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STUDY AND DESIGN OF A RECONFIGURABLE
ANTENNA USING DEFECTIVE GROUND
STRUCTURE FOR MOBILE COMMUNICATION

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Dedication

Greetings of love and gratitude and thanks to

our families

to our friends

*to everyone who contributed to
this work*

we say thank you

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Introduction

Introduction

The world of wireless communication has changed rapidly in recent years, reaching around 6 billion users in 2011, which is corresponding to 87% of the world's population, necessitating the development of new systems to keep pace with the rapid increase in users [1]. The use of different antennas for each wireless system in one device is no longer available due to space limitations in portable devices

New emerging applications in wireless communication require a developed antenna able to respond the needs of these applications. Among the solutions that have kept pace with the development in recent years is the reconfigurable antenna. A reconfigurable antenna is an antenna in which at least one of its characteristics is subject to be adjusted after manufacture (bandwidth, frequency, Radiation pattern, and polarization).

This reconfigurability will be done through an external application, which is the addition of an active electrical components (MEMS, Varactors, PIN diode), or optical components such as optical conductors. In some cases, reconfiguration is possible by modifying the shape of the antenna (adding slots at the ground plane) or changing the feeding location.

The radio spectrum is finite, but wireless communication is increasing exponentially. Therefore, there is a need for new technologies. Ultra-wide-band (UWB) could be a possible solution to this problem. UWB technology has a number of advantages those are the reasons why it presents a more efficient solution to wireless broadband than other technologies. (high capacity: hundreds of Mbps or even several Gbps with distances of 1 to 10 meters [2], robustness against noise).

The number of electronic devices in UWB technology is constantly increasing and the interference between these devices is increasing as well resulting mitigation of performance. A simple method to solve this mentioned problem is designing an UWB antenna with notched band characteristics to overcome the interference signals. Till now, many works have been reported to apply different methods in order to achieve band-notched characteristics. Etching slots on the UWB patch antenna are among the earliest methods widely discussed so far.

In our study, the frequency reconfigurable antenna will be designed to achieve a switching between three reconfiguration cases (only 2.4GHz band, full UWB, and UWB antenna for on-demand WLAN rejection). To design the antenna, a parametric study and optimization process will be done using CST simulator.

In the first chapter, we will provide an overview about the reconfigurable antenna with mention of the reconfigurable mechanisms and their classifications, and then we will finish this chapter with some advantages and disadvantages of the reconfigurable antenna.

Second chapter provides an overview about different tuning techniques for antennas reconfiguration using switching devices such as Varactors or PIN diodes.

In the third chapter, we developed an UWB antenna from a simple rectangular patch using parametric study and optimization process using the CST simulator. During the chapter, the effect of some parameters on the characteristics of the antenna will be illustrated.

In the last chapter, based on the designed antenna in the third chapter, we develop a reconfigurable notched-band UWB Antenna using six PIN diodes placed in specific places at the ground plane.

Finally, this document will be finished with a some concluding points and perspectives for future works

Chapter I:
An overview about
reconfigurable antenna

I.1 Background

The past decade has witnessed a revolution in the field of telecommunications systems dating back to 1900, which revealed the first wireless transmissions by Tesla and Marconi. Since then, communication systems have evolved very quickly resulting in a very large increase in data consumption. This development makes the need to use good technologies that enable us to improve the performance of information exchange and increase coverage, capacity, and improving the quality of service.

In last decades, wireless communications were limited to a single frequency antenna, a specific frequency bandwidth, and a fixed radiation pattern without the ability to change these characteristics, forcing companies to use unconventional printed antennas that would enable you to change the antenna characteristics after their design. These antennas are called reconfigurable antennas.

A reconfigurable antenna is an antenna in which at least one of the characteristics is subject to reset after manufacture (bandwidth, frequency, radiation pattern, and polarization).

This modification is done through an external application, which is the addition of active electrical components (MEMS, Varactors, PIN diode), or optical component such as optical conductors. In some cases, the reconfigurability can be done by modifying antenna shape (adding holes in the ground) Or change the feeding location ...)

In this chapter, we will give an overview of the reconfigurable antennas and the reconfiguration techniques that are reconfigured by frequency, radiation or polarization, and then finish the separation with the advantages and disadvantages of these antennas. The reconfigurable antennas can be classified into four categories: frequency reconfiguration, radiation, polarization, or a combination of two or more. In our study, the reconfigurable antenna will be designed to achieve a switch between frequencies for WLAN applications (2.4GHz and 5.8GHz) using CST simulator.

I.2 Reconfigurable antennas

I.2.1 Introduction

The great development of wireless systems requires antennas that provide more functionality than traditional designs. These antennas are known by reconfigurable antennas. The importance of these antennas lies on how make the antenna characteristics more flexible. The advantage of these antennas is to make communication systems more flexible and faster in different applications such as terrestrial and space communications, radar, and electronic warfare.

In this chapter, we will see some definitions of reconfigurable antennas, reconfigurability methods, and then some of their advantages and disadvantages.

1.2.2 Reconfigurable antennas

In recent years, the world noticed an evolution in technology, especially in wireless communications, when the data consumption has increased dramatically and this has been a reason for reducing frequency resources. Therefore, it was necessary to think about solutions that improve the speed and efficiency of data transmission. Among these solutions, one can suggest the reconfigurable antenna.

The first frequency reconfiguration was patented by A.N. Goldsmith in 1926, where an antenna was tuned using a variable inductive [3]. The second one was patented by E. Werndl in 1942, when the height of a dipole antenna is adjusted using liquid metal [4]. After the second world War, the scanning antennas played an important role in radar applications [5]. In 1959, the first antenna was designed by W. Rotman that produce a clear interaction with the radio wave radiation mechanism with a mechanical leak setting that allowed the antenna to perform a beam scan [6].

The reconfigurable antenna is an antenna which is able to adjust dynamically frequency, radiation, and/or polarization properties or even a combination of these features in a controlled manner [7]. In order to provide a dynamic response for the environment need, reconfigurable antennas include an internal mechanism (such as radio frequency switches, shapes, mechanical

motors or adjustable materials) allow an intentional redistribution of the currents on the surface of the antenna and produces a reversal modification to its characteristics.

The reconfigurable antennas differ from smart antennas because the reshaping mechanism is located inside the antenna, and not in an external beam formation network. The reshaping ability is used to maximize the antenna performance to respond to the changing requirements of the environment. Reshaped antennas have more advantages, for example, energy saving, eliminate the need of multiple antennas, which helps for reducing the interference among them.

The reconfigurable antennas have become more used and better due to their simplicity, lightness, and quality of performance. Therefore, it can be found in all electronic devices and small devices such as mobile phones, computers and others. The importance of these antennas lies, in light of this rapid development of communications, on the ability to break the limitations of traditional antennas that were unable to operate on different frequencies and gave flexibility and preference to the user.

Instead of placing more than one antenna in a small device such as a mobile phone, a single antenna can change its operating frequency, for example, to change the operating range itself and steer the main lobe towards the best direction for increasing system capacity.

The main goal of our work is the designing of an ultra-wide band antenna with frequency reconfigurable characteristics as in most works in the literature which presente reconfigurability in one parameter: frequency, pattern, or polarization.

I.2.3 Ultra-Wide Band Technology

Ultra-Wide band is a wireless technology intended for digital data transmission over short distances at low power density. The name reflects that the technology occupies a large bandwidth of the radio frequency spectrum. In unlicensed applications, the UWB uses short-duration pulses over a spectrum of frequencies between 3.1 GHz to 10.6 GHz. UWB technology provides a speed of very high transmission with minimal interference, it can achieve capacity as high as hundreds of Mbps or even several Gbps with distances of 1 to 10 meters.

Advantages of UWB

This technology presents many advantages in comparison to the other technologies. Among these advantages one can cite

- It has a low power spectral density which allows the coexistence of the UWB signal and the others existing services (the ULB band covers other radio systems).
- In addition, the signals ULB are more difficult to detect (low density) than other signals of conventional radio communications because they use a large bandwidth and can be noise-like signals, which improves the safety of this technology.
- Its robustness in noisy environment [6-8].

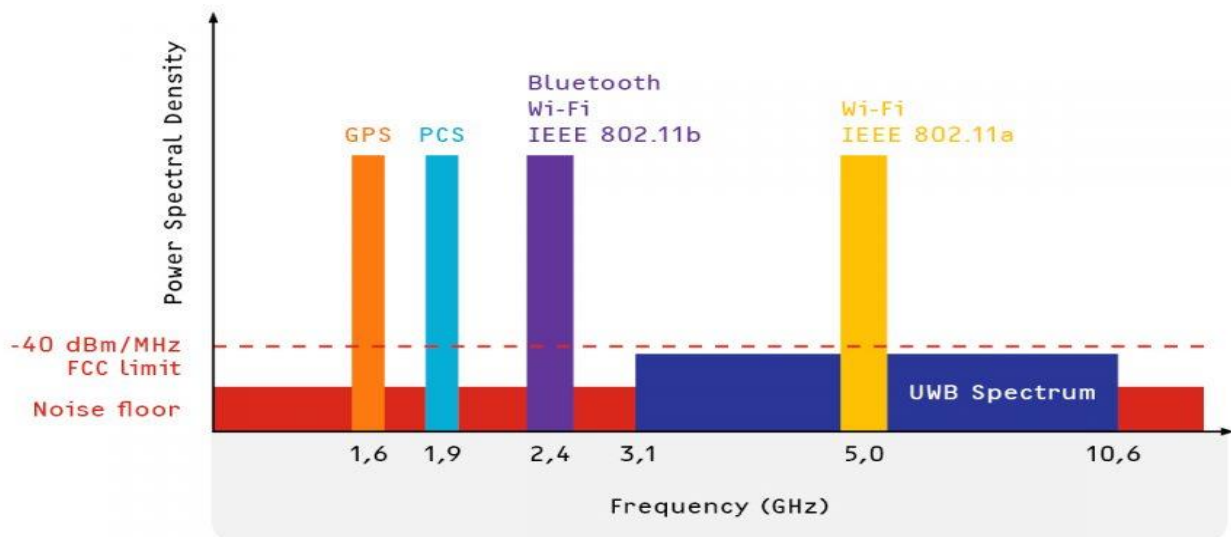


Figure I.1: Comparison of various communication standards [8].

Applications of UWB technologies

Due to its advantages, UWB has many domains of applications such as [9]

- Sensors networks, especially by using wireless (no wires) UWB sensor networks, the cost of installation and maintenance can drop significantly. These sensors can be found in medical applications for example.

- Due to high data transmission, positioning and tracking is another unique property of UWB technologies.
- It can be found in radar and imaging applications.

I.2.4 Mechanisms of reconfiguration

A reconfigurable antenna is an antenna in which at least one of these characteristics can be modified after its manufacture (frequency, polarization, Radiation pattern and Hybrid reconfiguration). There are various techniques for adopting reconfiguration.

In these techniques, the characteristics of the antenna will be modified using active components for electric type. Among these components, we can cite PIN diodes, RF-MEMS and Varactors.

In the optical domain, optical switching elements must be used such as photoconductors. Similarly, reconfiguration can be achieved by a mechanical modification in the antenna structure. This type is known by the physical reconfiguration.

There is another reconfiguration technique presented in the use of intelligent materials such as ferrites and crystal liquids. In our study, we are interested in electrical reconfiguration using PIN diodes.

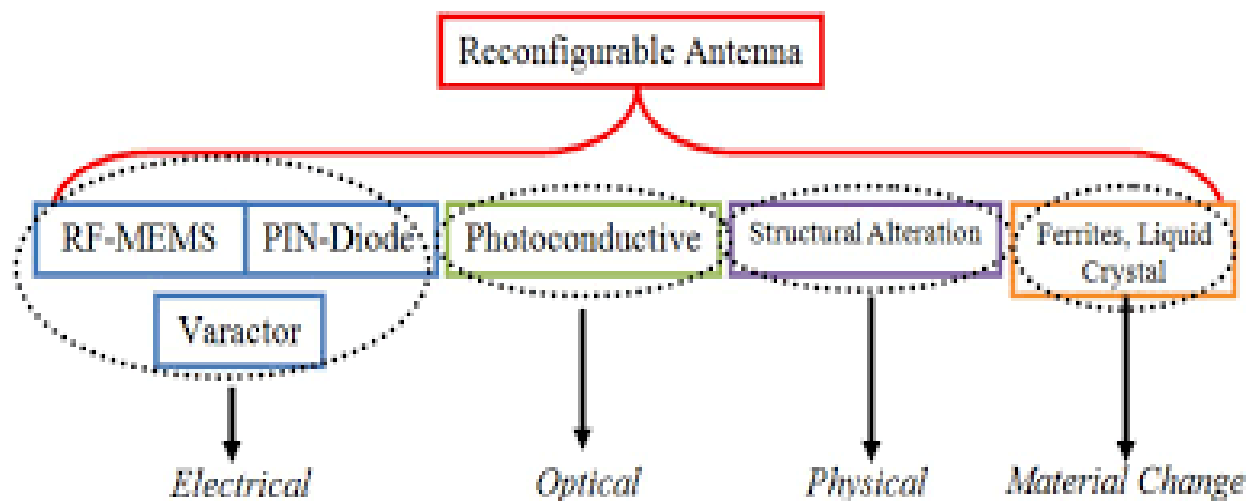


Figure I.2: Various mechanisms adopted to achieve reconfigurable antennas [10].

I.2.5 Reconfiguration classification

Whatever the reconfiguration mechanism, reconfigurable antenna can be classified into four classes (Figure I.3), according to their functionality on the characteristics of the antenna (frequency, spatial (radiation) or on polarization).

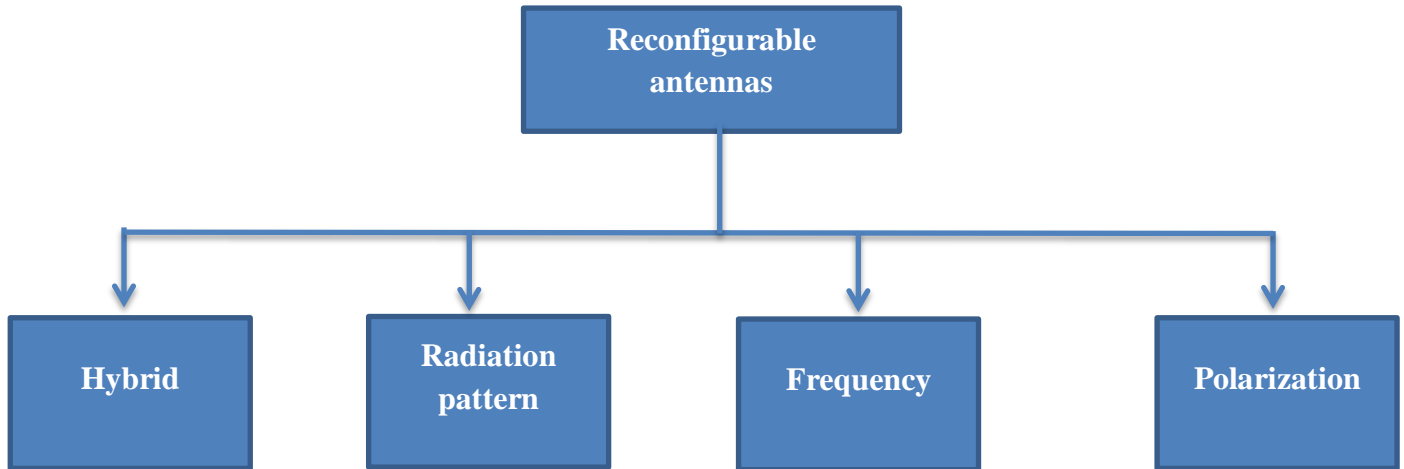


Figure I.3: Various categories for reconfigurable antennas

I.2.5.1 Frequency reconfigurable

Reconfigurable antennas adjust, dynamically, the operating frequency and are especially useful in situations where many communication systems converge, as a group of antennas of different frequencies can be replaced by a single antenna. This frequency tuning antennas provide the ability to continuously change one or more resonant frequencies, and frequency reconfiguration is generally accomplished by adjusting the antenna dimensions physically or electrically (RF-MEMS, diode PIN)

Frequency reconfigurable antennas are classified into two categories

- **Continuous tuning:** This can be achieved by using Varactors diodes where the antenna allows for smooth transitions within or between operating bands without hops.
- **Coarse tuning:** This can be achieved by using PIN diode switches. Coarse tuning employs different switching mechanisms to operate at multiple bands [11].

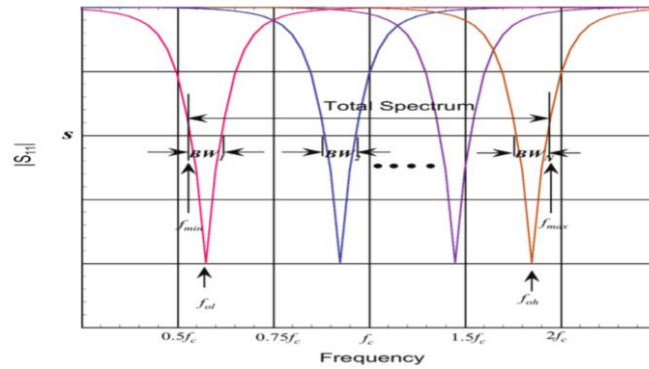
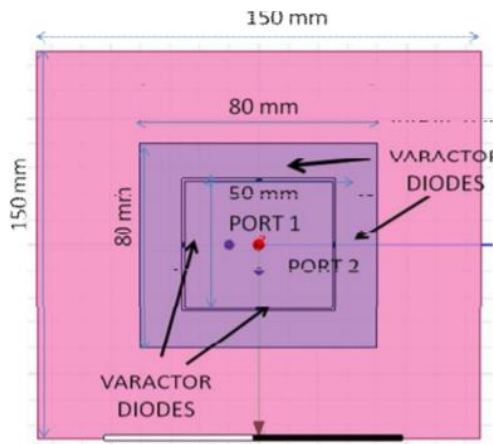
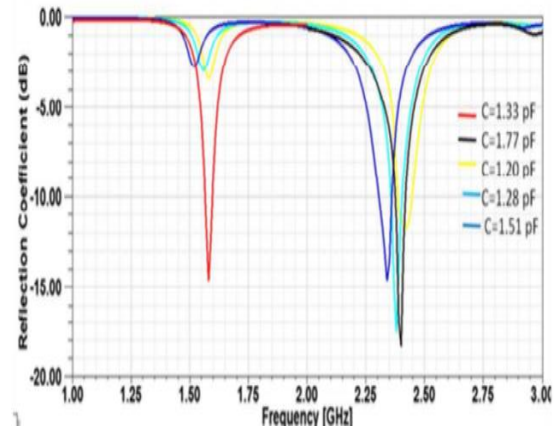


Figure I.4: Reflection coefficients of a frequency reconfigurable antenna [12].

The present reconfigurable antenna (Figure I.5) consists of a square microstrip patch which is connected to a square microstrip ring by using four Varactors diodes (variable capacitor diode). These Varactors diodes are used to achieve frequency reconfiguration between 1.6 GHz to 2.4 GHz (frequency agility bandwidth= 40%, $S_{11} \leq -10$ dB) [11].



(a)



(b)

Figure I.5: (a) Structure of frequency reconfigurable antenna, (b) Simulated reflection coefficient magnitudes (S_{11} , dB) for different Varactors capacitances [13].

1.2.5.2 Polarization Reconfiguration

Polarization reconfiguration allows to change the polarization of an antenna (horizontal / vertical, left or right of circular polarization, etc.). This kind of configuration increases the reliability and robustness of communication (immunity interference) as well as providing an additional degree of freedom (diversity). In order to maintain the other characteristics (frequency, antenna pattern), the polarization of the antenna will be done by acting on the phase and direction of the power supply. It means that the polarization of the antenna will be changed by altering the vectorial orientation of the E field and this without altering neither the resonant frequencies, nor the shape of the radiation diagram [14].

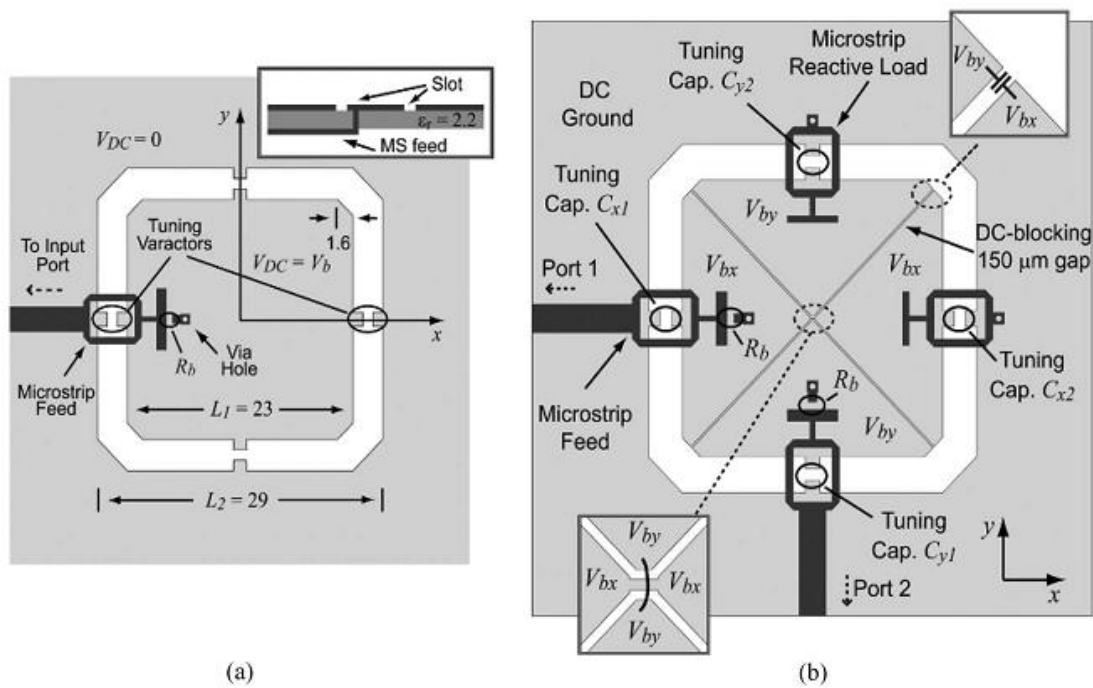


Figure I.6: (a) Single-polarized slot ring antenna (b) Dual-polarized slot ring antenna [15]

1.2.5.3 Radiation Pattern Reconfiguration

The reconfiguration of radiation pattern is one of the most important methods for beam steering applications. The ability to reconfigure the radiation allows the antenna to change the radiation pattern while maintaining the operating frequency and the other characteristics. This type of reconfiguration directs the main lobe towards useful directions providing improved coverage and higher data rates.

Reconfiguration of the radiation pattern can reject interference if the direction and its arrival are different from the direction of the signal, which reduce interference within the range.

Figure I.6 illustrate a reconfigurable antenna using a central circular patch and four parasitic patches. The radiation pattern of the presented antenna can be changed over three modes. Each mode can be achieved using a combination of four PIN diode switches which are located in gaps of parasitic rectangular patch. The configuration can be achieved by a simple electrical arrangement, where a short or open circuit can be provided in the gap. The designed antenna works at frequency of 5.8 GHz with a bandwidth of 2.2 GHz [16].

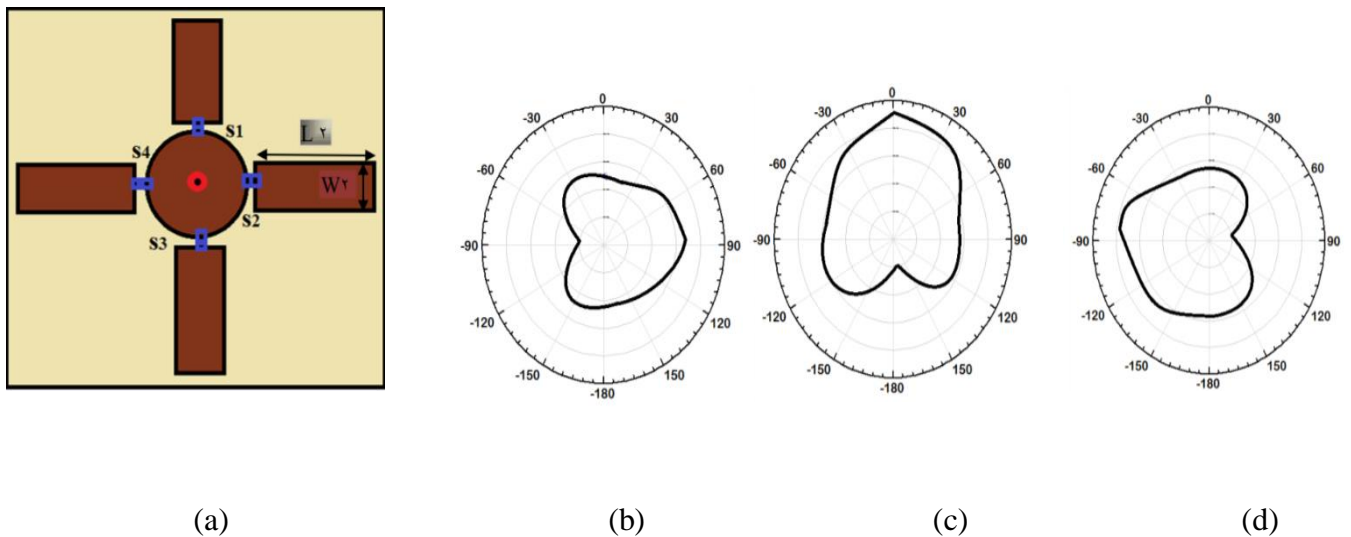


Figure I.7: (a) Geometry of reconfigurable antenna, (b, c, d) three modes of radiation pattern [16].

1.2.5.4 Hybrid reconfiguration

This hybrid reconfiguration is a combination of two of the three previous categories (frequency, radiation pattern and polarization). One of the most used combination is frequency-radiation pattern due to its important for many services (switches in frequency) and the need to steer beam, simultaneously.

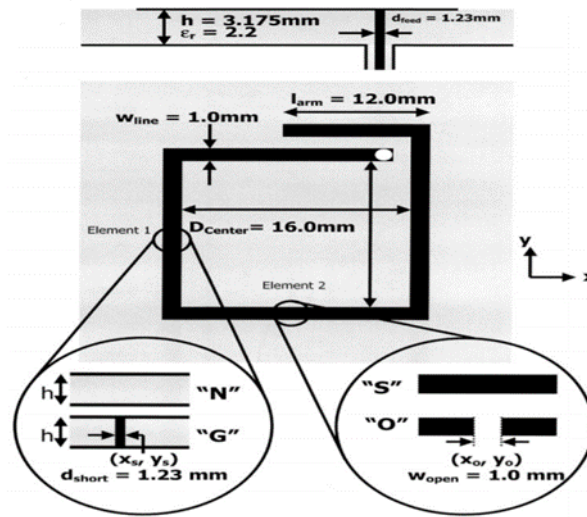


Figure I.8: The reconfiguration of the radiation using an antenna single turn square microstrip spiral [17].

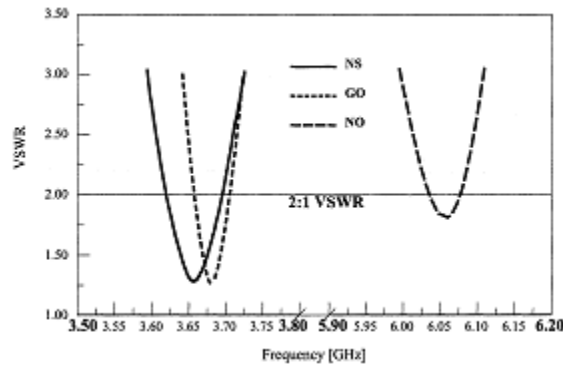


Figure I.9: Measured VSWR of the proposed antenna in Figure I.8 for three combinations [17].

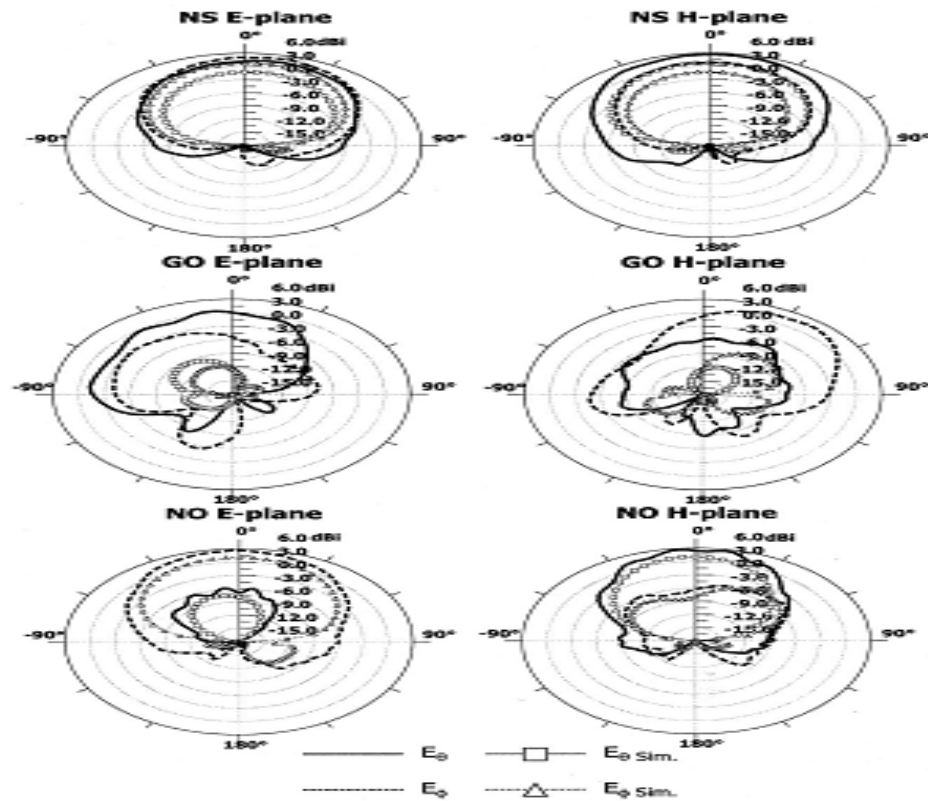


Figure I.10: Measured and simulated antenna pattern in E plane and H plane for three combinations [17].

As shown in this example, hybrid reconfiguration antennas can change many properties, and in one operation, simultaneously. This antenna can, for example, change the operating frequency and radiation pattern at the same time to improve efficiency, which is the most common application.

In the same way, there is another combination as can be seen in the following example, which is obtained using PIN diodes and capacitors. The hybrid reconfiguration changes frequency and polarization, simultaneously.

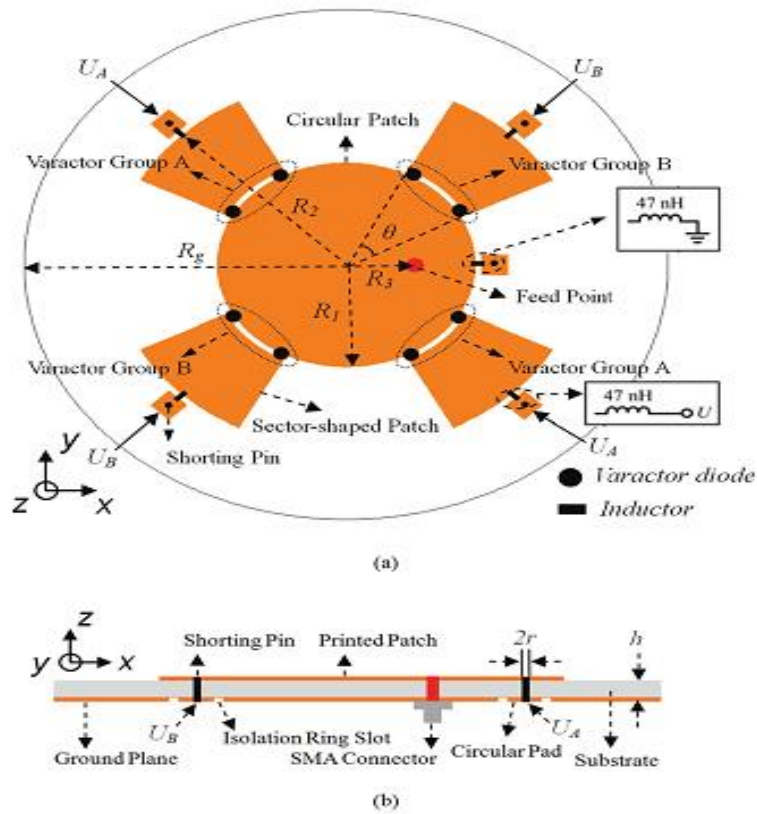


Figure I.11: Reconfigurable antenna with Frequency and Polarization Agility (a) Top view (b) side view [18].

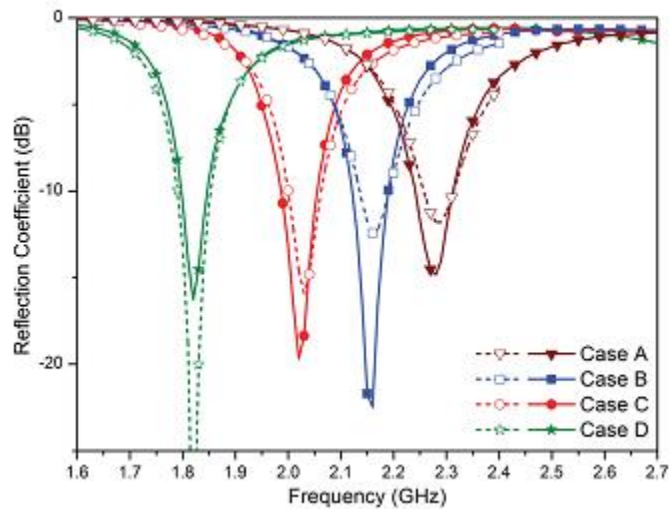


Figure I.12: Simulated (--) and measured (-) S_{11} of the illustrated antenna in Figure I.11

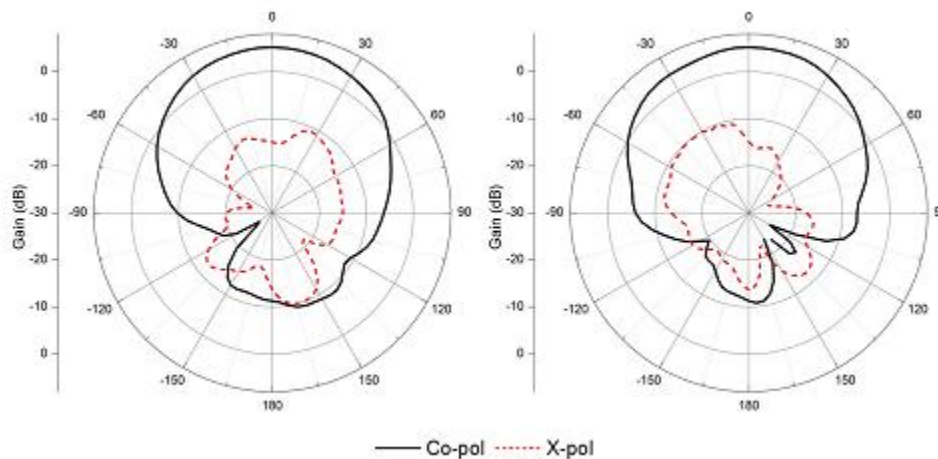


Figure I.13: Measured E-plane and H-plane of the reconfigurable antenna illustrated in Figure I.11

1.3 Advantages and Disadvantages of Reconfigurable antenna

a) Advantages

- ❖ One of the most important characteristics of a reconfigurable antenna is to reduce the number of antennas in communication systems, which facilitates the transmission and reception of data and reduces the size and cost of the device.
- ❖ High isolation between different wireless standards (WIFI, Bluetooth, 4G, ... etc.)
- ❖ The reconfigurable antennas are designed not only to obtain the necessary level of functionality, but also to integrate many functions into systems at the lowest possible cost.
- ❖ The reconfiguration of radiation offers the spatial diversity that was missing in conventional antennas.

b) Disadvantages

- ❖ Significant losses occur at the level of semiconductors, RF switches and smart materials. These losses affect negatively on efficiency and profitability.
- ❖ The cost of reconfigurable antennas is greater than that of conventional antennas, because it contains active components installed on the antenna.

- ❖ Install the active components on the antenna by welding, or adding holes at the surface level. It increases the weight and complexity of the antenna and thus increases the cost of its manufacture and maintenance.
- ❖ The biggest defects affecting reconfigurable antennas is the great complexity, which generates several problems in polarization, and thus the fragility of the materials that make up the antenna. Finally, these complications generate difficulty in simulation and in concepts related to electromagnetism and energy consumption.

1.4 Conclusion

In this chapter, we have presented a general and historical concept of reconfigurable antennas. In the same way, the main types of reconfiguration and techniques that allow modification of the antenna characteristics are presented. At the end of the chapter, some advantages and disadvantages of these reconfigurable antennas are delivered. To get the reconfiguration of an antenna, we must add an active component such as PIN diode, MEMS, and Varactors. These components will be seen, in detail, at the next chapter.

Chapter II:
Switching devices of
reconfigurable antenna

II.1 Introduction

Nowadays, the world is witnessing a great development in communication technology. This rapid technological development is accompanied with the emergence of several new sources, which increases the number of services and the need for wireless communications. In order to meet the needs of the system, these services require new devices of large capacity.

To solve such problems, the reconfigurable antennas are appeared. These antennas work on several different frequencies, in order to cover various services such as GSM, Bluetooth, WLAN, and others. The reconfigurable antennas can change their operational characteristics, which are operating frequencies and radiation patterns or the polarization using electronic, mechanical or optical technologies.

To obtain reconfiguration of these antennas, RF switches must be used. These RF switches can be MEMS, PIN Diode, Varactors diode, diode of Schottky, or optical conductors. In this chapter, we will see the various switches those are used to reconfigure the antenna. In our work, PIN diode will be used to reconfigure the antenna, which can easily operate in several frequency bands according to the condition of the PIN diode (ON or OFF).

II.2 Radio frequency switches

There are two main categories of switches. The first one is mechanical when the other one is based on semiconductors. Mechanical switch consists of two metal plates. When these plates touch each other, an electric current takes places. On the other hand, when these plates get separated from each other, current get interrupted and the energy is saved (no consumption). This in turn causes ON and off states in electrical circuit. The mechanical switches can be found in the form of waveguides and generally operate up to 40 GHz. Mechanical switches are slow and heavy and have very low insertion losses (0.4 dB) but the isolation is very high (60 dB). The main drawback of these mechanical switches is the long switching time; for that it is often replaced by the switches based on semiconductors (RF switches).

Radio frequency switches are used for reconfiguration. It can be used to separate the antenna parts from each other or create different paths to change the current distribution on the antenna patch. RF switches have many advantages in terms of their low losses, fast switching time, low consumption, high isolation and it can operate on wide ranges up to 40 GHz or more.

The switch can be modeled simply by a metal tab to be able to switch between two cases (ON or OFF). The switch (diode) will be replaced with a metal piece (ON) or without a metal piece (OFF).

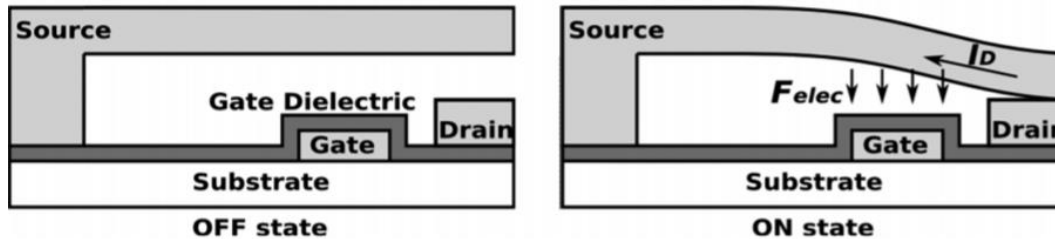


Figure II.1: Schematics of the Air-Gap Electrostatic Switch [19].

Three devices are commonly used in microwave switching, MEMS, FET field transistor, and PIN diode, and fabricated with IC batch-processing techniques. The RF-MEMS switch (Micro Electromechanical Systems) is a miniature system made of semiconductor materials, which is combining electrical and mechanical components. It can operate on a range up to 40GHz, but the switching time is long. RF-MEMS switches are commonly used in military applications and satellite systems. Actually, it is poised to enhance the efficiency of 5G antenna in the near future.

At the present time, PIN diode and FETs are considered reliable devices that are used in designing electrical devices. They work as resistance in operating cases (ON state) and operate as capacitance in the OFF state. In terms of power consumption, the PIN diode consumes more power than FET.

Due to several features, RF switches have many advantages over others [20]:

- Bandwidth: The switch can be considered as a filter, which will keep one band and eliminate others (low pass or band pass filter).
- Insertion and isolation losses: This is the input and output power ratio in presence and absence of the switch (ON and OFF)
- The switching speed: It is defined by two switching times: The conduction time T_{ON} (from reverse current to direct current) and the blocking time.
- Switches can be used to reconfigure antennas arrays (Figure II.2).

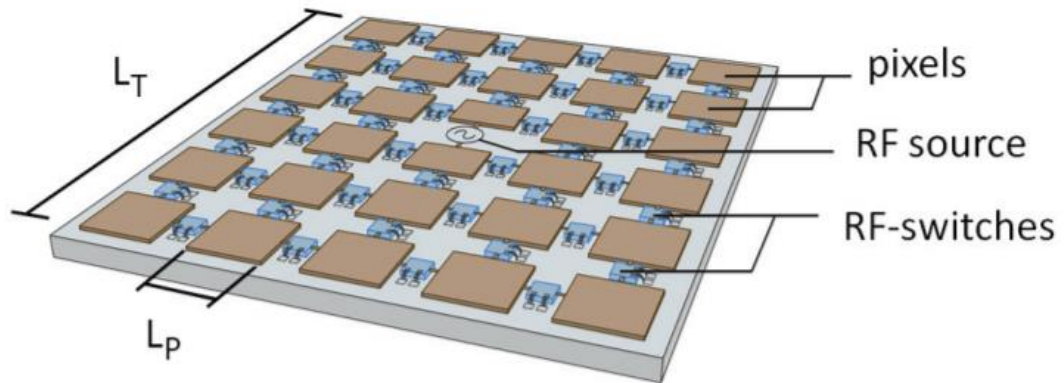


Figure II.2: A reconfigurable antennas array [21].

II.3 Switching techniques for a reconfigurable antenna

Reconfigurable antennas use RF switches to adopt the reconfigurability. These switches will change the distribution of the current on the antenna surface, which allows to vary the resonant frequency, to control and steer the radiation pattern, and others. Among these switches, we can cite PIN diodes, RF-MEMS, VARACTORS and photoconductors.

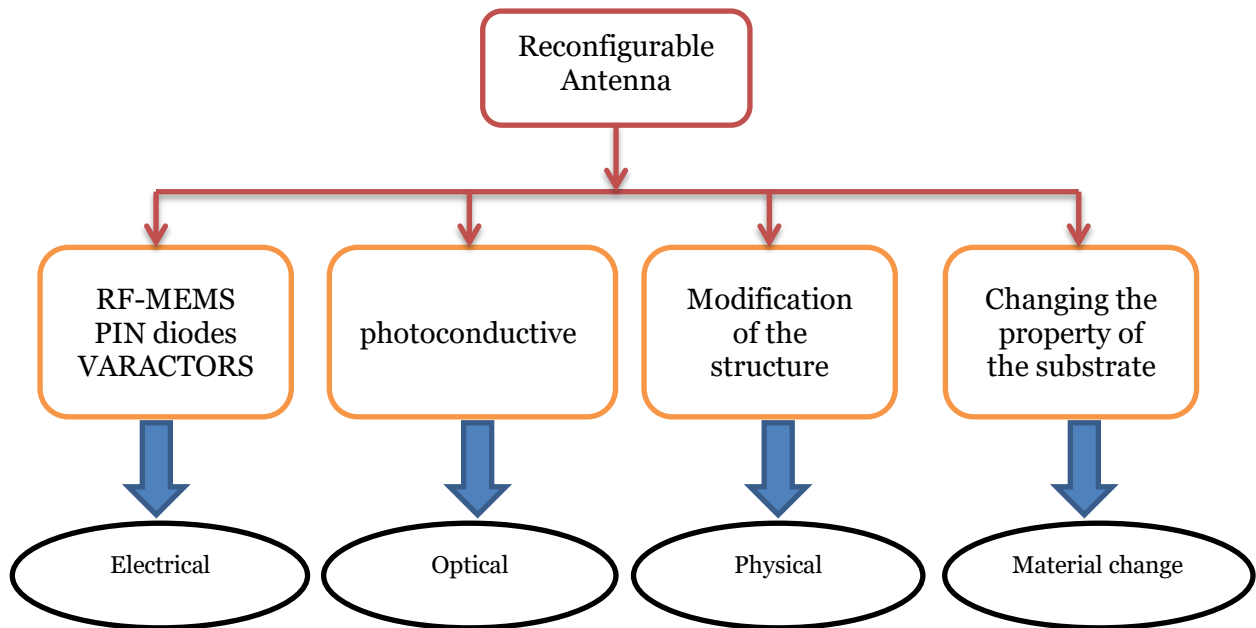


Figure II.3: Techniques of antenna reconfiguration.

II.3.1 Electrical technology

In this type of reconfiguration, the antenna characteristics can be changed using electronic components such as PIN diodes, Varactors, or MEMS. Using these switches, the antenna structure can be reshaped, causing a redistribution of the surface current, which can change some antenna characteristics in terms of radiation pattern, polarization, and frequency. These devices have high isolation with low insertion losses. As any technique, it has some disadvantages such as the complexity of the antenna will be increased by the number of the used devices.

II.3.2 Optical technology

Among the simple reconfiguration techniques is the optical switches, which are made using semiconductor materials (silicon or gallium arsenide). No need for metal wires, bias lines provide less interference and higher isolation compared to electrical switches and fast switching time (up to nanoseconds). Generally, these optical switches are used to control antenna bandwidth and radiation pattern.

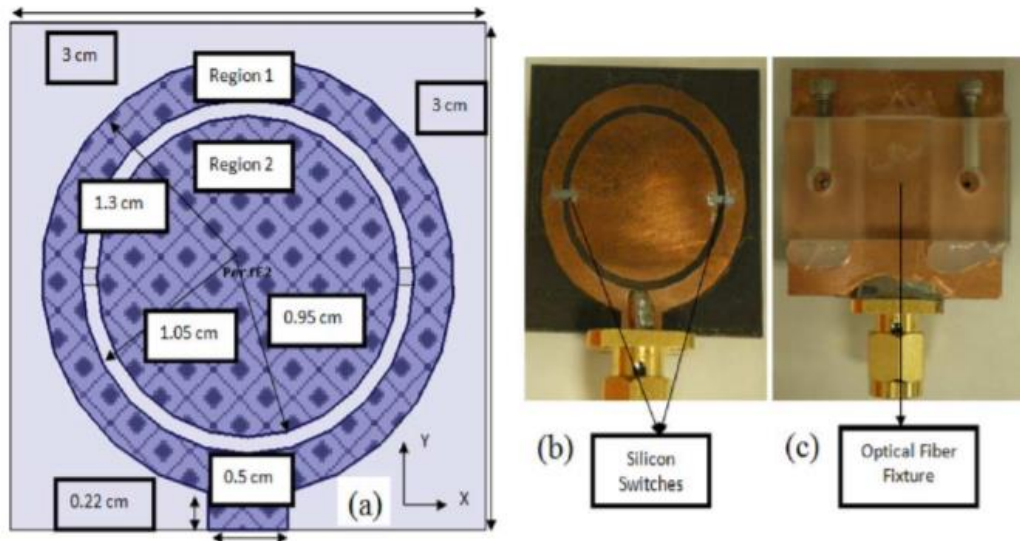


Figure II.3: (a) Antenna dimensions. (b) Antenna top view. (c) Antenna bottom view [22].

II.3.3 Physical technology

Any antenna can be reconfigured by changing its physical structure. The characteristics of an antenna can be adjusted by modifying its parts (patch, ground, ...). This simple technique is different from other techniques, because it does not require any transfer mechanisms, bias lines or optical fibers.

Among the main disadvantages of this technique is its limitation for the implementation of small devices.



Figure II.4: Geometrical (mechanical) reconfiguration of an antenna [23].

II.3.4 The technique based on intelligent materials

The reconfigurable antennas can be made using some smart materials such as liquid crystals, ferrite or metamaterials. These materials have the ability to alter some properties, such as electrical permittivity or magnetic permeability.

In fact, a liquid crystal is a nonlinear substance that can change its dielectric constant under various levels of voltage, when for ferrite materials, these properties are fixed.

II.4 Switches devices

In recent decades, reconfigurability has become popular in wireless communications. It is used to improve the performance of different systems and increase degree of freedom. The reconfigurability will be done after the manufacture of an antenna, where some antenna

characteristics can be changed by inserting RF components on the antenna surface. In this part, we will see some switching components widely used in reconfigurability.

II.4.1 RF-MEMS

MEMS (Micro Electromechanical Systems) is a micro system that has one or more mechanical components, used as a radio frequency switch, featuring high isolation and low insertion losses, suitable for switching over a wide range of frequencies. It has a switching time over 100 microseconds.

One of its drawbacks is presented in its slow manufacture and use on the antenna requires some conditions (very precise welding, controlled temperature) in addition to its limited lifetime. As shown in the following figure (Figure II.5), the proposed UWB antenna operates at frequency band from 3.2 GHz to 12 GHz. The notched frequency band is accomplished by combining switched meandered slot etched in the radiating patch. The reconfiguration is achieved by using RF-MEMS switches which allow an interference reduction to the primary users operating in WiMAX bands from 3.3 GHz to 3.9 GHz.

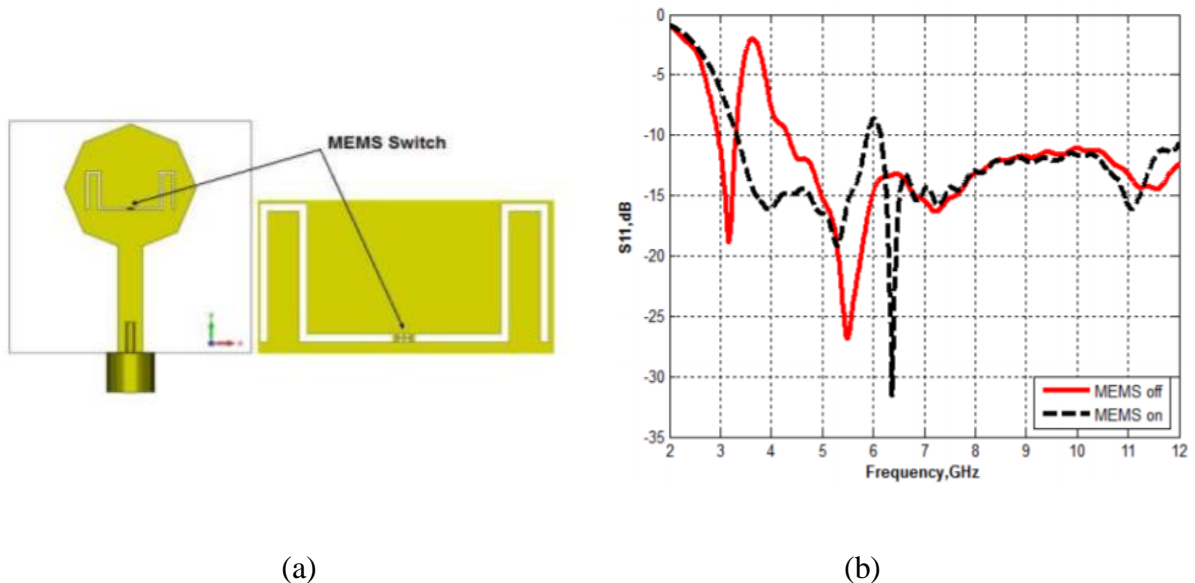


Figure II.5: (a) Structure of antenna with RF-MEMS Switch, (b) The simulated return loss of antenna with two states of RF-MEMS [24].

II.4.2 Optoelectronic switches

In optical electronic switches, reconfiguration is achieved using light source such as optical fiber or direct lighting. These switches have many advantages such as low loss, light weight, noise immunity and high isolation. Despite all these advantages, the optical switches require expert technicians and specialized tools, which increases cost of this technique. In the following example which is proposed by [20], a slotted waveguide antenna array (SWAA) is proposed and reconfigured using optical switches.

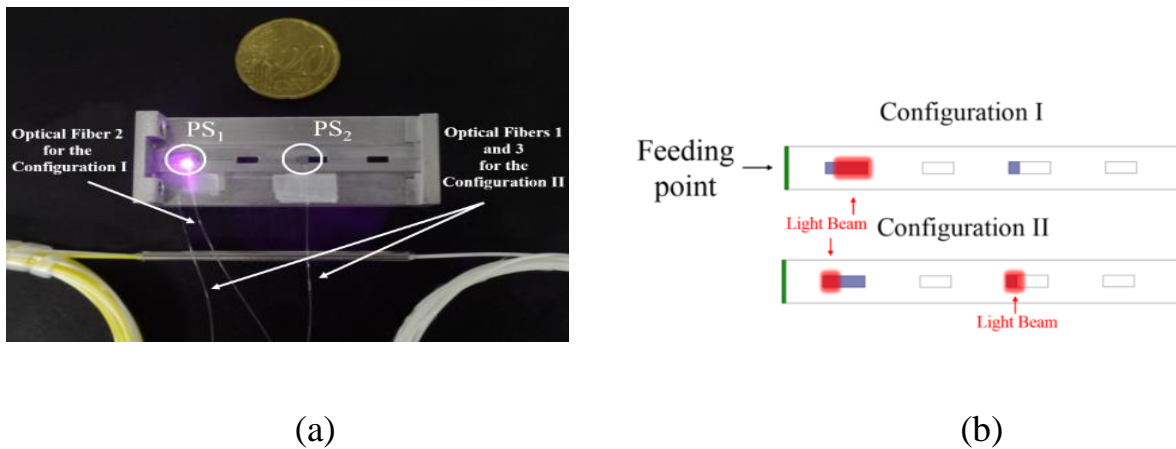


Figure II.6: (a) Photograph of the optical control reconfiguration SWAA, (b) different configuration [25].

II.4.3 Varactors Diodes

Varicap diode, also called Varactors (acronym for variable capacity) is a type of diode, which behaves as a capacitor. The value of this capacitor varies with the reverse voltage applied across the diode. The capacity can be varied from a few hundred femto Farad (fF) to a few tens of picoFarad (pF). These switches are characterized by its easy integration and its ability to continuous frequency reconfiguration. Varactors are widely used in communication applications. Due to its fast frequency tuning, varactors diodes are inserted in the slots as RF switches. On the other hand, the varactor switch suffers from some losses such as low capacitance and complexity due to the large number of diodes on the antenna surface.

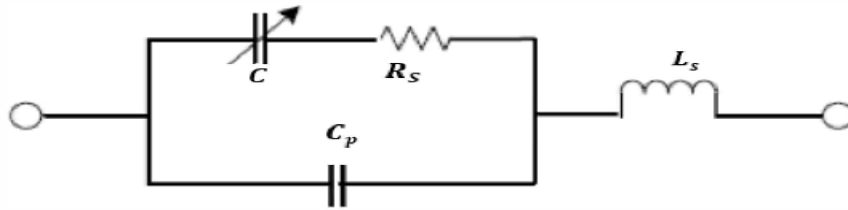


Figure II.7: Equivalent model of a varactor diode.

In the example of [24], the effective length of the slot is changed using varactors. This effective length influence on the resonant frequencies of the antenna. The varactors have been used, along the aperture, to design dual band reconfigurable aperture antennas.

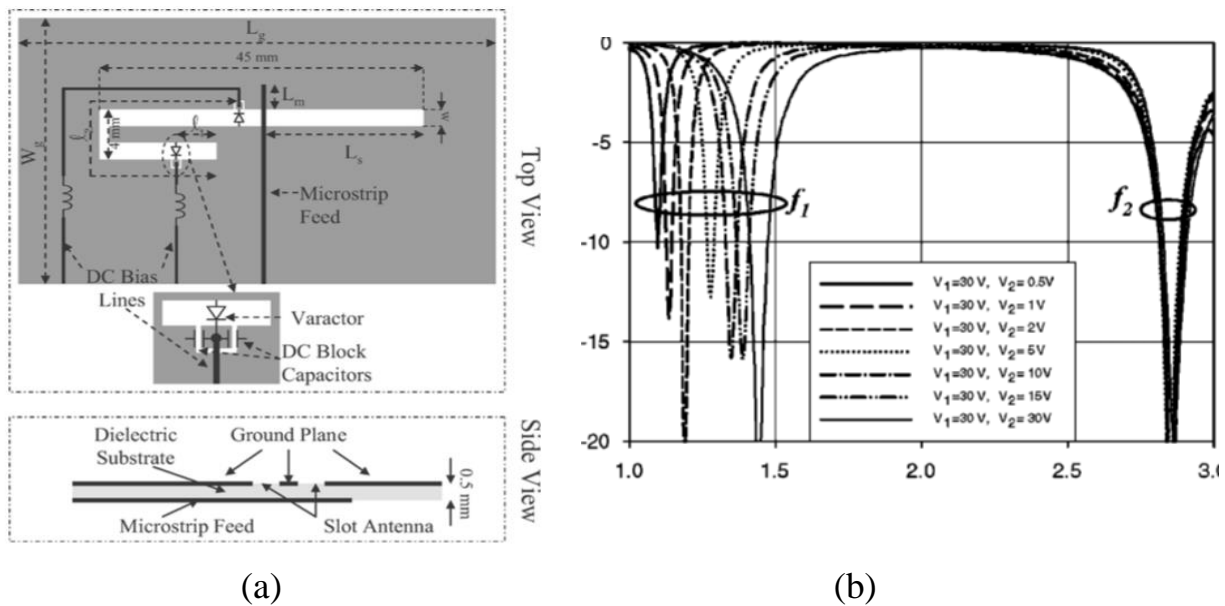


Figure II.8: Schematic of the proposed dual-band antenna with two Varactors. (b) the frequency of the second band is kept fixed while that of the first band is varied [26].

II.4.4 Agile materials

Reconfigurability can be obtained using tunable materials. These materials are used as substrates whose electromagnetic properties (permittivity and/or permeability) can be modified using an external command. The command (application of an electric and/or magnetic field) ensures the antenna's reconfigurability. Recently, an alternative technique using liquid dielectric materials for antenna reconfiguration has attracted significant attention. Some non-linear materials such as liquid crystals can modify their properties (permittivity and permeability), by adjusting the direction of the particles of this liquid. This technique has an advantage presented on the

simplicity and easy integration, but a great pressure must be applied to reconfigure the antenna. Moreover, it has important losses and long switching time. Its power consumption is relatively low; however, it must be kept at the temperature range between 20°C to 35°C in order to stay in the liquid crystal state.

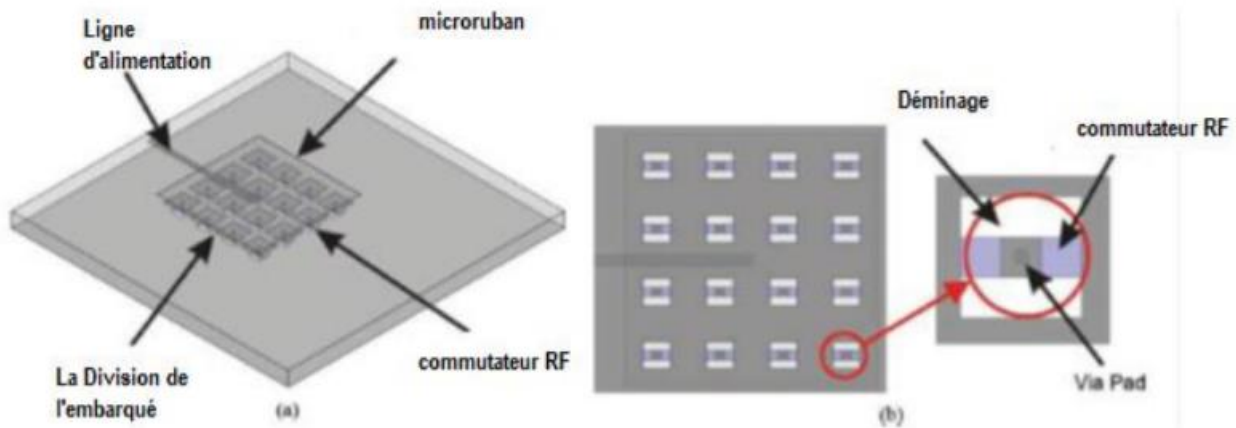


Figure II.9: Frequency reconfigurable patch antenna on EBG substrate [27].

II.4.5 Schottky diodes

The Schottky diode (named after the German physicist Walter H. Schottky), is consisting of a metal-semiconductor junction. It has less forward voltage drop and very fast switching time. When enough forward voltage is applied, the current flows in the forward direction. This requirement for low direct voltage allows for higher conversion speeds and better system efficiency.

The Schottky diode also has a very fast recovery time between the forward connection state (ON) and the reverse state (OFF) because it has an infinite amount of stored charges, which makes it partially very suitable for high speed switching applications as well such as RF and microwave applications. In conventional diodes, this time it can be several microseconds to less than 100 ns, but since Schottky diodes do not have a charge-exhaust area at the intersection, the switching time can be from 100 ps to 10 of ns, i.e. almost instantaneously. The major disadvantage of this diode has a lower maximum reverse voltage than standard diodes, usually

50V or less. Once this value is reached, the Schottky diode will break down and start to conduct a large amount of current in reverse. However, even before reaching this reverse value the Schottky diode will still leak a small amount of current like any other diode [28].

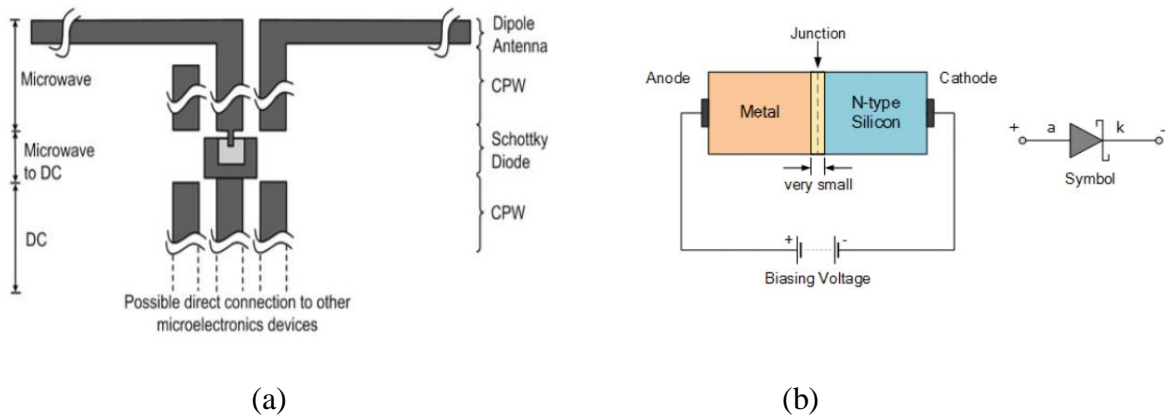


Figure II.10: (a) Schematic of direct integration between Schottky diode and dipole antenna (b) Schottky Diode Construction and Symbol [29].

II.4.6 PIN Diodes

Among the most popular type of diode which are used as switches in telecommunications applications is PIN diodes. These diodes are used for a variety of RF switching circuits. The PIN structure is also very useful in photodiodes.

The PIN diode found its first applications in 1952 as a low frequency high power rectifier. It was also used in many microwave applications, although it was not until 1960 before its use became more popular in this area.

II.4.6.1 Definition

A PIN diode (Positive Intrinsic Negative diode) is a semiconductor device consisting of an undoped region (called intrinsic region I) interspersed between two other regions doped with N and P type, respectively.

Figure II.11 shows an equivalent circuit of a PIN switch, which can be ON or OFF. In the ON state, the switch can be represented as a resistance and an inductance (Figure II.11.b). In the OFF state, the diode will be modeled by a capacitor in parallel with a resistor, all in series with an inductor as illustrated in (Figure II.11.c).

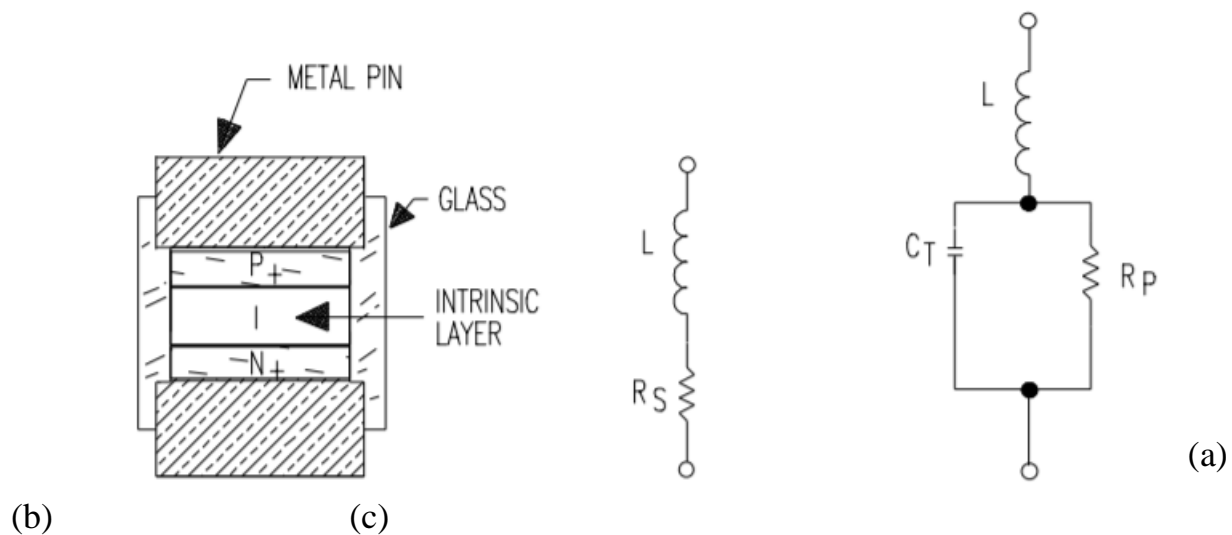


Figure II.11: The equivalent circuit of the PIN diode: (a) Cross Section of Basic PIN Diode, (b) Forward Bias Equivalent Circuit (c) Reverse Bias_Equivalent Circuit [30].

II.4.6.2 PIN diode characteristics

The PIN diode has many characteristics, which make this diode stand out from the rest diodes. Among these key characteristics, one can cite:

- The high frequency resistance is inversely proportional to the DC bias current through the diode. In direct polarization, PIN diode behaves as a variable resistor. This high frequency resistance can vary over a wide range from 0.1Ω to $10 \text{ k} \Omega$. In some cases, the useful range is smaller.

- The wide depletion layer, provided by the intrinsic layer, ensures that PIN diodes have a high reverse breakdown characteristic.
- When the control current is alternately varied, the PIN diode can be used for amplitude modulation of an RF signal.
- The diode has a fast switching time (less than 100 ns).

II.4.6.3 Advantages and disadvantages of a PIN diode

Like all the other switches, PIN diode has several advantages and disadvantages

a) Advantages

- PIN diode can be used as a high voltage rectifier. The intrinsic region provides a high separation between the P and N regions, allowing higher reverse voltages to be tolerated.
- Due to the large distance between P and N regions, which increases the isolation during the reverse bias. PIN diode can be considered as a perfect RF switch.
- As the conversion of light into current takes place within the depletion region of a photodiode, increasing the depletion region by adding an intrinsic layer, which improves the performance.

b) Disadvantages

- The main drawback of a PIN diode presented in its recovery time (state ON to state OFF)
- Due to the reverse recovery time, PIN diode has power losses.

II.4.6.4 PIN Diode (BAR50-02)

We mentioned previously several technologies and switches for reconfiguration including RF-MEMS, Varactors, PIN diode. But here we focus on PIN diode, which is used to reconfigure the proposed antenna in the next chapters.

The BAR50-02V is a PIN Diode from Infineon technology. It is single-pole single-throw (SPST). The SPST switch has one input port and one output port, as shown in Figure I.12. some characteristics of this diode is: frequency range 10 MHz to 6 GHz, Insertion Loss 0.27 to 0.56

dB, Isolation 12 to 24.5 dB, Forward Voltage 0.95 to 1.1 V, Forward Current 100 mA and 1100 ns recovery time.

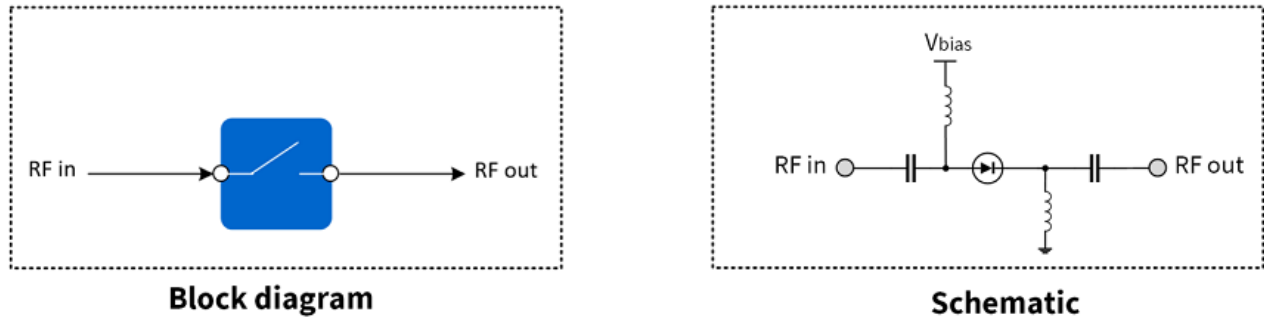


Figure II.12: schematic of SPST switch: PIN diode (BAR50-02)

II.5 Comparison between different switching systems

A comparison between different switches, which are the most commonly used in microwave and RF domain. Among these switches, we can cite RF-MEMS, PIN diodes and optical switches. As tabulated in the following table, some electrical characteristics are illustrated.

TABLE I.1: Comparison of the different switching system [27].

Electrical property	RF MEMS	PIN diode	Optical switch
Voltage [V]	20-100	3-5	1.8-1.9
Current [mA]	0	3-20	0-87
Power consumption[mW]	0.05-0.1	5-100	0-50
Switching speed	1-200 μ sec	1-100 n sec	3-9 μ sec
Isolation[1-10GHz]	Very high	High	High
Loss { 1-10 GHz } [dB]	0.05-0.2	0.3-1.2	0.5-1.5

II.5.1 PIN diode as RF switch

PIN diodes are widely used as switches in communication system. These diodes are ideal for a wide range of RF applications. Their low insertion loss and fast switching time makes them ideal

for use in Rx-Tx antenna switches. Their application areas mainly focus on reconfigurable slots for communications systems, switch networks for space communications, wireless devices, phase switches (digital), reconfigurable matching networks, programmable attenuators, etc...

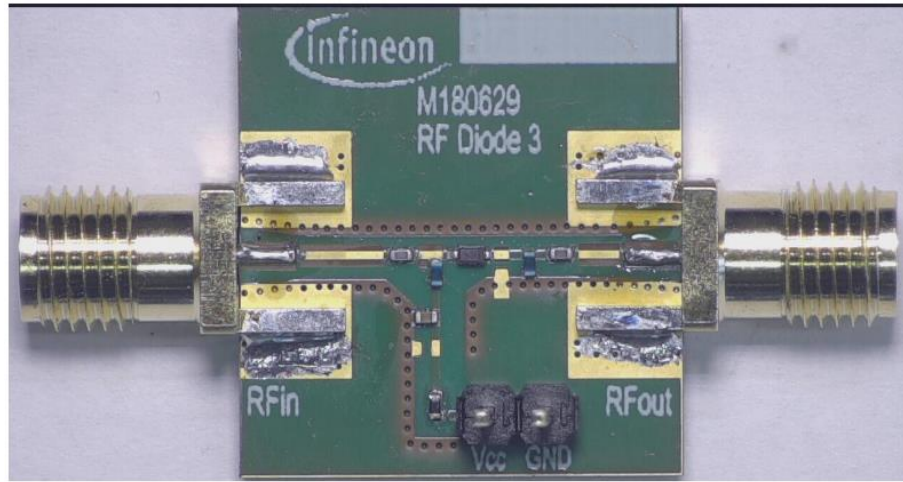


Figure II.13: Photo of an evaluation board for PIN diode (BAR63-02) in RF application

II.6 Conclusion

In this chapter, we present the different techniques and components those are used to modify the antenna characteristics. Among these components that can be added to the antennas, one can cite MEMS, PIN diodes, Varactors, and tunable materials. The reconfiguration makes the antenna able to adapt better to environment requests. In our thesis, we are interested by the reconfigurability of the printed antenna using PIN diodes (BAR 50-02). For that, some detailed characteristics of this diode are given in the present chapter. The next chapter will contain a parametric study, which can help to design a UWB antenna using CST studio simulator. The frequency reconfiguration, using a PIN diode (Bar50-02), will be used to notch some frequency bands of the obtained UWB antenna.

Chapter III :

Design of Ultra-

Wideband Antenna

III.1 Introduction

After the adoption of the frequency range, by the FCC, as an ultra-wideband (UWB) technology, many works are focusing on microstrip antenna design and fabrication within this band. These works taking into account many constraints such as miniaturization, low cost, wideband, easy to integrate, and the other characteristics like directivity, gain, ...

UWB Microstrip antenna can be designed using many techniques such as introducing slot on the patch or on the ground [31].

Enlarging the BW can be achieved by introducing many shapes slots on the ground. The introduced slots can be triangle, circle or other form.

In this chapter, an ultrawide band antenna will be designed. When a parametric study and optimization process will be done. The effect of different geometric parameters at the bandwidth of ultra-wide band antenna will be taken into account.

III.2 Parametric study of a microstrip antenna

During the parametric study, we must change only one parameter where the others must be fixed, which makes it possible to make an isolation between the different parameters, then we will observe the effect of the parameter variation on the characteristics of the designed antenna such as the resonant frequency, the radiation pattern and the return loss.

However, in optimization process, we change more than one parameter simultaneously till a stop criterion is achieved.

Firstly, we try to find an antenna which is operational on a WLAN band (2.4 GHz). In the second part, An UWB antenna will be developed.

III.2.1 Antenna geometry

A microstrip antenna with a rectangular patch and a full ground plane is chosen to be designed using CST studio. For this design, an FR4-epoxy substrate is chosen, which has a relative permittivity $\epsilon_r = 4.3$, dielectric tangent loss of 0.025, and a thickness of $H = 1.6$ mm. The thickness of the copper t is 0.035 mm. The dimensions of the substrate are $L = 40.00$ mm and $W = 36.67$ mm. The ground plane has the same dimensions of the substrate.

As illustrated in Figure III.1, the patch is directly connected to a feedline of 3 mm that provides a characteristic impedance $Z = 50\Omega$.

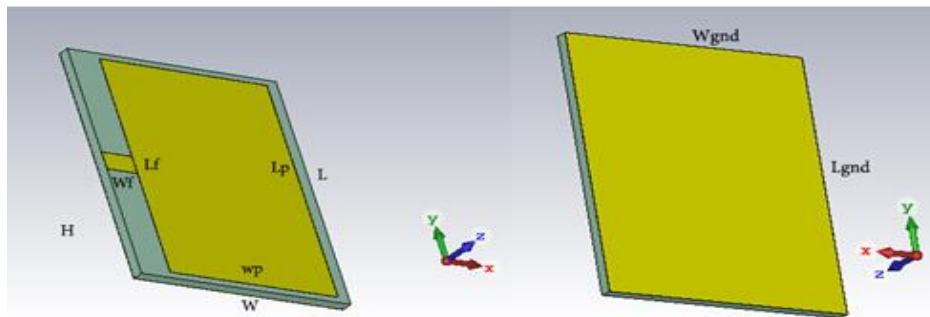


Figure III.1: Geometry of the rectangular patch antenna.

The different dimensions used in this first antenna are given in the following table (**Table III.1**)

Table III.1: The dimensions of the proposed rectangular patch antenna (in mm)

L	W	Lp	Wp	Lf	Wf	H	Wgnd	Lgnd
40.00	36.67	38.00	29.40	3.00	5.30	1.6	36.67	40

As shown in Figure III.2, the first structure with the dimensions mentioned above does not lead to interesting performances. In order to show the effects of various parameters on the performance of this antenna, a reliable solution presented in a parametric study will be done.

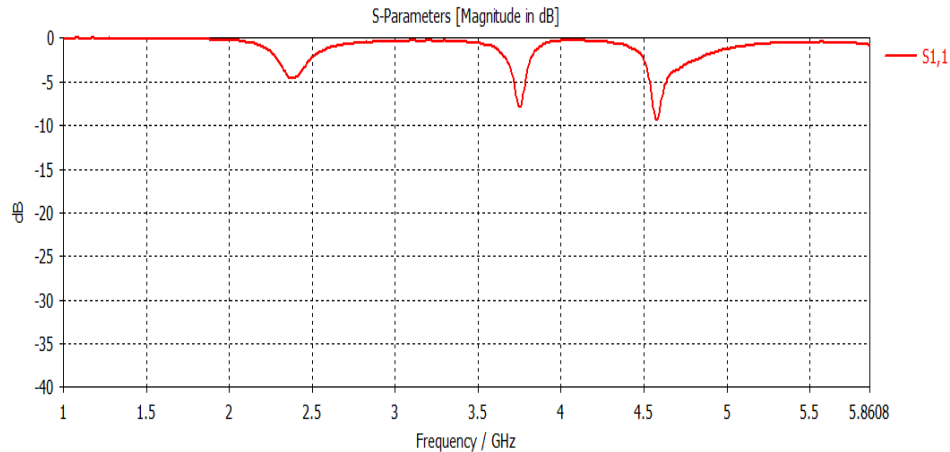


Figure III.2: Return loss curve S_{11} for the proposed antenna with the dimensions given in Table III.1

The reflection coefficient does not have any interesting performance, but it has various resonance at the frequencies 2.4 GHz, 3.7 GHz and 4.6 GHz. For that, a beveled rectangular patch will be used (Figure III.3), feedline position will be changed, and Partial Ground Plane will be taken.

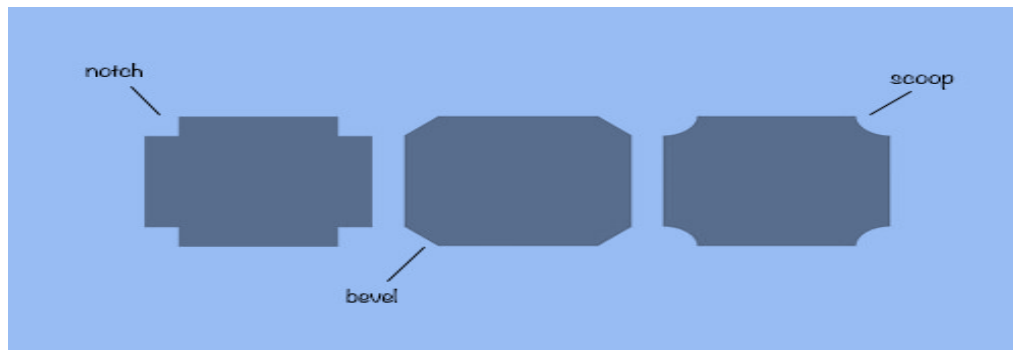


Figure IV.3: beveled, notch and scoop corners

III.2.2 Development of Design ultra-wide band antenna

The designing of the proposed structure is divided into six steps.

- Firstly, the rectangular beveled patch antenna with a partial ground plane is investigated to adapt the proposed antenna for UWB applications.
- In the second step, the feedline position will be changed to achieve at the optimal position (parametric study).

- In the third step, a second beveled corner will be added, while the position of first beveled corner will be modified (parametric study, optimization process).
- In the fourth and fifth steps, two rectangular notches will be added at the ground plane (optimization).
- In the last step, two rectangular shapes will be added around the feedline (optimization).

III.2.2.1 Rectangular beveled patch antenna with a partial ground plane

At the beginning, a beveled rectangular patch antenna was used with a partial ground plane, when its width is reduced to $W_{gnd} = 3.3$ mm and the position of the feedline is tuned to be under the beveled corner. Note that in the conventional designs the feedline position is in the middle of the rectangular patch, which results in a symmetric current distribution on the patch.

The structure of the designed antenna is shown in Figure III.4. In this structure, the beveled corner is added at the left corner of the patch.

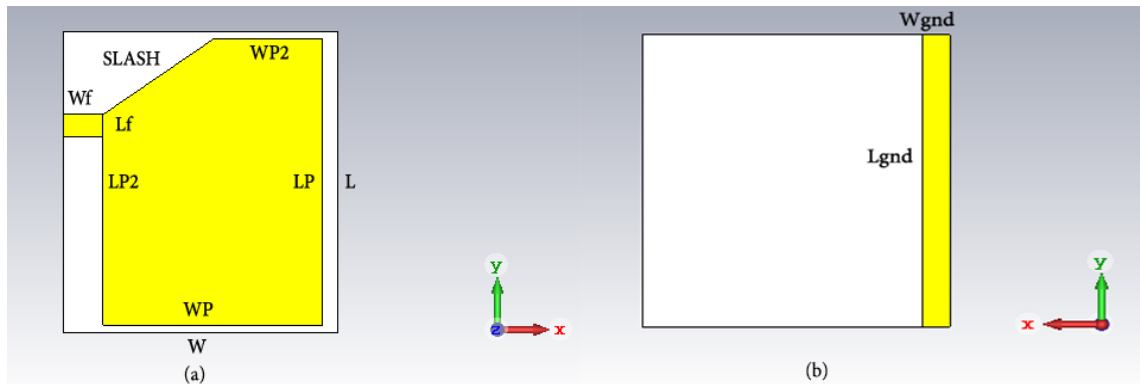


Figure III.4: Beveled rectangular patch with partial ground plane (a) top view of antenna, (b) bottom view of the antenna (step I).

The dimensions adopted during this step are tabulated in the following table (Table III.2)

Table III.2: The dimensions of the patch antenna proposed in mm (step I)

W	L	WP	LP	WP2	LP2	Lf	Wf	SLASH	Wgnd	Lgnd
36.67	40.00	29.40	38.00	14.70	28.00	3.00	5.30	17.78	3.30	40.00

To show the effect of ground plane width parameter (W_{gnd}) on the performance of the designed antenna, a parametric study is done.

After the parametric study, the return loss curves for many widths of the ground plane (Wgnd) are given in Figure III.5.

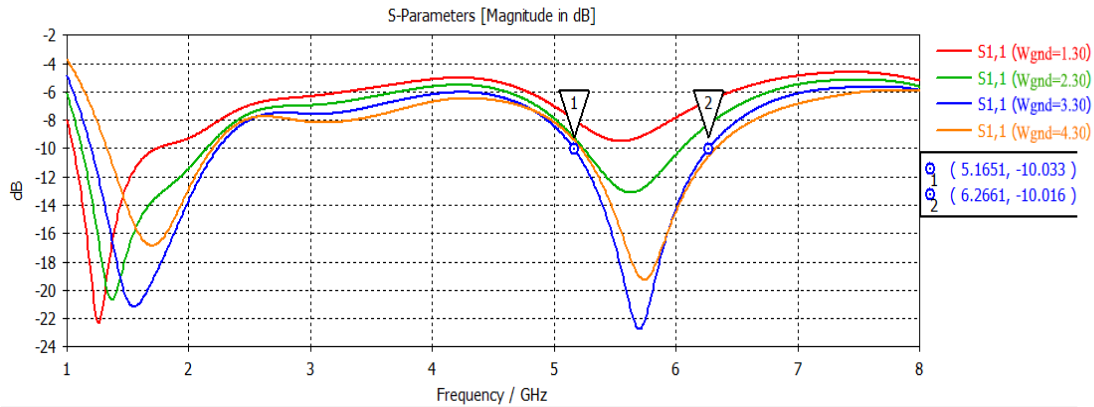


Figure III.5: Return loss curves S_{11} for many Wgnd values.

As illustrated in the figure above, many curves have low return loss (lower than -10 dB) in two bands [1.1-2.2 GHz] and [5.2-6.2 GHz]. The blue curve with Wgnd=3.30 mm gives the best result in terms of bandwidth and adaptation (deep S_{11} at 5.8GHz).

After some parametric studies, the width of the ground plane is set to 3.30 mm (Figure III.6). Moreover, the feed position was also tuned to provide optimum matching.

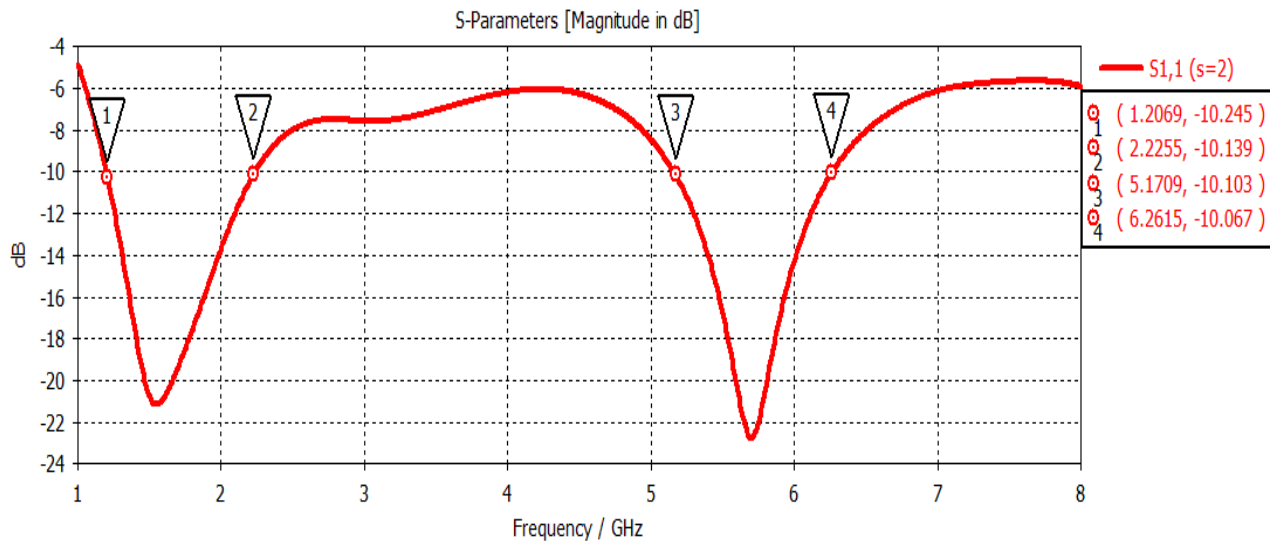


Figure III.6: Return loss curve S_{11} versus frequency for Wgnd=3.30

III.2.2.2 Effect of the feedline position

Among the efficient techniques which are used to improve the bandwidth of microstrip patch antenna is the change in the position of feedline.

The dimensions are set to those listed in Table III.2. In this step, we will move the feedline along L_{p2} with a K mm as illustrated in Figure III.7.

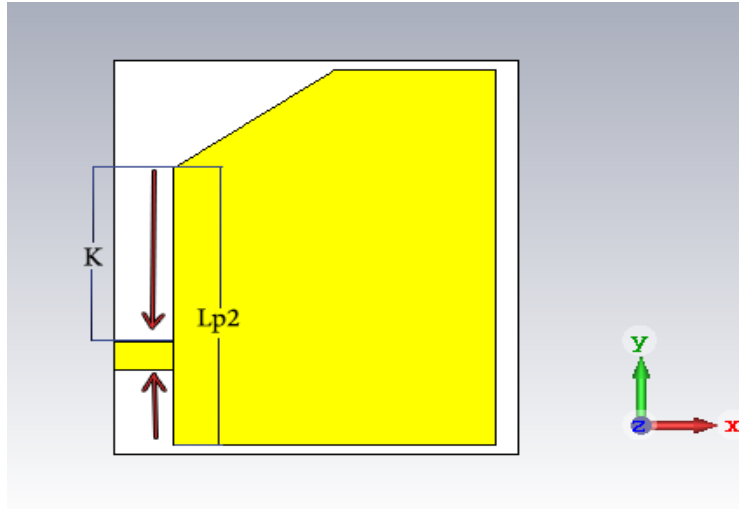


Figure III.7: Rectangular patch with beveled corner after changing feeder position

The parameters k and L_{p2} are listed in **Table III.3**.

Table III.3: The parameters k and L_{p2} which are used to change the feeder position

k	L_{p2}
17.50	28.00

To choose the best value of the parameter k , a parametric study was done as mentioned in Figure III.7.

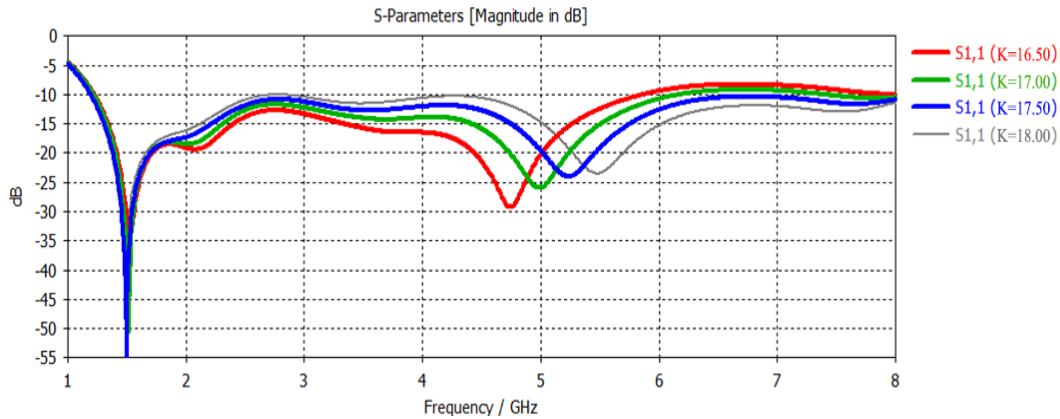


Figure III.8: Return loss curves S_{11} for many values of parameter k .

As illustrated in the figure above, the blue curve is best curve in terms of ultra-wideband ranging from 1.2 to 8 GHz, while the other curves are going upper of -10 dB for some frequencies.

The best result is illustrated in Figure III.9, when the designed antenna has a large band about of 6.8 GHz [1.2-8 GHz]. To make the band larger, another parametric study is needed.

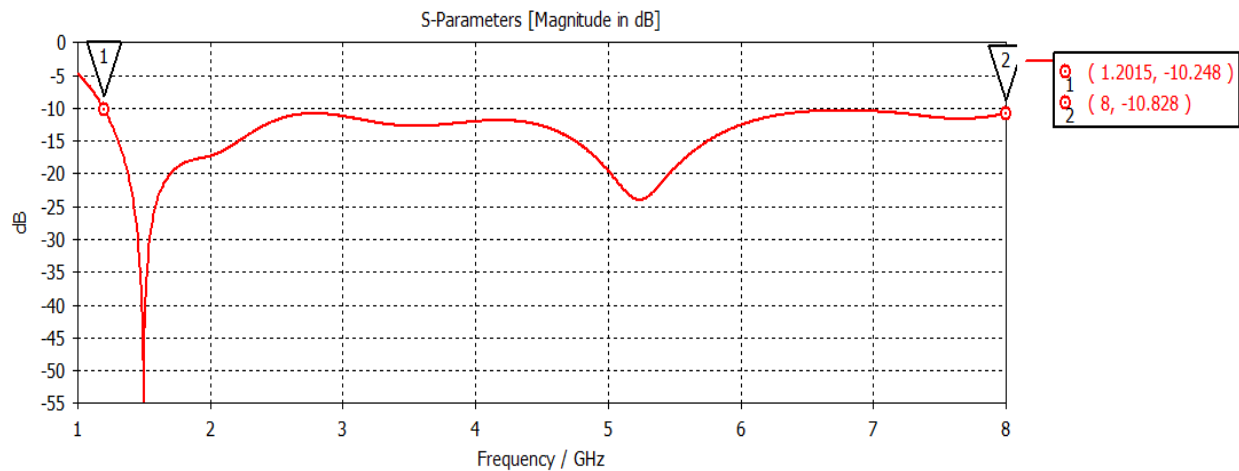


Figure III.9: Return loss curve S_{11} for best value of parameter K

III.2.2.3 Effect of beveled corner dimension in the presence of second beveled corner

The obtained result in last step is good, but we need to enlarge the bandwidth more. In the present step, we will change the dimension of the first beveled corner (SLASH) in the presence of another beveled corner. An optimization process will be run to achieve the best value of this dimension using CST genetic optimization method.

Figure III.10 illustrates S_{11} curve for many values of SLASH parameter.

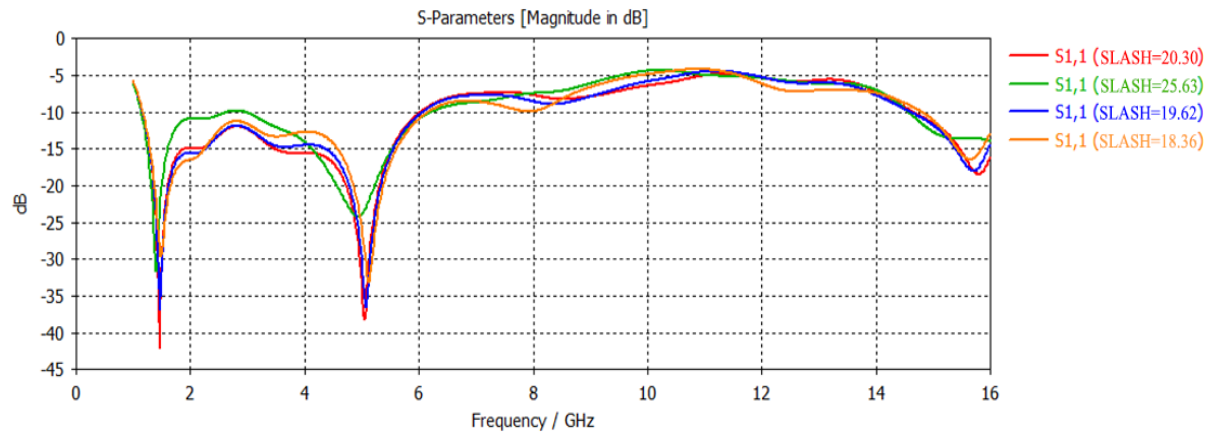


Figure III.10: Return loss curves S_{11} for many SLASH parameter.

As shown in the figure above, the red curve is better than the others in terms of bandwidth under -10 dB in the band ranging from 1.3 to 6 GHz and in another band ranging from 14.6 to 16 GHz.

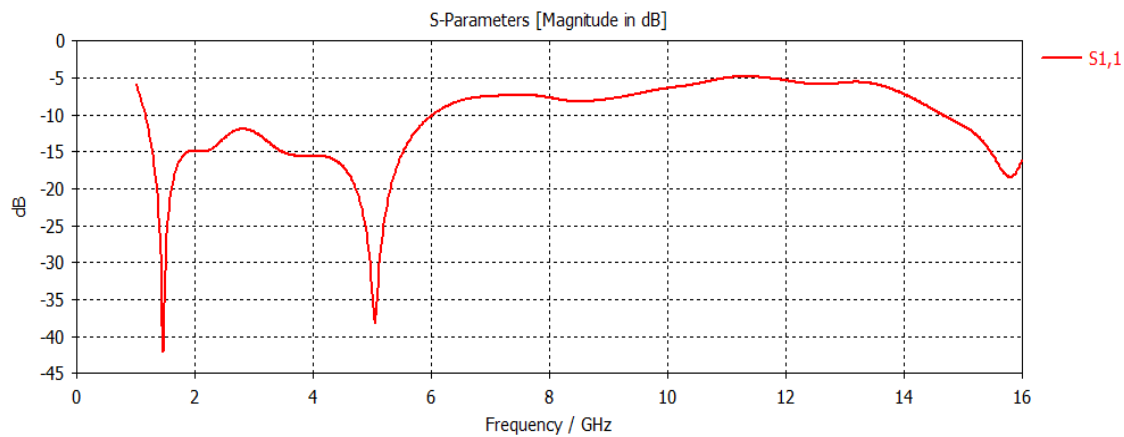


Figure III.11: Return loss curve S_{11} for best value of SLASH parameter.

As can be seen in Figure III.11, the curve of S_{11} for the best value of SLASH parameter (SLASH = 20.30 mm). the designed antenna presents a large band ranging from 1.3 to 6 GHz. Figure III.12 shows the top view of the designed antenna with the new value of SLASH parameter (SLASH = 20.30).

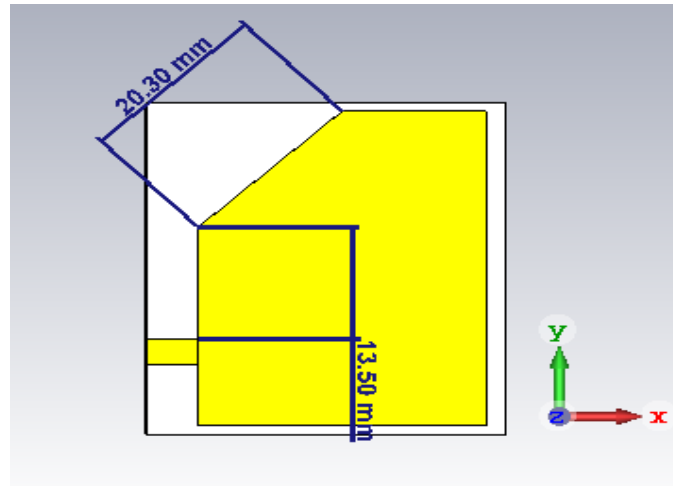


Figure III.12: Beveled Rectangular patch with the new value of SLASH parameter.

To achieve the best preference of the proposed antenna, another beveled corner will be added as illustrated in Figure III.13. In this case, an optimization process, using genetic optimizer debugged in CST studio, will be launched to obtain an optimal combination of two parameters of the second beveled corner ($Wp3$ and $Lp3$).

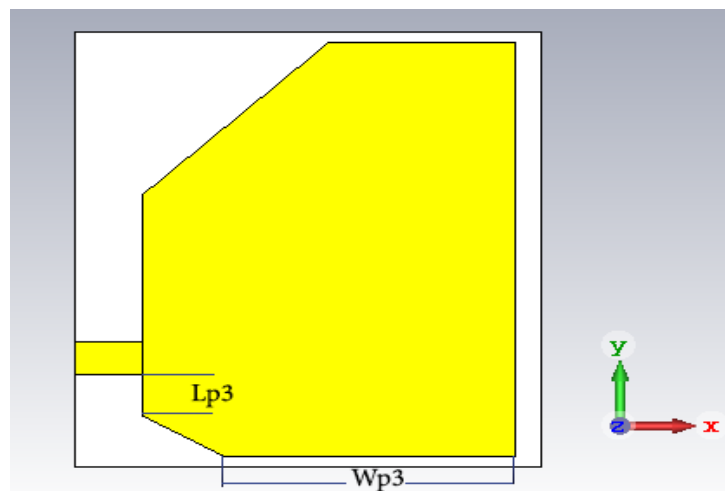


Figure III.13: Antenna patch with two beveled corners.

After the optimization process, the obtained result (S_{11} curve vs frequency) is shown in Figure III.14

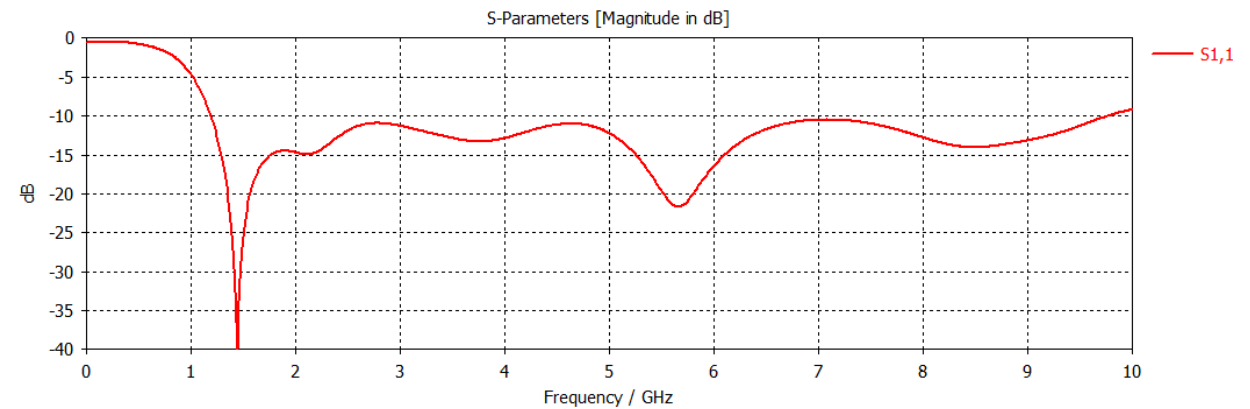


Figure III.14: Return loss curve S11 optimization result (best of far) step III.

As shown in Figure III.14, the bandwidth of the proposed antenna is enlarged to [1.2 ,10 GHz].

We notice here that this operation takes very long time. The time of run is commensurate with the frequency range and the number of parameters to be optimized.

The optimal combination for the parameters Wp3 and Lp3 is set to Wp3=22.90 mm and Lp3= 3.75 mm.

III.2.2.4: Addition a rectangular notch at ground plane

To improve the bandwidth of the last design, a rectangular notch at ground plane will be added. The position of the rectangular notch is given by $N_{fix} = 8.44$ mm, as mentioned in Figure III.15. The dimensions of the notch are given by the notch depth N1 and notch width N2. These two parameters will be optimized.

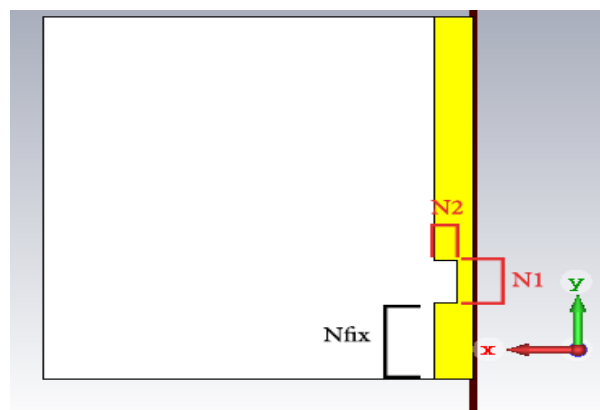


Figure III.15: Bottom view of the antenna with notched ground plane.

After the optimization, the optimal values of parameters N1, N2 are listed in Table III.4. this combination leads to the resulted Return loss curve (S_{11}) in the band [0-20 GHz] as shown in Figure III.16.

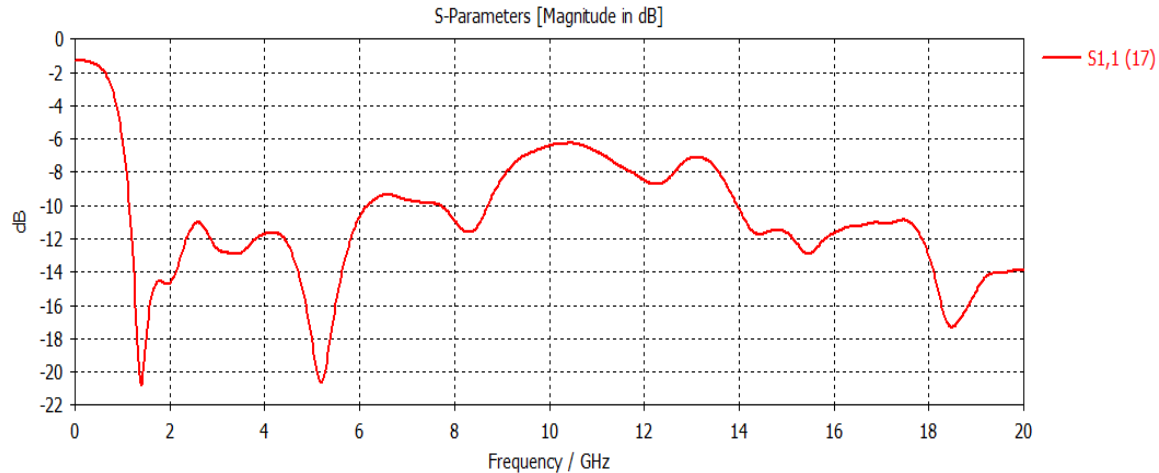


Figure III.16: Corresponding return loss curve S_{11} of optimized N1, N2

As shown in Figure III.16, the antenna presents two wide bands: the first one is ranging from 1.2 to 6 GHz, while the second band is ranging from 14 to 20 GHz. In other side, we can see clearly that the corresponding S_{11} is lower than -6 dB in the range [1 GHz - 20 GHz].

Table III.4: The optimal combination (N1, N2) of the proposed antenna in mm

N1	N2
4.66	1.94

III.2.2.5 Addition the second rectangular notch in ground plane

As can be seen in the last step, the notched ground plane affected on bandwidth of the proposed antenna. To enlarge more the bandwidth much more, another notch on the ground plane will be added. The notch dimensions and position are given by depth parameter N4, width parameter N3 and position NP (see Figure III.17).

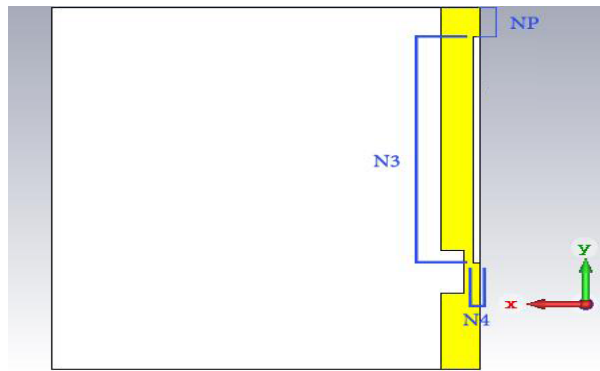


Figure III.17: Ground plane view in the presence of second rectangular notch.

The corresponding S11 curve in the presence of the second notch is illustrated in Figure III.18.

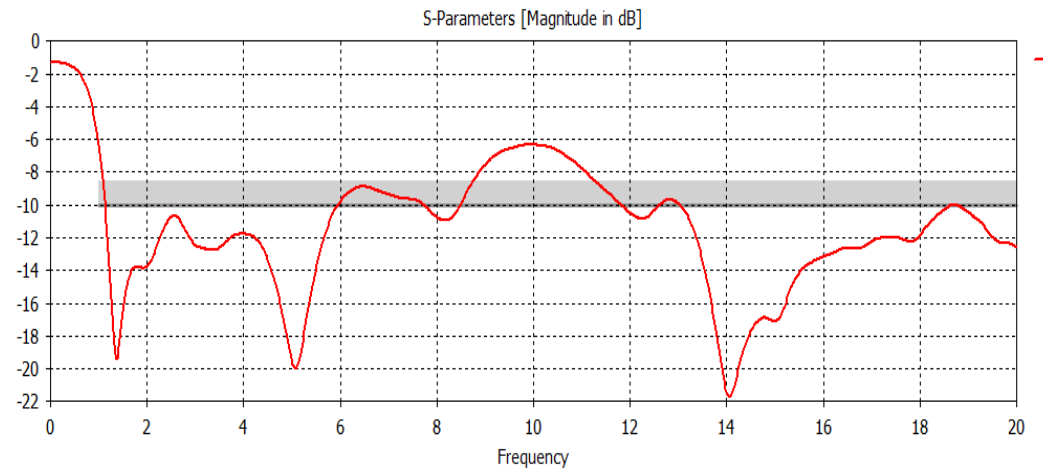


Figure III.18: Return loss curve S_{11} in the presence of the second notch at the ground plane.

As shown in Figure III.18, our designed antenna has a bandwidth ranging from 13 to 20 GHz, in the presence of the first band which is ranging from 1.2 to 6 GHz. To get the best notch position at the ground plane and its dimensions, an optimization process will be run. The optimal values of this second notch are tabulated in Table III.4

Table III.5: The optimal dimensions of the second notch at the ground plane in mm

N3	N4	NP
24.66	1.94	3.22

III.2.2.6 Addition of two rectangular shape at the patch

In this part, we suggest addition of two rectangular shape at the patch (near to the beveled corners) as can be illustrated in Figure III.19.

The first rectangular shape has three parameters L_{rec} , W_{rec} and P_{rec} for the long, width and position value at the top view of the proposed antenna.

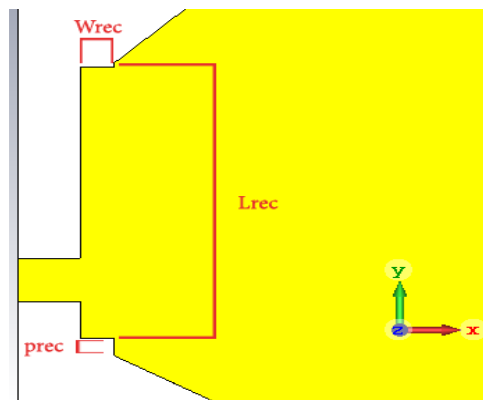


Figure III.19: the rectangular shape added around feeder and parameters place

The second rectangular shape has two parameters L_{rec1} and W_{rec1} for the dimensions of the rectangular shape. The position is relying directly to the first rectangular shape position (see Figure III.20).

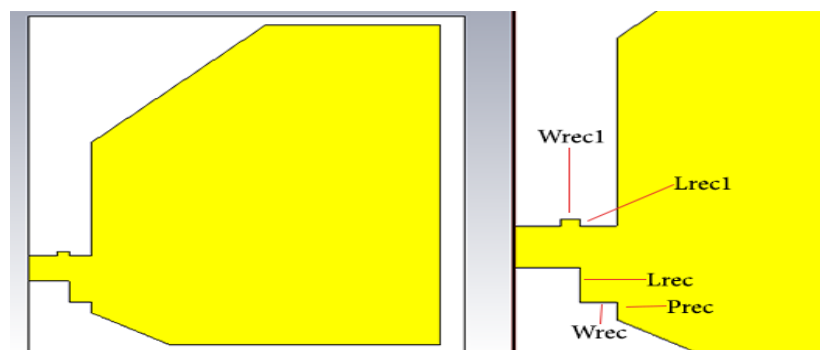


Figure III.20: Top view of the final microstrip patch antenna.

An optimization process will be applied to get the best combination of the following five parameters L_{rec1} , W_{rec1} , L_{rec} , W_{rec} , P_{rec} in terms of bandwidth in band range [1-25 GHz].

Figure III.20 shows the top view of the final ultra-wideband antenna. The optimal values for W_{rec} , L_{rec} , P_{rec} , W_{rec1} , L_{rec1} are tabulated in Table III.6.

Table III.6: The optimal dimensions of the final patch antenna in mm

W_{rec}	L_{rec}	P_{rec}	W_{rec1}	L_{rec1}
1.90	2.50	1.25	1.00	0.50

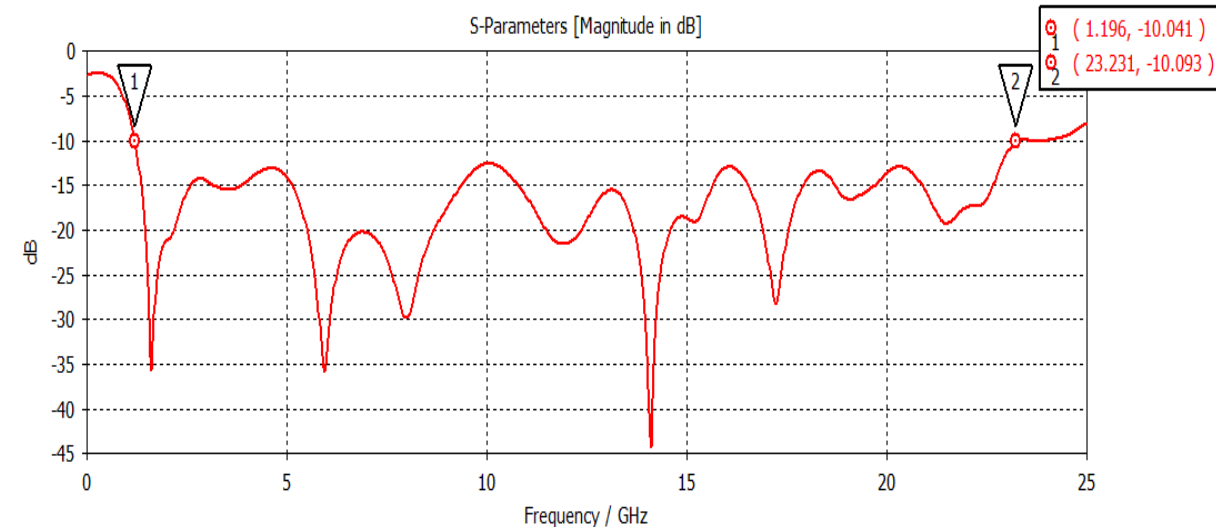


Figure III.21: Return loss curve S_{11} optimization result (best of far) step VI

After the optimization, the corresponding S_{11} curve is illustrated in Figure III.21. As can be seen, an ultra-wideband is achieved in the range [1.2, 23.2 GHz] with a bandwidth about 22 GHz which can be considered as a very satisfied result.

The obtained antenna is an UWB antenna perfectly. A comparison between the design concept and practical realization must be done to confirm the obtained results.

III.3 Conclusion

In this chapter, a parametric study and optimization process were done to achieve ultra-wideband antenna using the CST studio simulator. During this design, a rectangular beveled corner is added on the patch while at the bottom view, a rectangular notch was added to the reduced ground plane. The parametric study shows the effect of many parameters (dimension of beveled corners, dimension of ground, creation of notches in ground, feedline position, addition stabs in feeder) at the characteristics and performance of the obtained antenna such as the reflection coefficient and bandwidth. In the last, an UWB antenna is achieved with a frequency band ranging from 1.2 to 23 GHz.

Chapter IV :
Ultra-wide band
reconfigurable
antenna

IV.1 Introduction

In the previous chapter, an ultra-wideband antenna has been designed, after a parametric study and optimization process. The proposed antenna operates in frequency band ranging from 1.3 to 23 GHz.

In this chapter, the reconfigurable antennas are dedicated to wireless local area network (WLAN) applications according to the 802.11 standard on 2.4 GHz frequency band.

To show the effect of the frequency reconfiguration on the bandwidth of the designed antenna, notched circular shape will be added at the center of the bottom view. The slots of the added circle will be equipped with four PIN diodes to reconfigure the antenna. In the same way, a series of E shape at the ground will be added to the structure. Five diodes will be inserted at the end of these E shapes to notch a bandwidth of the UWB antenna by changing the state of these switching diodes.

The designing of the proposed structure is divided into three steps. Firstly, our goal was the design of an antenna that can operate on an ultra-wide band [1.3-23 GHz]. In the second step, the reconfigurable antenna can operate on WLAN band (at a frequency of **2.4 GHz**) while after the second reconfiguration the antenna will reject the previous WLAN band (**2.4 GHz** notched band).

IV.2 Design of a frequency reconfigurable antenna

A frequency reconfigurable UWB antenna will be designed, using PIN diodes (BAR50-02V) that talked about in chapter 2. The frequency range of this diode is from **2 MHz** to **6 GHz**, so we can control its state (ON or OFF) within that frequency range. In the other bandwidth (more than 6 GHz), the PIN diode cannot switch perfectly (staying ON). Because of this limitation, we will simulate our design only in the band 1 to 6 GHz for WLAN application.

IV.2.1 The geometry of the proposed antenna

We will start from the designed Ultra-wide band patch antenna in last chapter as illustrated in Figure IV.1. The different dimensions of the proposed antenna are tabulated in Table IV.1.

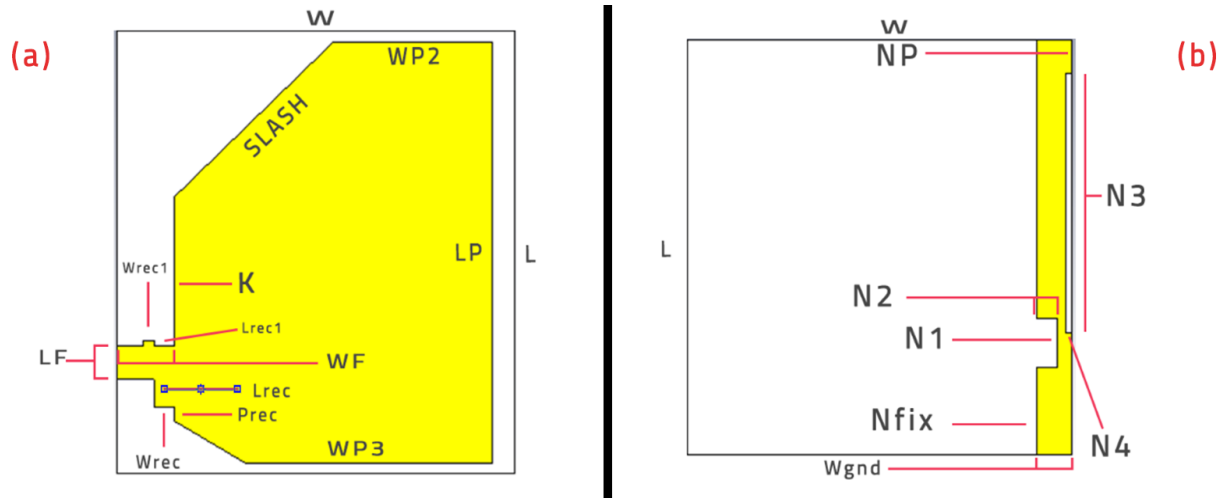


Figure IV.1: Geometry of the proposed UWB antenna, (a) top view of the antenna, (b) bottom view of the antenna.

Table IV.1: The dimensions in millimeter of the proposed UWB antenna.

W	36.67
L	40.00
LP	38.00
WP2	14.70
WP3	22.90
SLASH	20.30
K	13.50
LF	3
WF	5.30
Lrec	2.50
Wrec	1.90
Prec	1.25
Lrec1	0.50
Wrec1	1.00
Wgnd	3.30
N1	4.66
N2	1.94
N3	4.66
N4	1.94
Nfix	8.44
Np	3.22

Firstly, a circular shape will be added at the ground as can be seen in Figure IV.2. The shape has a rayon of 20.28 mm and a width of 2 mm. To see the effect of it at the band between 1 and 6 GHz.

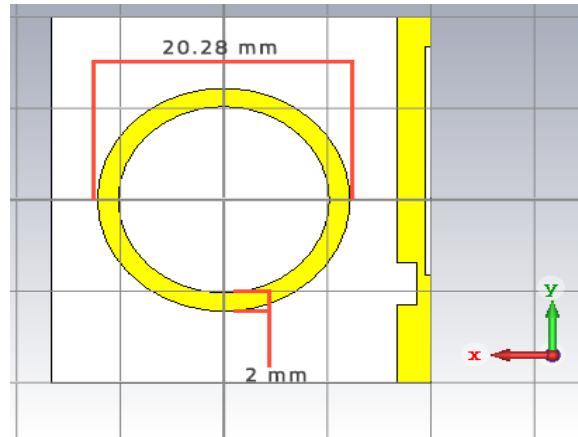


Figure IV.2: Bottom view after addition of circular shape.

After simulation, we clearly seen an effect of the added circle on Return loss curve S_{11} (Figure IV.3), when S_{11} presents two rejected bands. The first band ranging from 2.3 to 2.4 GHz, while the second band ranging from 4.1 to 4.65 GHz.

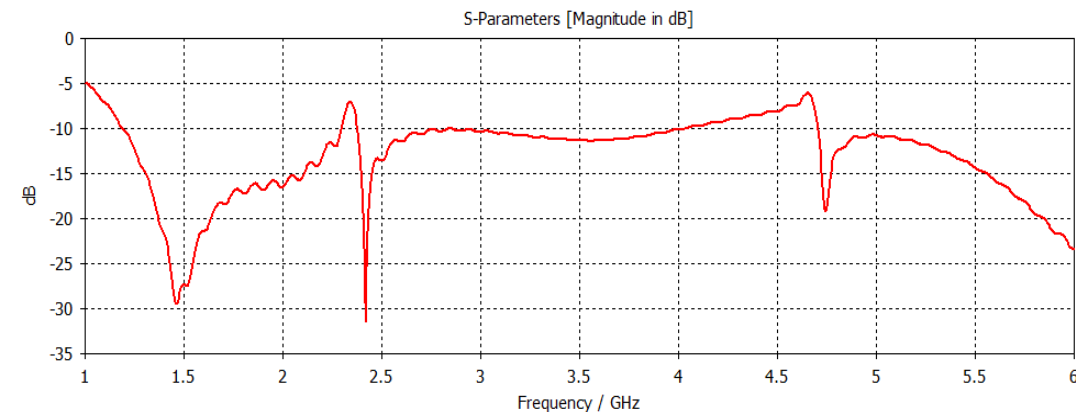


Figure IV.3: Return loss curve S_{11} after the addition of circular shape at the ground.

To investigate more about the effect of the added circular shape at the band 2.4 GHz, it is necessary to illustrate the current distribution at the ground surface for the frequency of 2.4 GHz as presented in the following Figure IV.4.

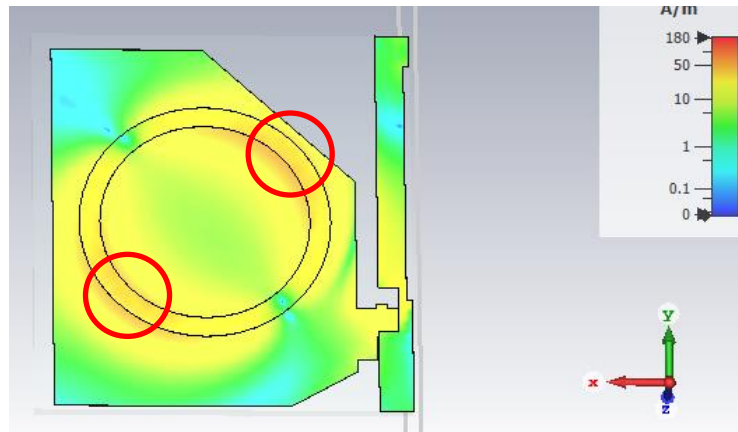


Figure IV.4: Surface current density distributions on the added circular shape at the ground for 2.4 GHz.

We will create slots on along the circumference of the circular shape at the places those have a huge amount of current distributions as indicated by the red circles in Figure IV.4. The new design of the proposed antenna is shown in Figure IV.5. The added slots change the electric surface current distribution of antenna as can be seen in the same Figure IV.5.

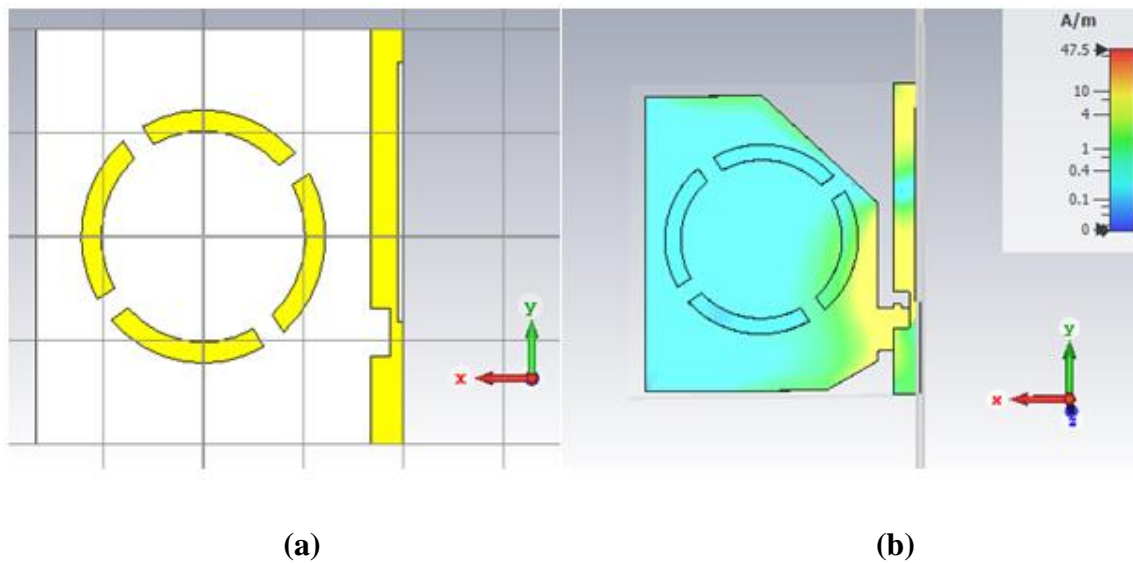


Figure IV.5: The bottom view after adding the slots on circular shape in (a) and the current density distributions on 2.4 GHz frequency in (b).

The PIN diodes can be added in the slots as shown in Figure IV.6. Each PIN diode has two states (ON-OFF) which makes 16 possible cases (four diodes) to simulate the proposed antenna.

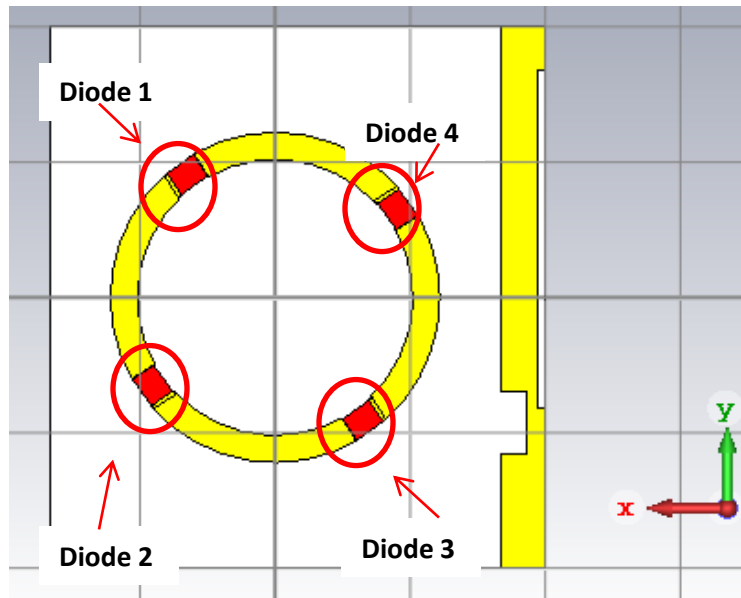


Figure IV.6: The placement of the added four diodes on the circumference circular shape.

IV.2.1.1 Simulation of some possible cases

Due to the huge number of possible cases, we will simulate just five cases in order to achieve two reconfigurations. The first one is to obtain full frequency bandwidth ranging from 1 to 6 GHz. The second one will be done to reject the 2.4 GHz band from the previous full bandwidth.

The five cases are illustrated in Figure IV.7, with the resulted Return loss curves S_{11} for each case.

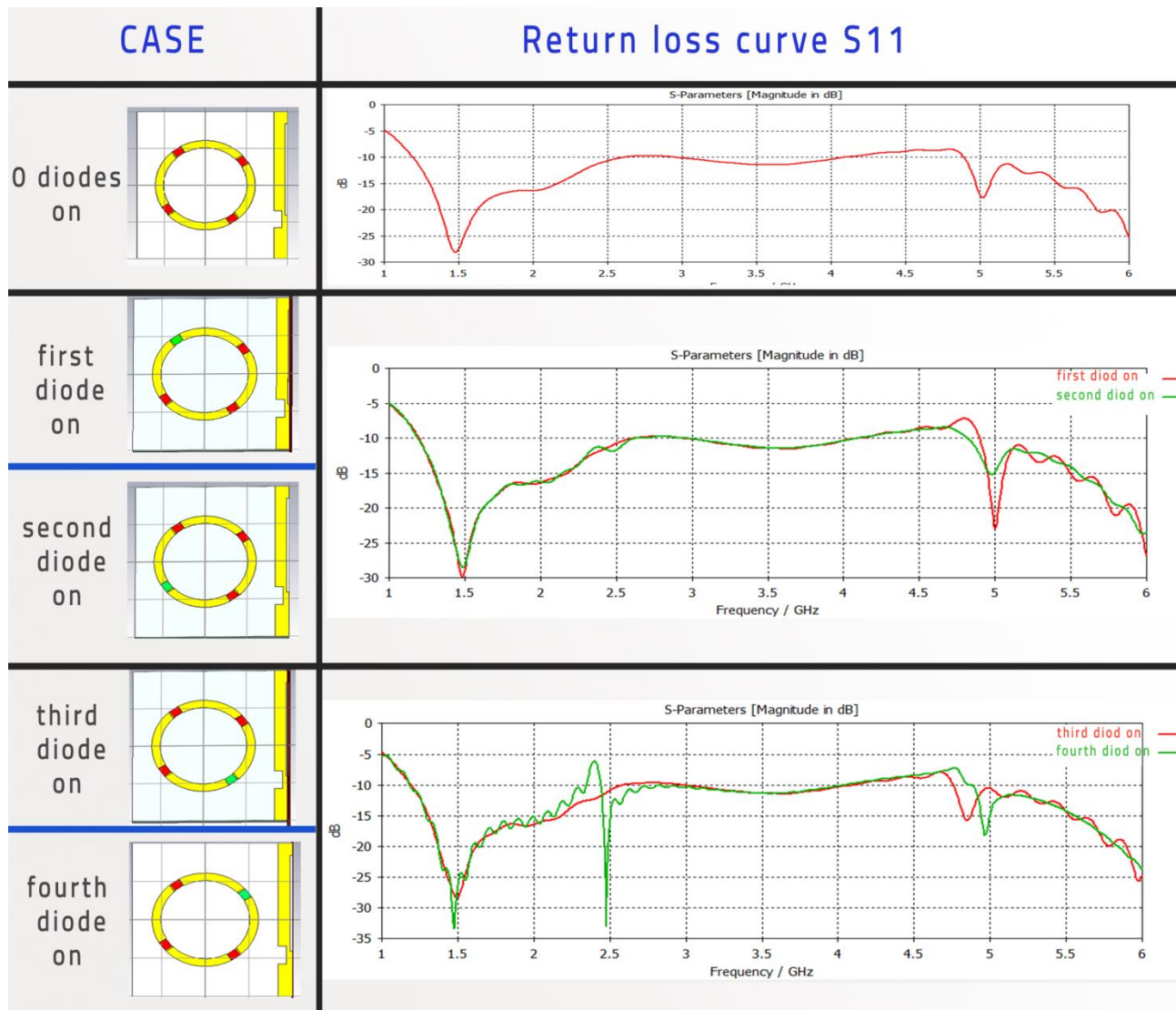


Figure IV.7: Some simulated reconfiguration with the resulted Return loss curves S₁₁.

- **First case:** All PIN diodes are OFF

In this case, the designed antenna has a full band ranging from 1.3 GHz to 6 GHz, with a notch band in in the range [4.2 GHz -4.9 GHz].

- **Second case:** The first diode is ON, while the others are OFF

In this case, the antenna presents a full band in the range [1.3 GHz- 6 GHz] with a notch band in the range [4.1 GHz -4.9 GHz].

- **Third case:** The second diode is ON while the others are OFF

In this third case, the obtained antenna presents a full band [1.3 GHz -6 GHz] with a notch band in the range [4.1 GHz -4.8 GHz]

- **Fourth case:** The third diode is ON while the others are OFF
In this case, the antenna has a full band ranging from 1.3 GHz to 6 GHz, with a notch band in the range [4.1 GHz -4.7 GHz].
- **Fifth case only fourth diode ON and the other diodes OFF**
In this last case, the obtained antenna operates at the band [1.3 GHz -6 GHz] with two notch bands. The first one is ranging from 2.35 GHz to 2.45 GHz, while the second one is in the range [4.1 GHz -4.9 GHz].

After comparing the obtained results, as can be seen, the fifth case is the only one that has a notch band around the frequency 2.4 GHz but it still notches another band [4.1-4.8 GHz]. Therefore, we propose to remove the second half of the circular shape that has no effect on the target frequency.

IV.3 Improve the obtained results

In order to improve the obtained results, we suggest three steps:

- Firstly, we remove the second half of the circular shape that has no effect on the target frequency (2.4 GHz).
- Secondly, a parametric study in slash parameter will be done, to show the influence of this parameter on the target frequency (2.4 GHz).
- In third step, a series of E-shape slots in the ground will be added.

IV.3.1 Removing the second half of the circular shape

As seen before, we notice that the case when the fourth diode is ON is the only case that effect on the 2.4 GHz frequency band (see Figure IV.7). The switching of the other diodes had no strong effect on the target frequency. For that, we suggest removing the second half of the circular shape which will become as shown in Figure IV.8.

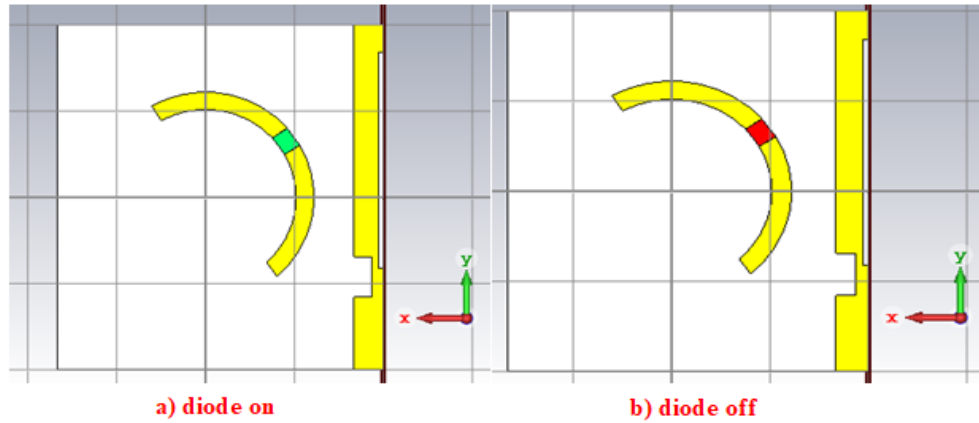


Figure IV.8: Bottom view of antenna after removing the half of the circular shape with one diode, (a) diode is ON, (b) diode is OFF.

Figure IV.9 show the simulated S-parameter S_{11} for the proposed antenna which clearly shows that a frequency notch band is achieved around 2.4 GHz for the case when the diode is ON, and the return loss is slightly upper than -10dB from 4 to 4.7 GHz. So, it can be is conclude that other parameters will be optimized.

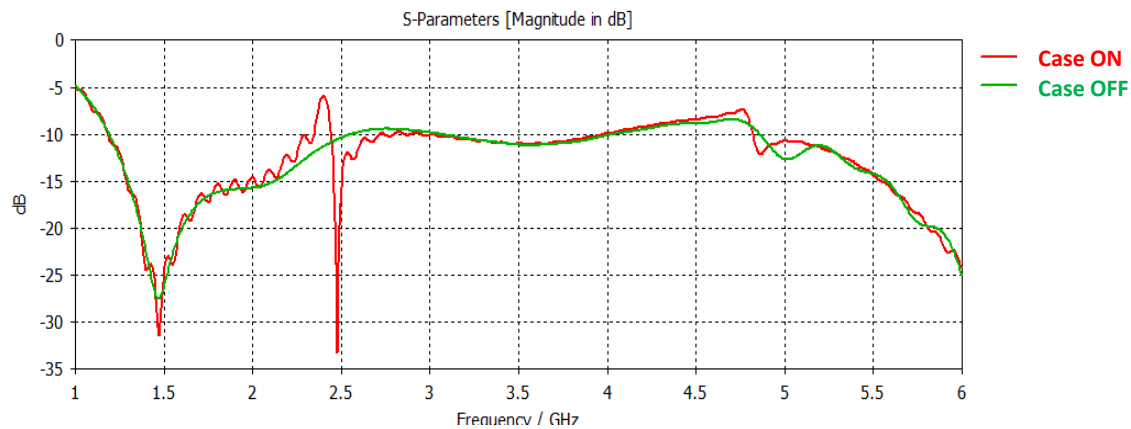


Figure IV.9: Return loss curves S_{11} of two cases of the diode ON/OFF.

IV.3.2 Effect of 'SLASH' parameter

In the previous step, we noticed that the S_{11} curve in the frequency range [4 - 4.9 GHz] was upper than -10 dB, (about -7 dB). Therefore, to improve the performance of the antenna in the range [4 - 4.9 GHz] without affecting on the frequency band around 2.4 GHz, we propose to re-apply the parametric study on **SLASH** parameter when diode is ON.

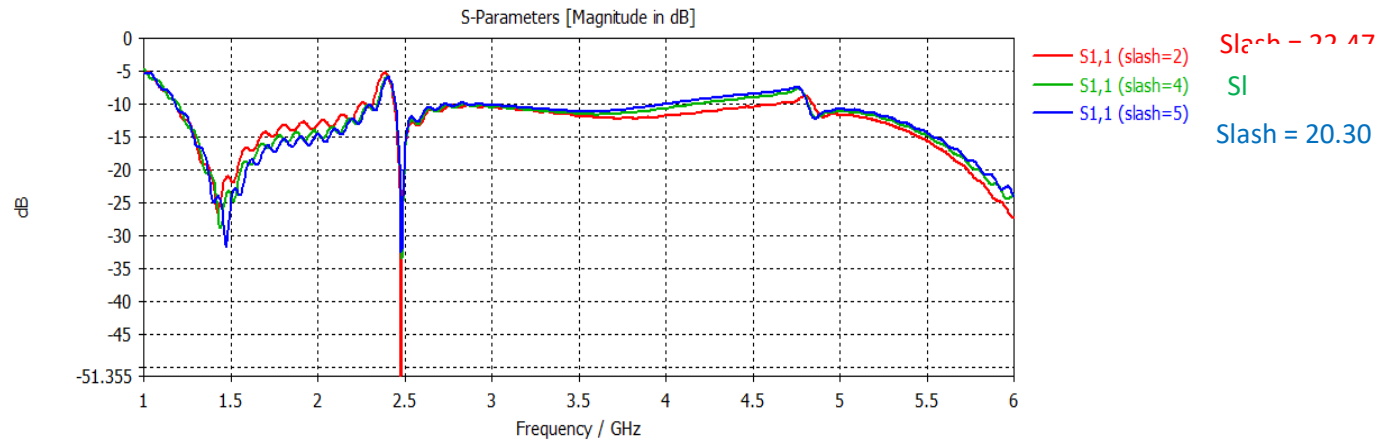


Figure IV.10: Return loss curves S_{11} for parametric study on the parameter (SLASH).

The Figure IV.10 shows slight effect of the parameter Slash on the return loss of the antenna in the frequency range from 1 to 6 GHz. For that, we need another step to enhance much more our results. We notice the Slash parameter will take the new value (22.47 mm).

IV.3.3 Adding a series of E-shaped slots at the ground

To improve the antenna performance, it is necessary to study the current distributions over the ground, for a given frequency (2.4 GHz). Figure IV.11 presents the electric current distribution which is high as indicated in the area surround with red circle.

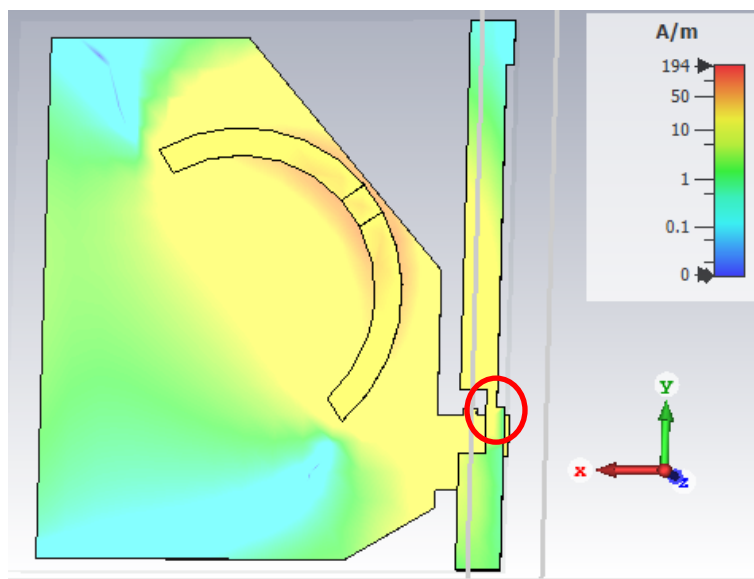


Figure IV.11: Surface current distributions over the ground for 2.4 GHz.

We suggest adding series of 5 E shaped-slots in the area of the red circle as shown in the Figure IV.11. The E shape is chosen because it has three heads, which is suitable to insert diodes at those heads. These E shapes will change the electrical current distribution on the surface of the ground. The figure below (Figure IV.12) shows the placement of those E-shapes and its dimensions in millimeter.

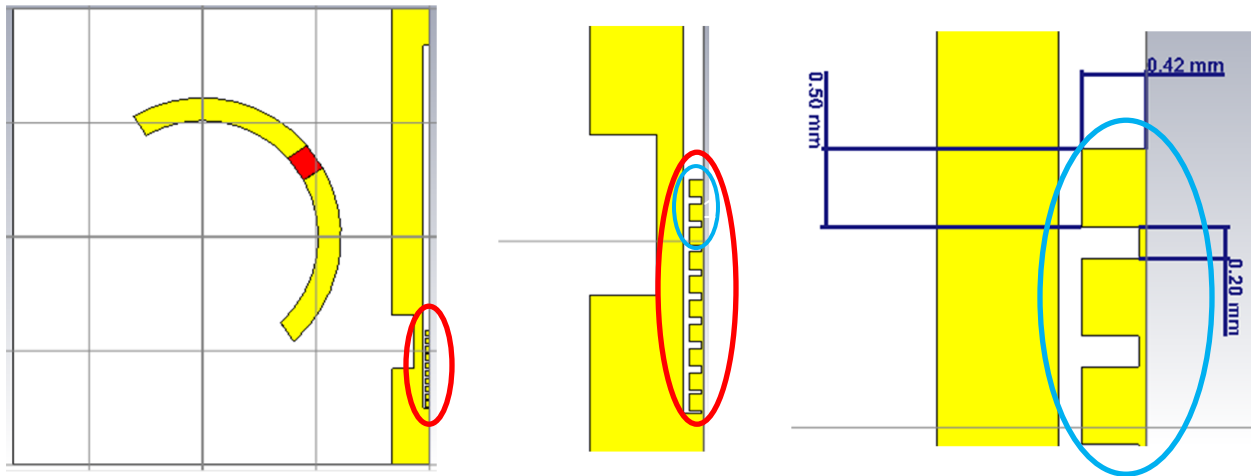


Figure IV.12: Bottom view of the designed antenna after the addition of E-shapes.

After the addition of the E-shapes, the new return loss S_{11} curve is shown in the figure below (Figure IV.13) with the case when the first diode is OFF. This new design has a resonance at the frequency 2.4 GHz, which is corresponding to the WLAN 1 band, with a bandwidth ranging from 2.23 GHz to 2.69 GHz.

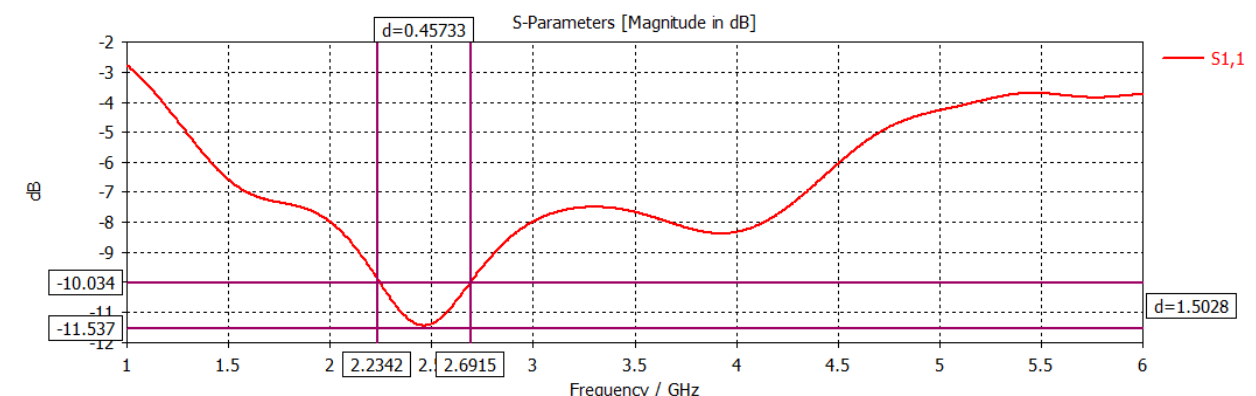


Figure IV.13: Return loss S_{11} curve after adding of E-shapes for the case when the first diode is OFF.

When the PIN diode is ON, the antenna presents the following S_{11} curve as shown in Figure IV.14. The antenna has a notch band at 2.4 GHz for WLAN rejection, but it has a resonance at the 2.31 GHz frequency with a bandwidth ranging from 2.16 GHz to 2.81 GHz.

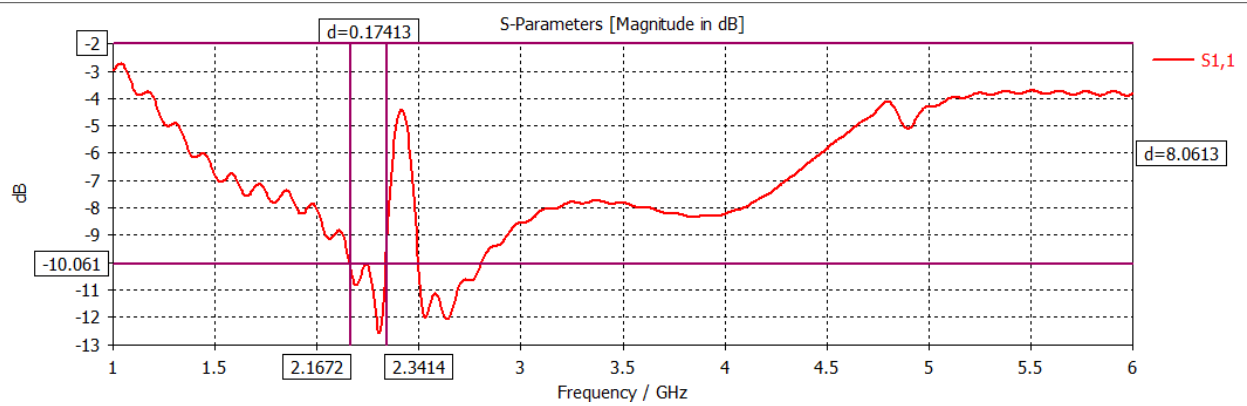


Figure IV.14: Return loss curves S_{11} after adding E-shapes, when the first diode is turned ON.

After seeing the effect of the E-shapes, we suggest adding five diodes in specific placements as illustrated in Figure IV.15. The five diodes are inserted between the 2 notches that we made it at the ground to alter the distribution of the current distribution.

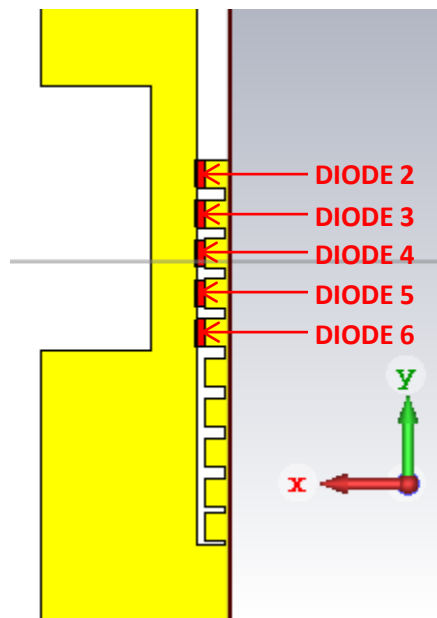


Figure IV.15: The placement of the added diodes at the ground.

IV.4 Simulation results

The present antenna has six diodes, which means that we have 36 possible cases ON-OFF. Therefore, we will see just some cases following to our goal (stop band at 2.4 GHz, UWB antenna, and operating frequency at 2.4 GHz).

- **Case 1 (Diodes 1, 2, 3, and 4 are ON and the others are OFF)**

In this case, the diodes number 1, 2, 3, and 4 are On, while the diodes number 5 and 6 are OFF.

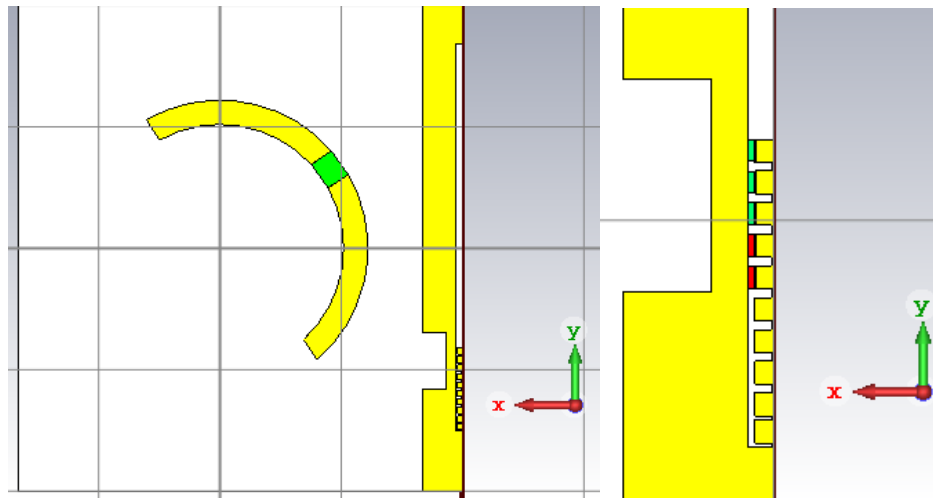


Figure VI.16: Diodes placements at the ground 'Red : diode is OFF , Green : diode is ON.

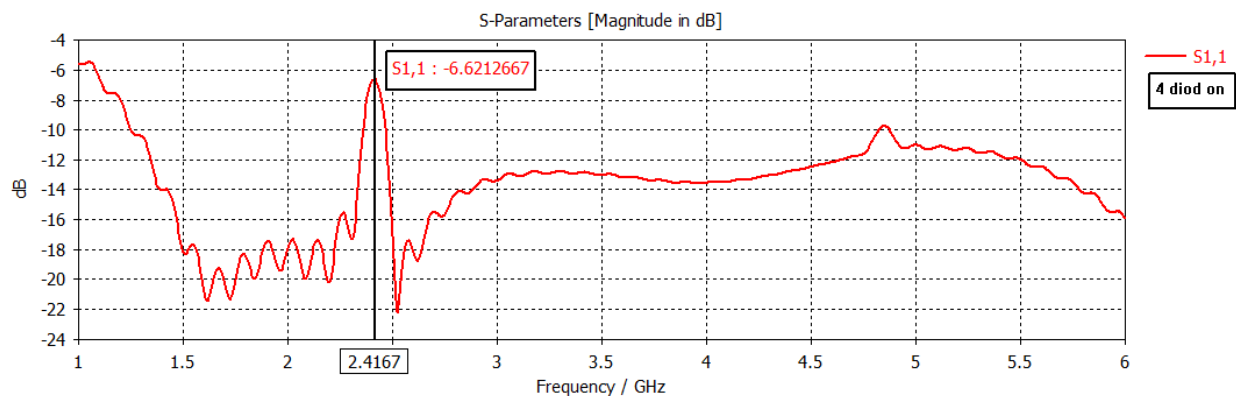


Figure VI.17: Return loss curve S_{11} for the first case presented on Figure VI.16.

This reconfiguration present full band ranging from 1.3 to 6 GHz with a notch band at 2.4 GHz (S_{11} around -6.62 dB) which is corresponding to the WLAN 1 band with a bandwidth ranging from 2.33 GHz to 2.48 GHz.

- **Case 2 (All diodes are OFF)**

In this case all the six diodes are turned OFF. This reconfiguration has a resonance frequency at 2.4 GHz which is corresponding to the WLAN 1 band with a bandwidth ranging from 2.23 GHz to 2.69 GHz at -10dB (see Figure IV.18).

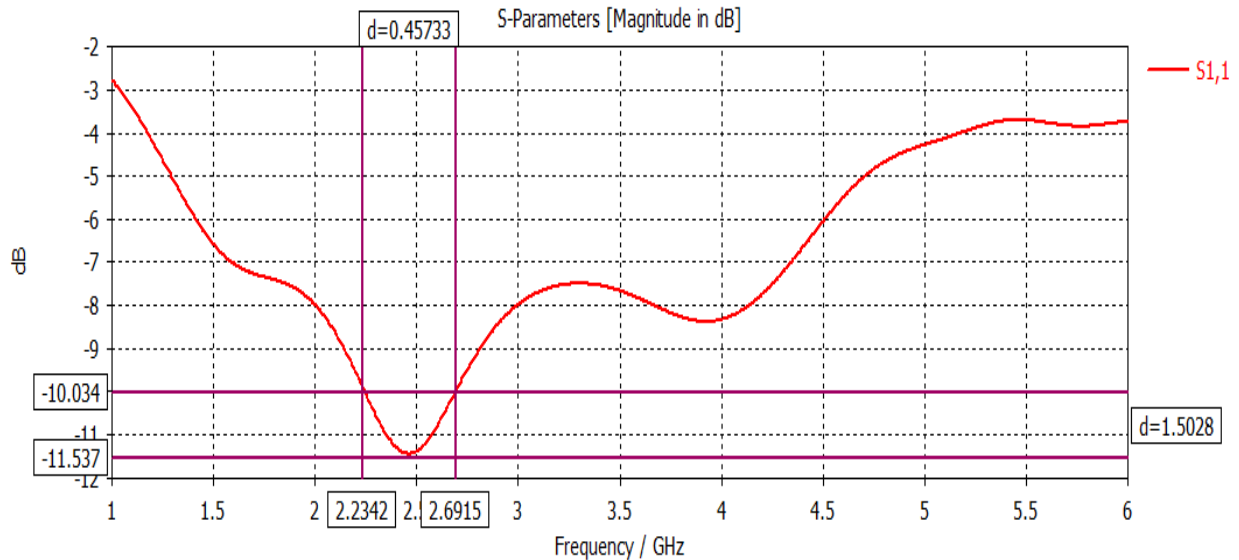


Figure IV.18: Return loss curve S_{11} for the second case (all diodes are OFF).

- **Case 3 (diodes 2 and 6 are ON and the others are OFF)**

In this case, diodes number 2 and 6 are turned ON, the others are turned OFF. This reconfiguration presents a resonance frequency at 1.6 GHz frequency at -20.2 dB with a bandwidth ranging from 1.3 GHz to 6 GHz at -10dB.

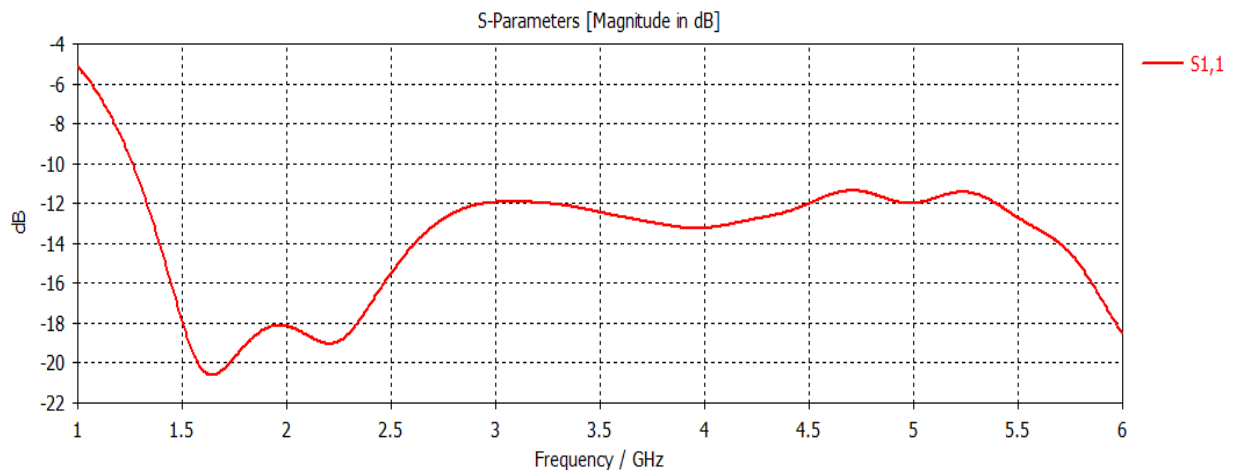


Figure IV.19: Return loss curve S_{11} for the third case.

- **Case 4 (diodes 1, 2 and 6 are turned ON while the others are turned OFF)**

In the present case, the diodes 1,2, and 6 are ON while the diodes 3, 4, and 5 are OFF. This reconfiguration makes the designed antenna having a wide band [1.2 – 6 GHz] with a notch band on 2.4 GHz frequency (S_{11} around -7.4 dB) which is corresponding to the WLAN 1 band, with a range from 2.34 GHz to 2.47 GHz.

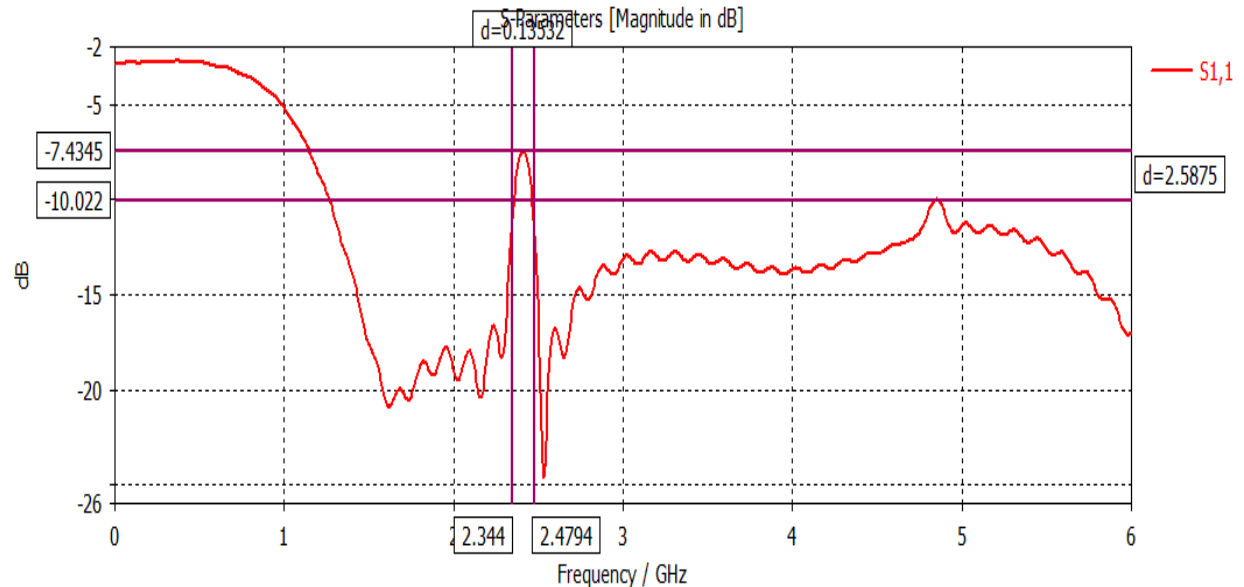


Figure IV.20: Return loss curve S_{11} for the fourth case.

- **Case 5 (all diodes are ON)**

In this reconfiguration, the antenna has a wideband ranging from 1.2 to 6 GHz, with a notch band at the frequency 2.4 GHz (S_{11} around -7.4 dB) which is corresponding to the WLAN 1 band with a bandwidth ranging from 2.34 GHz to 2.47 GHz. The frequency 4.8 GHz is about -12 dB which makes this model has a sufficient adaptation on all bandwidth.

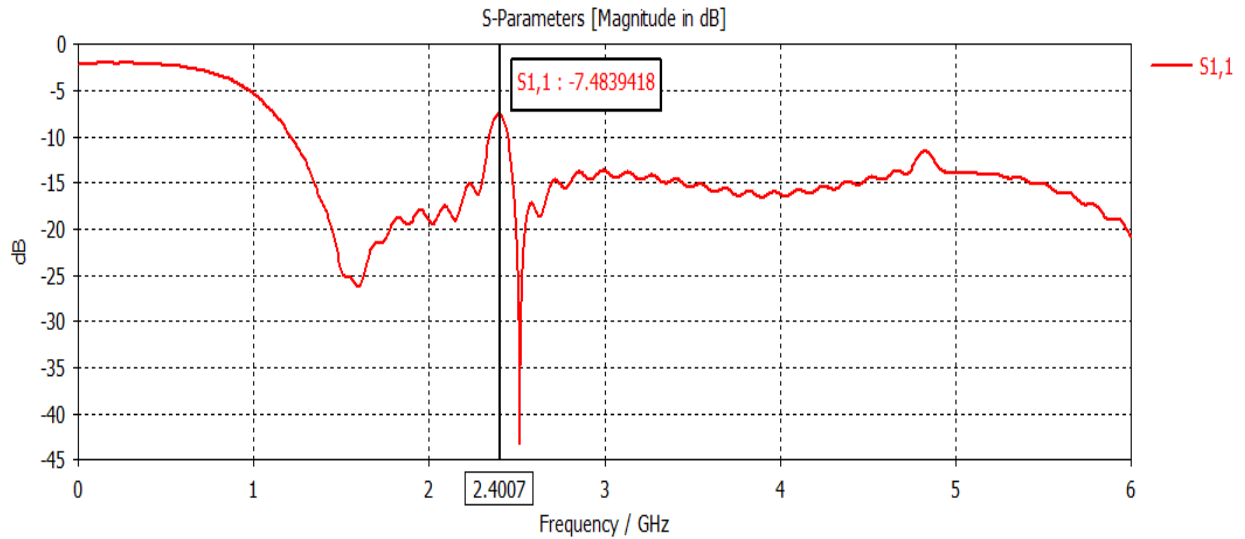


Figure IV.21: Return loss curve S_{11} for the fifth case.

- **Case 6 (the first diode is turned OFF while the others are turned ON)**

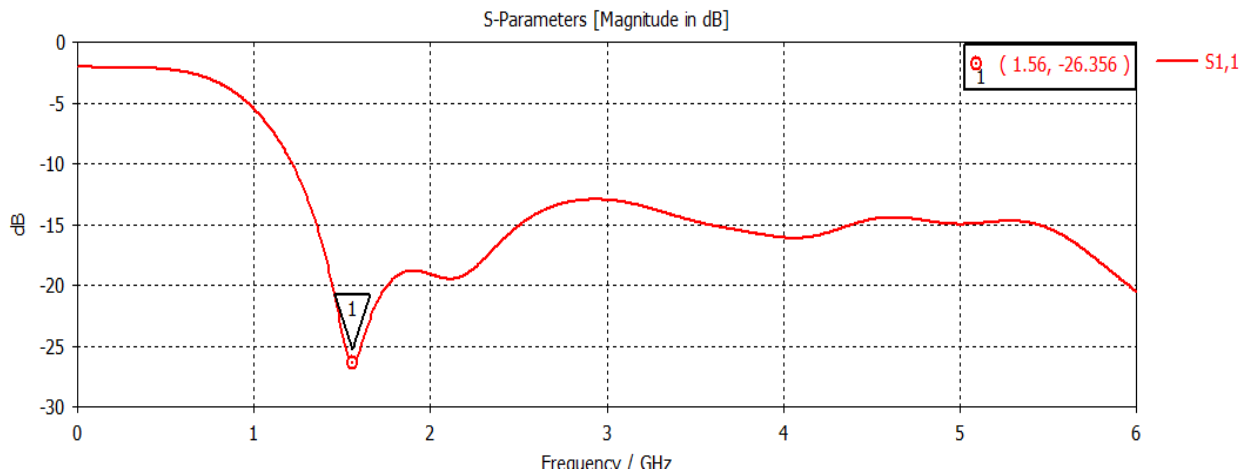


Figure IV.22: Return loss curve S_{11} for case 6

This last reconfiguration makes it possible to have a wide band with a resonance on a 1.56 GHz frequency at -26.3 dB with a bandwidth ranging from 1.2 GHz to 6 GHz at -10 dB.

IV.5 Conclusion

In this chapter, a frequency reconfigurable antenna is designed using PIN diodes. The proposed antenna is reached after adding half circle and series of E-shaped in the ground. Reconfigurability is achieved using active components presented in the PIN diode which was modeled as a single piece of metal for the state ON and a discontinuity for the state OFF.

The reconfigurable antenna can switch between 3 cases:

- Ultra-wide band antenna [1.2 – 6 GHz]
- Antenna operates on WLAN band (2.4 GHz)
- Ultra-wide band antenna [1.2 – 6 GHz] with notched band at 2.4 GHz frequency.

As perspectives,

Conclusion

Conclusion

In this thesis, a new frequency-reconfigurable antenna design has been presented for UWB technology and 2.4 GHz band (WLAN 1 band) applications. In the last decades, the design problem of reconfigurable antennas has received great attention, especially in the field of telecommunications. The reconfigurable antennas have the ability to switch between its functionalities using active components such as PIN diodes.

The goal of our work is to design a frequency reconfigurable antenna for UWB applications. The designed microstrip antenna can switch between three cases (operational at 2.4 GHz band, full UWB ranging from 1.3 to 6 GHz, and UWB (1.3-6 GHz) with notched band at 2.4 GHz). To achieve this goal, a parametric study and optimization process was done using full-wave electromagnetic simulator presented in the CST studio 2019.

During this work, a UWB antenna was developed from a simple rectangular patch antenna using a deep parametric study which give us a good idea on the effect of many parameters on the characteristics of antennas such as the reflection coefficient and bandwidth. The resulted antenna has UWB with a frequency ranging from 1.3 GHz to 23 GHz. In the same way, to achieve an optimal reconfigurable antenna, an optimization process was run using the integrated genetic algorithm in the CST software. The reconfigurable antenna was designed by adding a number of E-shaped slots and a half circle shape divided on two arc-resonators at the ground plane. For the reconfigurability, six PIN-diodes are used at the end of the added E-shaped slots.

In this study, we try to use PIN-diode (BAR 50-02V) because it works in the frequency range [1-6 GHz], but unfortunately, the realization of the simulated antenna cannot be done due to the Corona pandemic.

As perspective, we propose to develop the final antenna, using other diodes that operate in the full antenna frequency range, such as the PIN-diode (APD0810-000) which can operate on frequency ranging from 100 MHz to 30 GHz. In the same way, we propose to use other techniques of reconfigurability (pattern, polarization), which is used in beamforming domain.

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المخلص:

تعتبر الهوائيات أكثر المجالات التي تشهد تطورا ملحوظا واهتماما متزايدة في الفترة الراهنة، وذلك لمواكبة متطلبات الأنظمة الخلوية الجديدة والمتمثلة في الحاجة لدعم التطبيقات عريضة المجال . مما أدى بدوره لظهور أنواع من الهوائيات تدعم نطاق ترددي واسع جدا .

ولذلك تم في هذا البحث تقديم نوع جديد من الهوائيات الشرائحية القابلة للتشكيل ذات نطاق واسع جدا لدعم تطبيقات الهاتف المحمول ، وتم في هذا الهوائي إضافة عدد من الشقوق على شكل الحرف E ورنان مقوس على شريحة الأرضي والاعتماد على ستة ثنائيات PIN DIODE في شريحة الأرضي و تمت دراسة تأثير هذه الثنائيات في حالة التوصيل وحالة الفصل على الاستجابة الترددية للهوائي ، عملت هذه الثنائيات على تغيير توزيع انتشار التيار الكهربائي على الشريحة بصورة ساهمت بالحصول على حالات إعادة الضبط المطلوبة وتحسين أداء الهوائي عموما تمت محاكاة الهوائي المقترح واختباره باستخدام برنامج CST studio وذلك لإظهار فعالية الطريقة المتبعة .

الكلمات المفتاحية: الهوائي الشرائحي ، زيادة عرض المجال ، نطاق ترددي واسع جدا ، قابل للتشكيل، شريحة الارضي.

Abstract :

Antennas are one of the most important fields that witnessed remarkable development and a growing interest in the current period, to meet the urgent needs such as supporting more applications and increasing the required frequency band for each application. Many antennas have been presented to support multiband application and increase the frequency bandwidth.

This research present a novel notched band ultra-wideband reconfigurable patch antenna to support the mobile application at this proposed method multi E-shaped slots and Arch resonator have been made at the ground of ultra-wideband microstrip patch antenna and six PIN diode at ground The Reconfigurability is done by changing the status (ON-OFF) of the PIN diode on the ground to get better current distribution on the surface which led to notched band ultra-wideband reconfigurable antenna.

The proposed antenna has been simulated and tested using the CST studio program to demonstrate its superior effectiveness.

Key words : ultra-wideband , microstrip patch antenna ,CST, notched band, reconfigurable ,ground

Résumé :

Les antennes sont l'un des domaines les plus importants qui ont connu un développement remarquable et un intérêt croissant dans la période actuelle, pour répondre aux besoins urgents tels que la prise en charge de plus d'applications et l'augmentation de la bande de fréquences requise pour chaque application. De nombreuses antennes ont été présentées pour prendre en charge l'application multibande et augmenter la bande passante de fréquence.

Cette recherche présente une nouvelle antenne patch reconfigurable à bande rejetée ultra-large bande pour prendre en charge l'application mobile à cette méthode proposée.Des fentes en forme de E multiples et un résonateur Arch ont été réalisés a la mass d'une antenne patch ultra-large bande et de six diodes PIN la mass. La reconfigurabilité se fait en changeant l'état (ON-OFF) de la diode PIN au sol pour obtenir une distribution de courant de beurre sur la surface qui a conduit à une antenne reconfigurable à bande ultra large bande crantée. L'antenne proposée a été simulée et testée à l'aide du programme studio CST pour démontrer son efficacité supérieure.

Mots-clés: reconfigurable, ultra-large bande, antenne patch, la mass , bande rejetée