable antennas enable frequency tuning and efficient spectrum utilization across specified frequency bands.

As an intelligent system, cognitive radio (CR) technology can dynamically allow a given spectrum to be used by secondary users based on the functioning of the primary users. The goal of this research is to construct a reconfigurable antenna by researching the design of an octagonal-shaped patch antenna, which hasn't been properly examined in the past for the development of CR antennas.

An octagonal printed patch architecture is combined with a non-traditional coplanar waveguide (CPW) feed. This geometry, which has been modified from the typical rectangular coplanar ground plane design, Sleeve-like structures, which are symmetrical in printed antennas, incorporate two symmetrical horizontal T-shaped sleeve-like structures. Sleeve-like shapes can boost impedance bandwidth. By acting as an extra parasitic element that creates resonance, the sleeve can be utilized to make ultra-wideband (UWB) antennas. A frequency-configurable ultra-wide band antenna based on a FR4 substrate is demonstrated in this paper.

The proposed antenna can be tweaked to emit on multiple bands while preserving a small footprint and high gain by using pin-diode switches. The proposed antenna employs two-pin diode switches. The following is a breakdown of the paper's structure: The suggested switchable multiband antenna's design method and geometry are explained in each Section and describe the simulated analysis and observed consequences, bringing this investigation to a close.

## 4.2 Antenna Design

The proposed multi-band frequency reconfigurable antenna's basic geometry and design theory are presented in this section. In the simulation, the suggested antenna's frequency and pattern are re-configured by utilizing lumped RLC components, i.e., the PIN diode is incorporated into the fabrication. By utilizing the ON/OFF condition of the diodes, the proposed antenna can be operated at various frequencies.

## 4.2 Defective Ground Structure

The compact geometrical slots embedded on the ground plane of microwave circuits are referred to as Defected Ground Structure (DGS). A single defect (unit cell) or a number periodic and aperiodic defects configurations may be comprised in DGS. Thus, periodic or aperiodic defects etched on the ground plane of planar microwave circuits are referred to as DGS. Earlier Photonic Band Gap (PBG) and Electromagnetic Band Gap (EBG) have been reported with irregular ground planes. The comparison between PBG, EBG, and DGS is depicted.

### 4.2.1 Working principle

DGS has been integrated on the ground plane with planar transmission line, that is, micro-strip line, coplanar waveguide, and conductor backed coplanar wave guide. The defects on the ground plane disturb the current distribution of the ground plane; this disturbance changes the characteristics of a transmission line (or any structure) by including some parameters (slot resistance, slot capacitance, and slot inductance) to the line parameters (line resistance, line capacitance, and line inductance). In other words, any defect etched in the ground plane under the microstrip line changes the effective capacitance and inductance of microstrip line by adding slot resistance, capacitance, and inductance.

## 4.3 Design of an Antenna

## Procedure

Step 1: Launch the Ansoft HFSS.

Step 2: In an Ansoft HFSS window, from the menu item click file → New.

Step 3: From the Project menu, select Insert HFSS Design.

Step 4: Create a ground plane using rectangle

Step 5: Create dielectric box with same dimensions of ground and Z as 1.6mm and make material as FR4-epoxy.

Step 6: Create an octagonal patch with side length “s” and a step structure is implemented to the ground structure

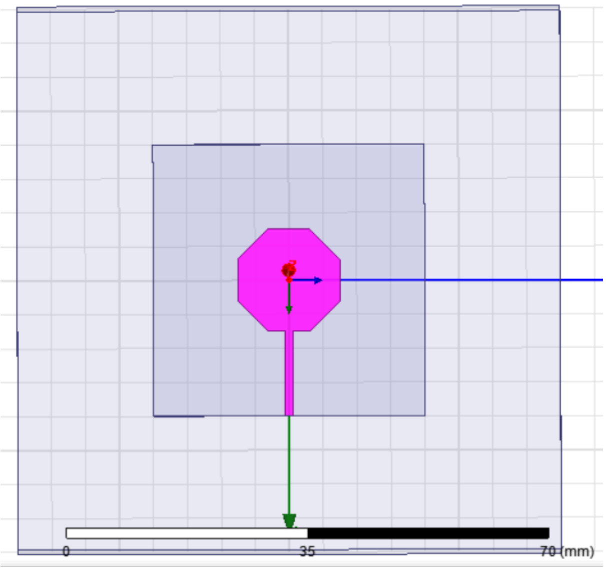


**Fig 4.3.1** Patch in HFSS window

Step 7: And a step structure is implemented to the ground structure and a T-pattern is added to the left and right halves of the ground and make the ground as Defective Ground Structure (DGS).

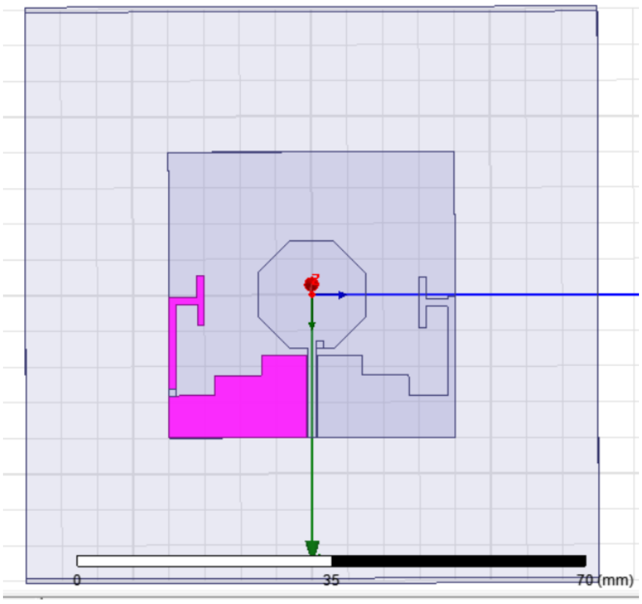


**Fig 4.3.2** step structure & T pattern is implemented to the ground structure in HFSS window

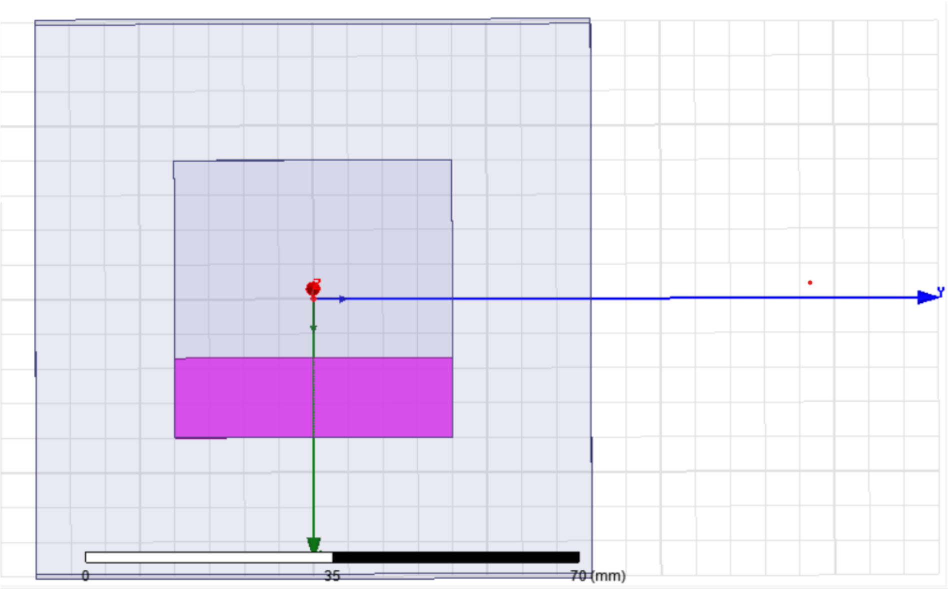


**Fig 4.3.3** Defective Ground Structure in HFSS window

Step 8: Create strip line of given dimensions and give excitation as perfect E.

Step 9: Now create a feed along ZY plane of dimensions and apply feed i.e., lumped port.

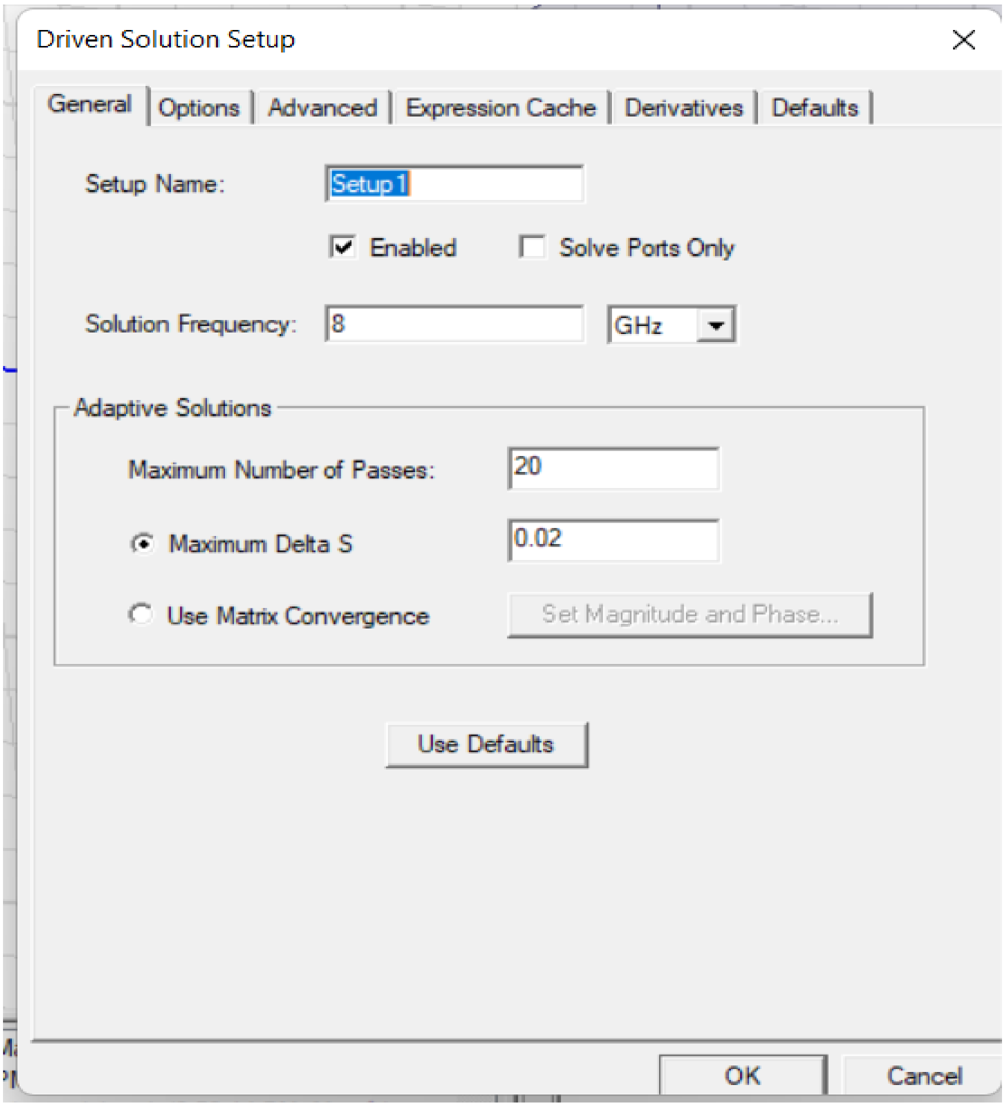
Verify whether line is defined or not.

Step 10: Now create a radiation box such that antenna is exactly at its middle and excite

Box with radiation.

Step11: Now go to analysis setup-add operating frequency and number of passes

Step 12: Now add frequency sweep i.e., fast and linear count



Setup Name: Setup1

☑ Enabled ☐ Solve Ports Only

Solution Frequency: 8 GHz

Adaptive Solutions

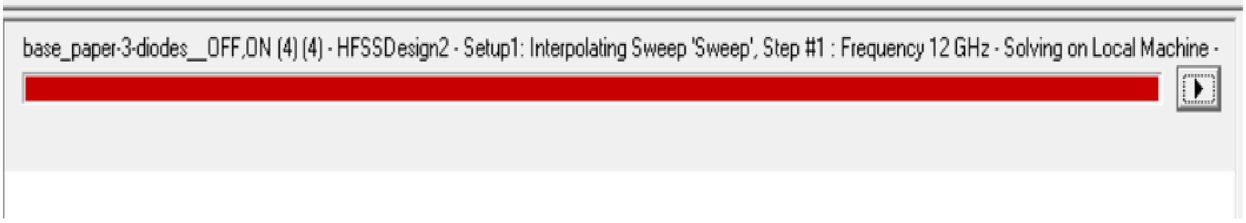
Maximum Number of Passes: 20

● Maximum Delta S 0.02

○ Use Matrix Convergence

**Fig 4.3.4** Solution setup

Step 13: Go for validate check, if all are correct then click on analyze all



base_paper-3-diodes__OFF,ON (4) (4) - HFSSDesign2 - Setup1: Interpolating Sweep 'Sweep', Step #1 : Frequency 12 GHz - Solving on Local Machine -

**Fig 4.3.5** Analysis setup

Step 14: For results go to HFSS -> create model solution-> rectangular plot -> new plot for reflection coefficient and VSWR.

Step 15: For gain plot first go to HFSS -> radiation far field -> rectangular plot -> Gain and adjust Start and stop values of phi and theta as-180 degrees to 180 degrees and 0 to 360 degrees respectively. Step size as 10 for both phi and theta

Step 16: Observe the output graphs, verify the frequency and corresponding Results.

## 4.4 The PIN Diode and it’s biasing circuit

The proposed antenna's frequency reconfigurability is achieved by changing the ON and OFF modes of each PIN diode. Because they act like a variable resistor in the radio frequency (RF) band, two-pin diodes (BAP 75-02) are utilised for switching. At their respective insertion sites, these pin diodes provide open and short circuit behaviour, altering the antenna's effective resonant length and, as a result, reconfiguring the antenna's operational frequency. The relevant circuits for both the OFF and ON states of a pin diode switch are shown in Figures 4-a and 4-b. In Figures 4-a and 4-b, you can see how For the ON state, it's just an RL series circuit with a low-value resistor "Rs" and an inductor "Ls." It is like an RLC circuit since it has an inductor "Ls" in parallel with a high-value resistor "Rp" and a capacitor "Cp" in the OFF state. There are three operational modes on the antenna in issue, each with its unique set of resonance frequencies. The antenna operates at 8.4 and 10.5GHz in Mode 1 (SW1 to SW2 = ON). The proposed antenna resonates at 7.1 GHz in Mode 2 (SW1 = ON, SW2 = OFF). When in Mode 3 (SW1 = OFF, SW2 = ON), the antenna covers two different bands of 5.7, 6.8, 7.5, 10.6, and 11.1 GHz.

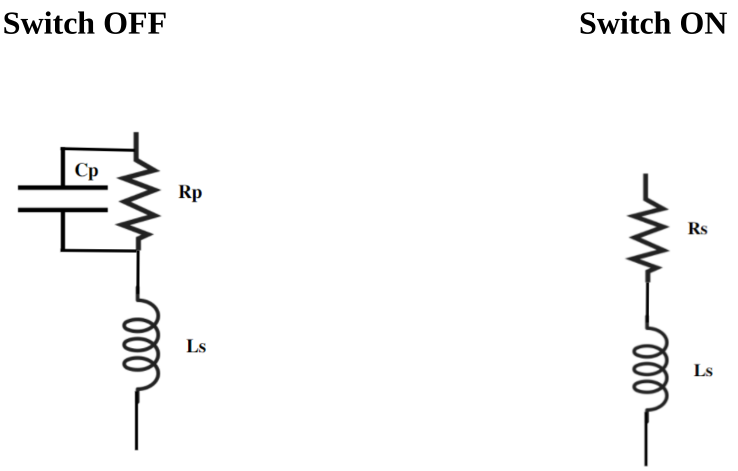


**Figure 4.4.1** (a) Equivalent circuit of PIN diode when OFF state

(b) Equivalent circuit of PIN diode when ON state

## 4.5 Design parameters of antenna

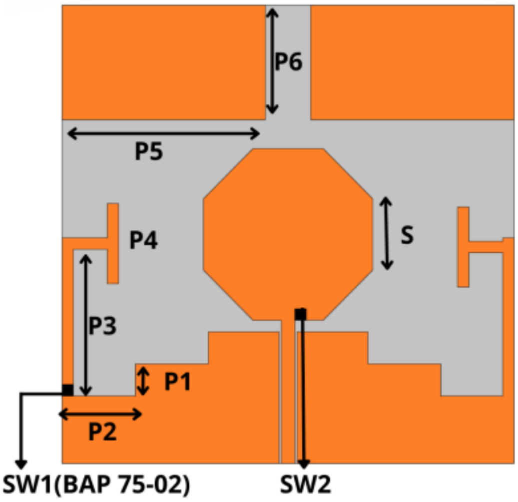


**Fig 4.5.1** The Proposed antenna- Top view (orange colour-copper, black colour- pin diodes, grey color-substrate)

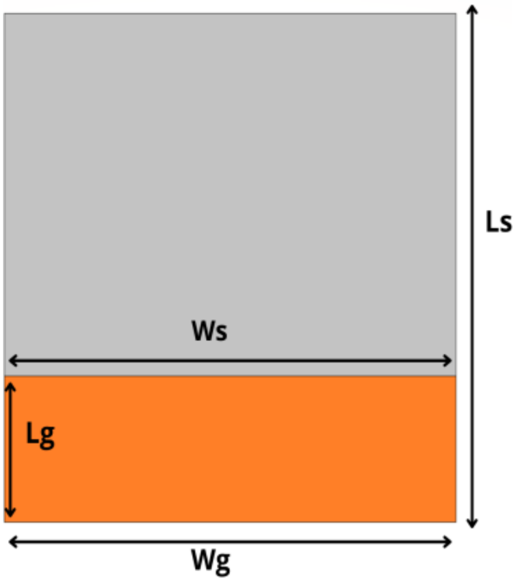


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**Fig 4.5.2** The Proposed antenna- bottom view (orange colour– copper) DGS

**Table 4.1** Optimized the proposed antenna's parameters

| **Element** | **Parameter** | **Values(mm)** |
|---|---|---|
| Substrate | Ws | 40 |
| | Ls | 40 |
| | h | 1.6 |
| Patch | S | 6.2 |
| Ground | Lg | 11.5 |
| | Wg | 40 |
| | P1 | 5 |
| | P2 | 8 |
| | P3 | 13.8 |
| | P4 | 7×1 |
| | P5 | 18 |
| | P6 | 10 |
| Feed | F | 1.2 |

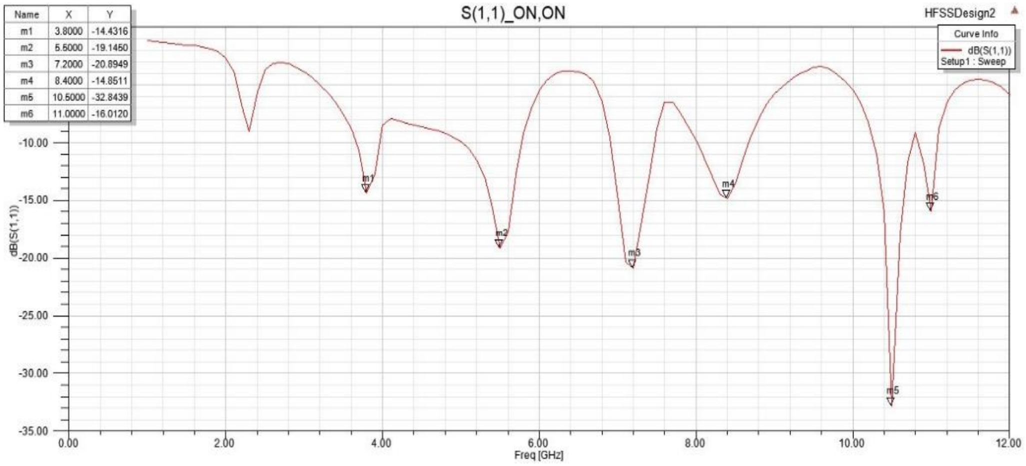
# Chapter-5

# Simulation and Results

**Table 4.2** PIN diode conditions for various resonant bands.

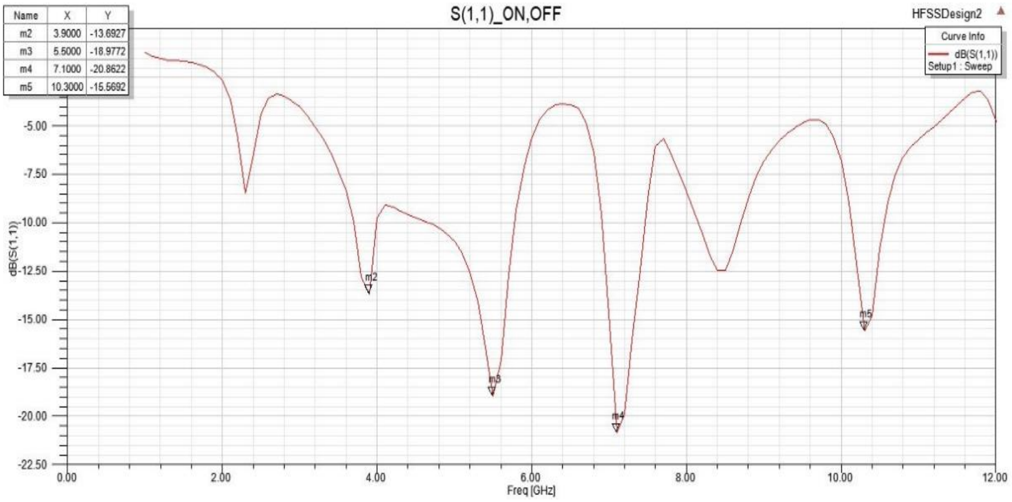
| **Modes** | **Operating frequency (GHz)** | **The frequency at S11minima corresponds to the gain.** |
|---|---|---|
| 1.SW1 and SW2 ON | 8-11.5 | a) 3.4dB at 8.4GHz<br>b) 6.2dB at 10.5GHz |
| 2.SW1 ON SW2 OFF | 3.9-7.5 | 1.4dB at 7.1GHz |
| 3.SW1 OFF SW2 ON | 3.8-7.5<br>8.1-11.5 | a) 0.6 dB at 5.7GHz<br>b) 4.8 dB at 6.8GHz<br>c) 7.8 dB at 7.5GHz<br>d) 4.7 dB at 10.6GHz<br>e) 3.4 dB at 11.1GHz |

The S11 features for each situation are depicted in Figure 5. In each sample, the gain characteristics for the frequencies corresponding to the S11 minima were examined and listed in Table 2. For instance, I have both SW1 and SW2 switched on. Two frequency bands, running from 8.4 to 10.5 GHz, can be shown in Figure 5-a. In mode 2, SW1 is turned on and SW2 is turned off, as shown in Figure 5-b. The frequency band is 7.1 GHz. All of the switches are in conducting mode in the last situation, which is mode 3. (SW1 OFF, SW2 ON). This results in a frequency spectrum spanning 3.90 to 13.07 GHz. In the inset view of Figure 5, the operating frequency in each of the three circumstances is presented. It can be noted that it utilizes both the C and X bands (4-8 GHz) and (8-12 GHz).



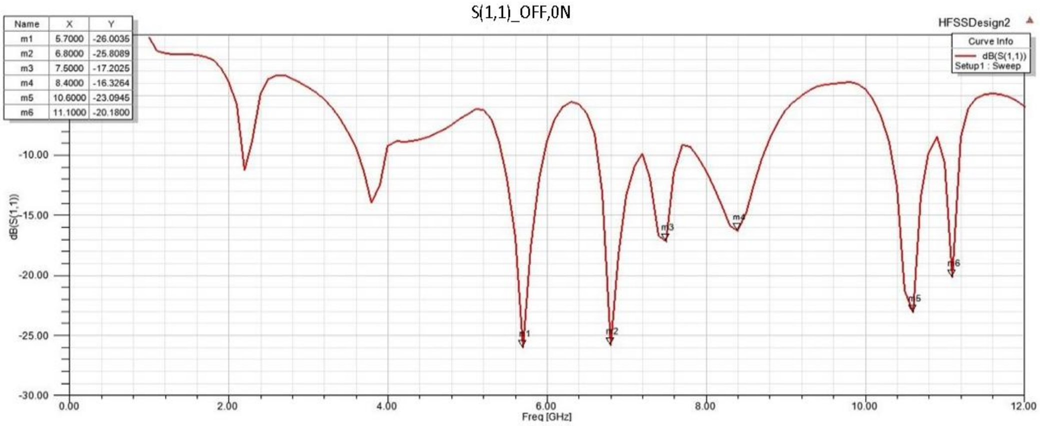
| Name | X | Y |
|---|---|---|
| m1 | 3.8000 | -14.4316 |
| m2 | 5.5000 | -19.1450 |
| m3 | 7.2000 | -20.8949 |
| m4 | 8.4000 | -14.8511 |
| m5 | 10.5000 | -32.8439 |
| m6 | 11.0000 | -16.0120 |

**Figure 5.1** Simulated S11 characteristics curve of a pin diode in 1st Mode (SW1 and SW2 are both turned on).



| Name | X | Y |
|---|---|---|
| m2 | 3.9000 | -13.6927 |
| m3 | 5.5000 | -18.9772 |
| m4 | 7.1000 | -20.8622 |
| m5 | 10.3000 | -15.5692 |

**Figure 5.2** Simulated S11 characteristics curve of pin diode in 2nd Mode (SW1 ON, SW2 OFF)



| Name | X | Y |
|---|---|---|
| m1 | 5.7000 | -26.0035 |
| m2 | 6.8000 | -25.8089 |
| m3 | 7.5000 | -17.2025 |
| m4 | 8.4000 | -16.3264 |
| m5 | 10.6000 | -23.0945 |
| m6 | 11.1000 | -20.1800 |

**Fig 5.3** Simulated S11 characteristics curve of pin diode in 2nd Mode (SW1 OFF, SW2 ON)

For all resonant bands, There is a Voltage Standing Waves Ratio (VSWR) of less than 2, indicating that an antenna and the feed line connecting to it are matched. Figure 6 shows the VSWR for all operating frequency bands.

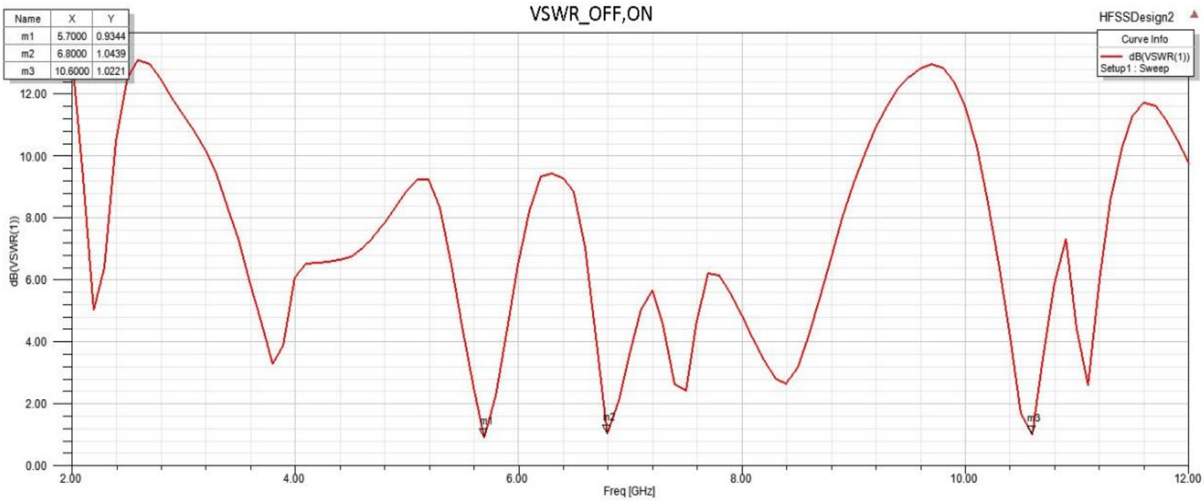


**Fig 5.4** The Voltage Standing Waves Ratio of the proposed antenna is (VSWR) in Mode 3

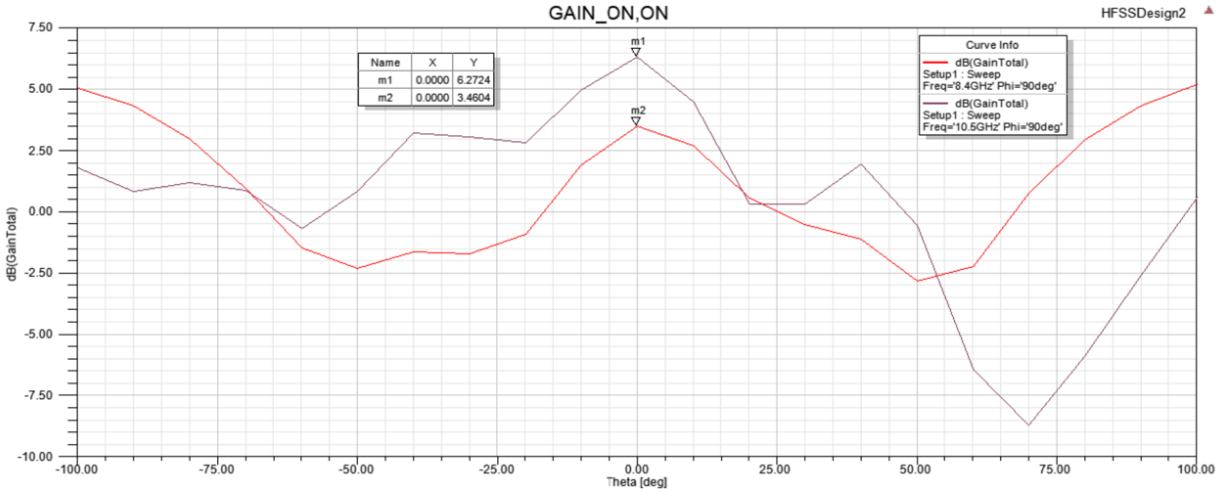


**Fig 5.5** The Mode 1 Proposed Antenna's Simulated Gain Plot at (A) 8.4 GHz and (B) 10.5 GHz

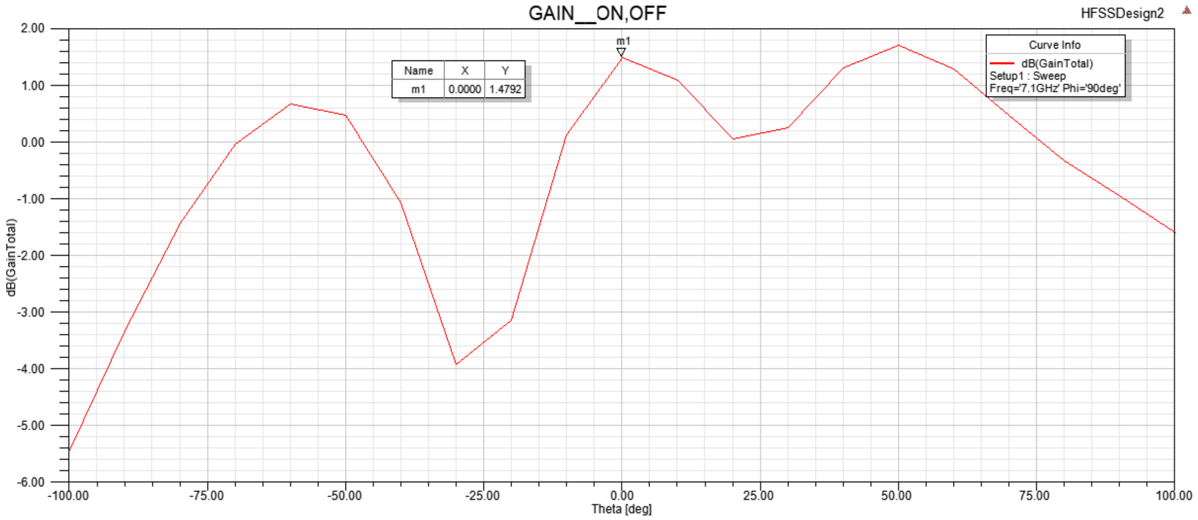


**Figure 5.6** The Mode 2 Proposed Antenna's Simulated Gain Plot at 7.1GHz

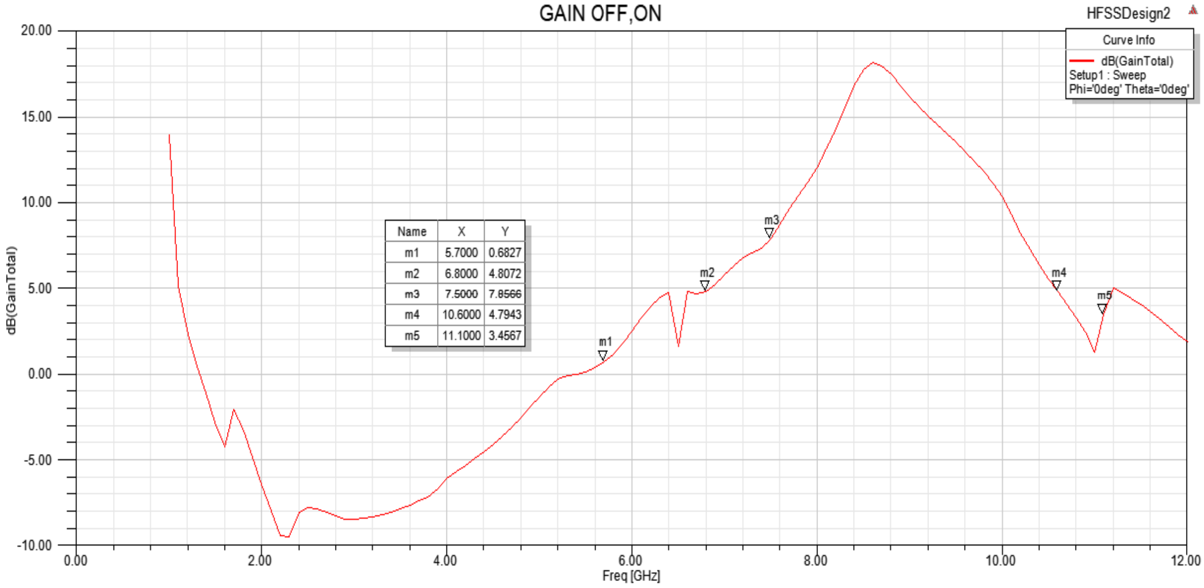
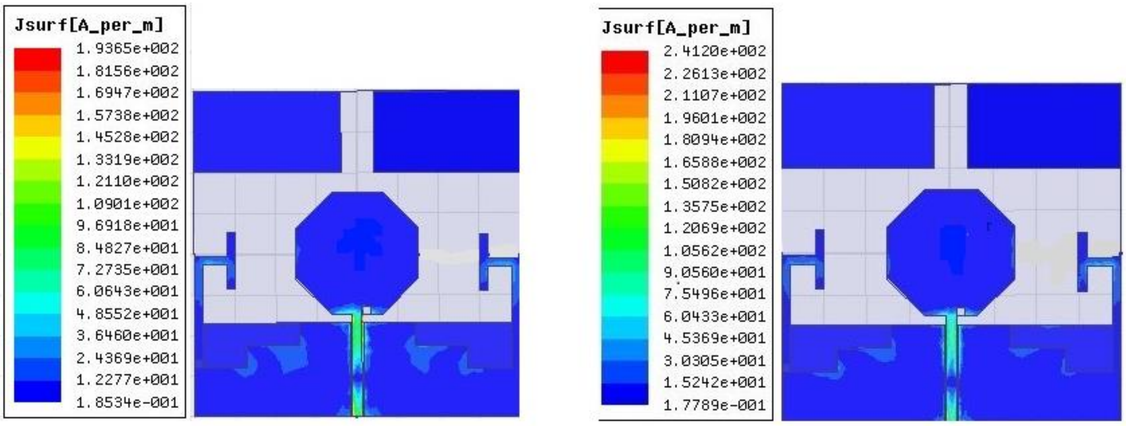


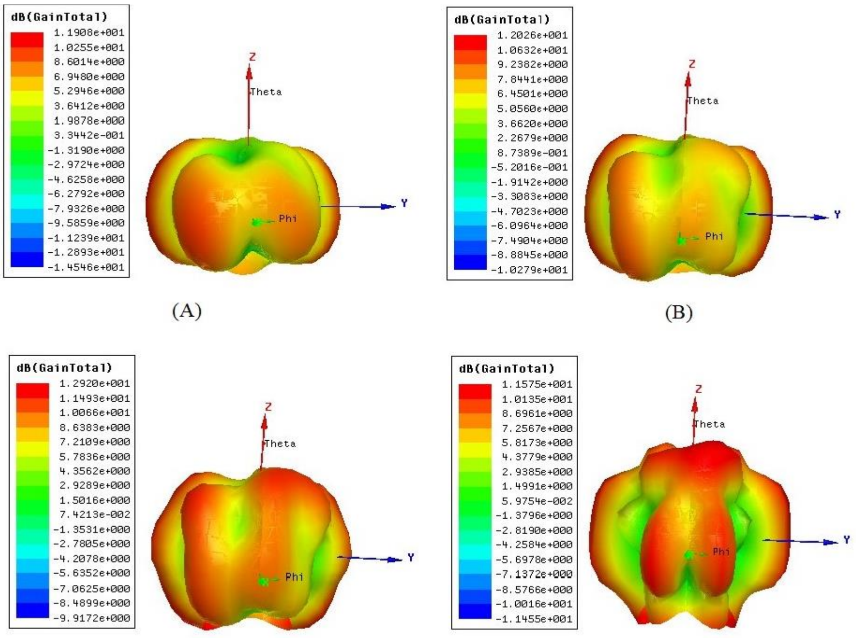
**Figure 5.7** The Mode 3 Proposed Antenna's Simulated Gain Plot at ( (A) 5.7 GHz, (B) 6.8 GHz, (C)7.5 GHz, (D)10.6 GHz, and (E) 11.1 GHz

For all scenarios, the predicted surface current distribution has been investigated at various frequencies, with some results shown in Figure 5.8. Higher-order current modes are activated at higher frequencies, causing the surface current density on the radiator to become unevenly distributed. It means that changing the switching conditions can affect the surface current distribution, causing a tuning or notch in the antenna's reflection coefficient, and that the radiating structure can vary its operational frequency by hopping between different frequency bands.



(A) (B)

**Figure 5.8** The proposed model's surface current distribution at: (A)Mode1 (SW1, SW2 is ON) (B)Mode 3(SW1 OFF, SW2 ON).



(A) (B) (C) (D)

**Figure 5.9** The Mode 3 Proposed Antenna's Simulated 3D Polar Gain Plot at (A) 5.7 GHz, (B) 6.8 GHz, (C)7.5 GHz, and (D)10.6 GHz

# Conclusion

The suggested antenna is a single-port reconfigurable antenna with a bandwidth of 3.8 to 11.1 GHz that is appropriate for Cognitive Radio applications. Its re-configuration is determined by the switching conditions of the diode. BAP 75-02 PIN diodes are employed between the frequency bands to achieve the reconfigurability. The switches are arranged so that the narrow band communication antenna covers nearly the whole broadband spectrum. In this proposed antenna, three switching scenarios are investigated, and it is discovered that the diverse switching conditions cover practically the full band (Table 2). The proposed antenna performance can be further improved by using Defected Ground Structure (DGS). Furthermore, the suggested antenna can be used as a narrowband communication antenna in the Ultra-wideband with operating frequencies of 3.8–7.5GHz and 8.1–11.5GHz. As a result, this antenna can be utilized for Cognitive Radio in both the C-band and the X-band.

# References

[1] Constantine A. Balanis, United States of America, "Antenna Theory Analysis and Design", Vol. TK7871.6.B354 2016.

[2] Ramesh Grag, Boston, London, "Microstrip Antenna Design Handbook".Vol. TK7871.6.M515 2000.

[3] Goswami A, Bhattacharya A, Dasgupta B. " Reconfigurable hexagon shaped printed antenna for cognitive radio application," International Journal RF and Microwave Computer-Aided Engineering. Vol.10.1002/mmce.22514, 2020.

[4] Tawk Y, Constantine J, Christodoulou C. Antenna Design for Cognitive Radio. Norwood: Artech House; 2016.

[5] Majid, H. A., M. K. A. Rahim, M. R. Hamid, and M. F. Ismail, “Frequency and pattern reconfigurable slot antenna,” IEEE Trans. Antennas Propag., Vol. 62, 5339–5343, 2014.

[6] Tawk Y, Christodoulou CG. A new reconfigurable antenna design for cognitive radio. IEEE Antennas Wirel Propag Lett. 2009;8:1378-1381.

[7] Khraisat YSH, Al-Tawalbeh N, Abdel-Hafez IA, et al. A hybrid reconfiguration antenna design for cognitive radio system combination of sensing and reconfigurable antennas. J Electromag Anal Appl. 2013;5:328-332.

[8] Al-Husseini, M., Tawk, Y., Christodolou, C.G., et al. A reconfigurable cognitive radio antenna design. Paper presented at: IEEE Antennas and Propagation Society International Symposium, Toronto, Canada. 2010, 1–4.

[9] Abdulhameed AA, Alnahwi FM, Swadi HL, et al. A compact cognitive radio UWB/reconfigurable antenna system with controllable communicating antenna bandwidth. Aus J Elect Electron Eng. 2019;16:1-11.

[10] Bharadwaj, S.S.; Sipal, D.; Yadav, D.; Koul, S.K. A Compact Tri-Band Frequency Reconfigurable Antenna for LTE/Wi-Fi/ITS Application. Prog. Electromagn. Res. 2020, 91, 59–67. [CrossRef]