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أنظمة الاتصالات

Design of Frequency and Pattern Reconfigurable Antenna for UWB Applications

تصميم هوائي لتطبيقات النطاق العريض مع خاصية تغيير التردد ونمط الانبعاث

Mahmoud Ibrahim AboJalambo

Supervised by

Dr. Talal Skaik

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إقــــــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Design of Frequency and Pattern Reconfigurable Antenna for UWB Applications

تصميم هوائي لتطبيقات النطاق العريض مع خاصية تغيير التردد ونمط الانبعاث

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **محمود ابراهيم محمود ابو جلمبو** لنيل درجة الماجستير في **كلية *الهندسة*** قسم **الهندسة الكهربائية – أنظمة الاتصالات** وموضوعها:

تصميم هوائي لتطبيقات النطاق العريض مع خاصية تغيير التردد ونمط الانبعاث

Design of Frequency and Pattern Reconfigurable Antenna for UWB Applications

وبعد المناقشة التي تمت اليوم الأربعاء 05 جمادي الأولى 1438هـ، الموافق 2017/02/01م الساعة العاشرة والنصف صباحاً في قاعة المؤتمرات مبنى طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة

Abstract

The main target of this proposed work is designing antenna with various features and characteristics particularly frequency agility and pattern re-configurability. Reconfigurability is the capacity to change an individual radiator’s fundamental operating characteristics through electrical, mechanical. This thesis presents both radiation pattern and frequency reconfiguration of Ultra Wide Band (UWB) antenna. Novel antenna structure is proposed here with circular shapes added to the feed line and around the main circular patch for both frequency and pattern reconfiguration. PIN switches are used in the design to select the frequency band and to re-configure the antenna radiation pattern. The antenna can operate in eight frequency bands and it can be re-configured to operate in one of eight different radiation patterns. The antenna return loss, radiation patterns and gain were simulated using CST Microwave Studio. The simulation results showed gain greater than 4 dBi for all the reconfigured patterns, and the return loss was better than 6.5 dB.

Keywords: Reconfigurability, (UWB) antenna, CST Microwave Studio.

الملخص

الهدف الأساسي من هذا العمل هو تصميم هوائي بخصائص ومميزات متنوعة ، وخصوصا اعادة تشكيل التردد والنمط الاشعاعي ، تغيير خصائص الهوائي هو القدرة على تغيير النمط الاشعاعي والتردد من خلال الأدوات الالكترونية والكهربية للحصول على نتائج ذات كفاءة عالية مع الحفاظ على المتغيرات الأخرى . هذه الرسالة تقدم تغيير التردد والنمط الاشعاعي الخاص بنوع أنتينا واسع النطاق. شكل جديد للهوائي قدم في هذا العمل من خلال وضع أشكال دائرية على خط التغذية والبنية الخلفية للهوائي ، تستخدم مفاتيح الدايود كجزء أساسي من العمل من أجل التحكم في أطول القطع النحاسية والتي يتم اضافتها بأشكال دائرية على خط التغذية والبنية الخلفية للهوائي للتحكم في تغيير التردد والنمط الاشعاعي للهوائي ، قسمت الأشكال الدائرية الى ثمان قطع نحاسية ، حيث استخدمت الدائرة الأولى من الواجهة الأمامية للهوائي للتحكم في تغيير التردد واستخدمت القطع الثمانية الأخرى من الجهة الخلفية للهوائي للتحكم في تغيير النمط الاشعاعي للهوائي ، حيث حققت كسب طاقة عالي جدا مقارنة بالهوائي الأصلي ، وبلغت قوة بث الهوائي الى 4 ديسبل، وكان الفقد في الطاقة أقل من6,5 ديسبل.

بسم الله الرحمن الرحيم

"قل إن صلاتي ونسكي ومحياي
ومماتي لله رب العالمين* لا شريك
له وبذلك أمرت وأنا أول
المسلمين"

صدق الله العظيم

[الأنعام:163]

Dedication

This thesis is firstly dedicated to God almighty and to my parents, who were immense sources of support throughout my education. I thank you. Thanks for all your love and support through the end.

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First and the foremost, I would like to thank the Almighty Allah for bestowing His blessings upon me and giving me the strength to carry out and complete this work. I am extremely grateful to my supervisor Dr. Talal Skaik for this valuable advice, guidance, beneficial discussions and encouragement throughout my research. I am hugely grateful to my family for their generous support me, and indeed the whole of my life. Their wisdom, kindness and excellent advice have made me who I am today and I hope that I have made them proud. Thanks father for believing in me and thanks Mom for your infinite love. And all my family for their continuous encouragement, support, love and sacrifice throughout my studies.

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List of Abbreviations

CST	Computer System Technology
dB	decibel
dBi	decibel isotropic
DSP	Digital Signal Processing
EM	ElectroMagnetic
FCC	Federal Communications Commission
FET	Field-Effect Transistor
FR4	Flame Retardant 4
GaAs	Gallium Arsenide
IEEE	Institute of Electrical and Electronics Engineers
MEMs	MicroElectroMechanical systems
RF	Radio Frequency
RL	Return Loss
SNR	Signal to Noise Ratio
USRP	Universal Software Radio Peripheral
UWB	Ultra-WideBand
VNA	Vector Network Analyser
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave

Chapter 1

Introduction

Chapter 1

Introduction

1.1 Background

Newly, with the development of novel communication systems, frequency reconfigurable antennas have gained a lot of attention, by adapting their properties to achieve selectivity in frequency, polarization, bandwidth, and gain (Pazin and Leviatan, 2013). A reconfigurable antenna is an antenna capable of modifying dynamically its frequency and radiation properties in a controlled and reversible manner (Bernhard, 2007). In order to provide a dynamical response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tunable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications over its properties. Reconfigurable antennas differ from smart antennas because the reconfiguration mechanism lies inside the antenna rather than in an external beam forming network. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements. Reconfigurable antennas apply various techniques and methods to achieve the required change in one or more of its operation parameters.

The most common technique is based on using switches such as PIN diodes, Gallium Arsenide Field Effect Transistors (GaAs FETs) or Micro-Electro Mechanical System (MEMS) switches. Other techniques include the use of optical switches or mechanical structure alteration to achieve the necessary change in the antenna configuration and these are promising methods to overcome the enormous biasing problems of the electronic switches.

1.2 Types of antenna reconfiguration

Reconfigurable antennas can be classified according to the antenna parameter that is dynamically adjusted, typically the frequency of operation, radiation pattern or polarization (Huff and Bernhard, 2008).

- Frequency reconfiguration
- Radiation pattern reconfiguration.
- Polarization reconfiguration.
- Compound reconfiguration.

1.2.1 Frequency reconfiguration

Frequency reconfigurable antennas can adjust dynamically their frequency of operation. 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 modifying physically or electrically the antenna dimensions using RF-switches, (Panagamuwa, Chauraya, and Vardaxoglou. 2006). Impedance loading (Erbil, Tonally, Ulna, Civil, and Akin, 2007). Or tunable materials (Liu, and Langley, 2008).

1.2.2 Radiation pattern reconfiguration

Radiation pattern reconfigurability is based on the intentional modification of the spherical distribution of radiation pattern. Beam steering is the most extended application and consists in steering the direction of maximum radiation to maximize the antenna gain in a link with mobile devices. Pattern reconfigurable antennas are usually designed using movable/rotatable structures (Rodrigo, Joffre, and Center, 2012). Or including switchable and reactively loaded parasitic elements (Aboufoul, Parini, Chen, and Alomainy, 2013).

1.2.3 Polarization reconfiguration

Polarization reconfigurable antennas are capable of switching between different polarizations modes. The capability of switching between horizontal, vertical and circular polarizations can be used to reduce polarization mismatch losses in portable devices. Polarization re-configurability can be provided by changing the balance between the different modes of a multimode structure (Simons, Donghoon, and Katehi, 2002).

1.2.4 Compound reconfiguration

Compound reconfiguration is the capability of simultaneously tuning several antenna parameters, for instance frequency and radiation pattern. The most common application of compound reconfiguration is the combination of frequency agility and beam scanning to provide improved spectral efficiencies. Compound reconfigurability is achieved by combining in the same structure different single- parameter reconfiguration techniques (Aboufoul , Chen, Parini, and Alomainy, 2014)

1.3 Advantages and Disadvantages of reconfigurable antenna

The advantages are significant:

- Have a multiband antenna in a single terminal for various applications.
- Easy to integrate with switching devices and control circuit.
- Small in size.

However, the design of reconfigurable antenna are typically driven by the balance of trade-offs. Compared with fixed-tuned antenna, due to its short developing time, there are still some disadvantages waiting to be solved:

- The technology of reconfigurable relies largely on RF switch technology, which is not mature enough yet.
- Increased complexity and cost to the mobile phone.
- Reduced Efficiency.

1.4 Motivation

Large number of wireless systems use the ultra-wideband (UWB) bandwidth. There are several reasons for use this type of antenna, high data rate, low construction cost, and low power consumption. But there are many challenges facing the user, some of these challenges, fading loss occur due to a rapidly changing UWB propagation channel environment, need for multiple antennas that expand system performance. So to get rid of this problem is by implementing reconfigurable antenna to eliminate the need for multiple antennas , improve the quality of communications, and filtering performance of the antenna. A reconfigurable frequency and radiation pattern antenna that operates across the entire UWB frequency band was proposed in this thesis. Most research also focused on frequency or radiation pattern reconfigurable, that combines reconfigurable in frequency and pattern together at the same antenna, this is the main motivation for the current work on this topic.

1.5 Contribution

The main target of the proposed work is design of an ultra-wide band antenna with reconfigurable characteristics mainly in frequency and pattern. Most research in literature presented re-configurability in one parameter: frequency, pattern, or polarization. In this work, we present a combined frequency and pattern reconfiguration in order to obtain more antenna features. Moreover, pattern re-configurability presented in literature involved only limited number of switchable patterns. Here the proposed antenna is intended to have multi-switchable patterns so it can be used for beam scanning purposes. Moreover, a significant number of reconfigurable antennas that had been reported in the literature review were only capable to switch between two or few bands and to increase the number of reconfigured frequency bands, here a new UWB antenna structure is proposed with both pattern and frequency reconfiguration and with the ability to switch between various bands and patterns. The antenna will be able to switch from ultra-wideband operation to narrowband operation with multiple different radiation pattern configurations.

1.6 Literature Review

Many of the studies on the re-configurable of an UWB antenna;

In (Majid, Rahim, Hamid, and Ismail 2014). A frequency reconfigurable slot-patch antenna with reflector at the back of an antenna is presented. The proposed antenna consists of a microstrip patch antenna and a microstrip slot antenna where the slot antenna is positioned at the ground plane underneath the patch. Three switches are placed in the slot. The antenna is capable to reconfigure up to six different frequency bands from 1.7GHz to 3.5GHz. The microstrip patch antenna produces three different frequency bands with directional radiation pattern while the microstrip slot antenna produces another three frequency bands with bidirectional radiation pattern. Due to the reflector placed at the back of the antenna, the radiation pattern is directional at all frequency bands. Simulated and measured results are used to demonstrate the performance of the antenna. The simulated and measured reflection coefficients and radiation patterns are presented and compared.

In (Yanng, Pan, Fathy, and Nair, 2009). A frequency-reconfigurable coplanar-waveguide (CPW) fed monopole antenna using switchable stubbed ground structure is presented. Four PIN diodes are employed in the stubs stretching from the ground to make the antenna reconfigurable in three operating modes: a single-band mode (2.4-2.9 GHz), a dual-band mode (2.4 to 2.9 GHz/5.09-5.47 GHz) and a triple-band mode (3.7 to 4.26 GHz/5.3-6.3 GHz/8.0-8.8 GHz). The monopole antenna is resonating at 2.4 GHz, while the stubs produce other operating frequency bands covering a number of wireless communication systems, including WLAN, WiMAX, C band, and ITU.

Furthermore, an optimized biasing network has been integrated into this antenna, which has little influence on the performance of the antenna. This paper presents compares and discusses the simulated and measured results. In (Al-hussein,Taw, Christodoulou, Kabala, and El-Hajj, 2009). Re-configurability is achieved by using different stubs of different lengths. These microstrip stubs can be connected to the monopole microstrip feed line and multiple switches can change the length of the stubs, radiation patterns remain almost unchanged. In (Mehri, Pejman, & Vahid 2015). A novel frequency reconfigurable slot antenna for suitable switchable radiations at WLAN and a tri-band at Bluetooth, WiMAX and upper WLAN applications is designed and fabricated. Switchable frequency responses are achieved by implementation of a PIN diode within the antenna ground plane. The antenna structure consists of a square radiation patch with an E-shaped slot, a modified ground plane with an inverted T-shaped strip that acts as a parasitic stub and two parallel slots and a protruded strip, which is connected to the parasitic stub with a PIN diode. The presented antenna has a compact size of20 × 20 mm2 while providing switchable radiations at2.36-2.5 GHz Bluetooth, 3.51-3.79 GHz WiMAX, and

5.47-5.98 GHz WLAN when the diode is ON and5.04-6.13 GHz WLAN when the diode is OFF. In (Jianxin Liang 2006) a radiation pattern reconfigurable planar antenna operating at an ultra-wide band frequency range of 2.78–10.85 GHz is proposed. The proposed antenna is a combined structure of a monopole and a tapered slot, and it has two types of radiation patterns that can be chosen to be a monopole pattern or tapered slot pattern by controlling the states of four diodes.

In addition, the shape of both radiation patterns is maintained across the whole operating frequency range. In (Klemp, 2009). A novel blueprint with a small physical dimension has been proposed and analyzed for Ultra Wide band (UWB) applications with integration of Multi-Input Multi-Output (MIMO) technique. The configuration study is made on MIMO antenna with the duplication of two single antennas. The preferred typical parameter, which reflects to the antennas performance, has been conferred in terms of input reflection coefficient, mutual coupling and radiation pattern. The proposed antennas work proficiently for the entire interest band, 3.1GHz to 10.6GHz.

In(Xiang, Ringling, and Tenders, 2010). Reconfigurable antennas, with the ability to radiate more than one pattern at different frequencies and polarizations, are necessary in modern telecommunication systems. The requirements for increased functionality (e.g., direction finding, beam steering, radar, control, and command) within a confined volume place a greater burden on today’s transmitting and receiving systems. Reconfigurable antennas area solution to this problem. This paper discusses the different reconfigurable components that can be used in an antenna to modify its structure and function. These reconfiguration techniques are either based on the integration of radio-frequency micro electromechanical systems (RF-MEMS), PIN diodes, varactors, photoconductive elements, or on the physical alteration of the antenna radiating structure, or on the use of smart materials such as ferrites and liquid crystals. Various activation mechanisms that can be used in each different reconfigurable implementation to achieve optimum performance are presented and discussed. Several examples of reconfigurable antennas for both terrestrial and space applications are highlighted, such as cognitive radio, multiple-input multiple output (MIMO) systems, and satellite communication.

1.7 Structure of the Thesis

Chapter 1: Introduction; this chapter is organized in six points: Background

Contribution, Literature Review, Advantages and Disadvantages of reconfigurable antenna ,Types of antenna reconfiguration and structure of the thesis.

Chapter 2:Antenna Theory; it contains review for antenna theory, electromagnetic waves, antenna types and antenna parameters, also the types of antennas .

Chapter 3: Design of frequency and pattern reconfigurable antenna, and simulation results for each parameters.

Chapter 4: Conclusions; it includes comments on the results of the simulations and provides a summary of the main contributions and findings of the study and concludes the accomplished work packages. It also introduces suggestions for future research activities.

Chapter 2

Antenna Theory

Chapter 2

Antenna Theory

In this chapter we will start to read a brief presentation concerning to the theory of antennas, allowing the comprehension of its main features, types and parameters. Finally, a study of the UWB antennas and their advantages and disadvantages .

2.1 Antenna Definition

An antenna can be defined as a usually metallic device which radiates and receives electromagnetic waves (EM waves – see section 2.2), more specifically,(Kraus and Marhefka, 2003). Another explanation says that an antenna is the transition between a guided EM wave and a free-space EM wave (Balanis, 2005). And vice-versa. This process is explained by a general communication between a transmitting antenna and a receiving antenna.

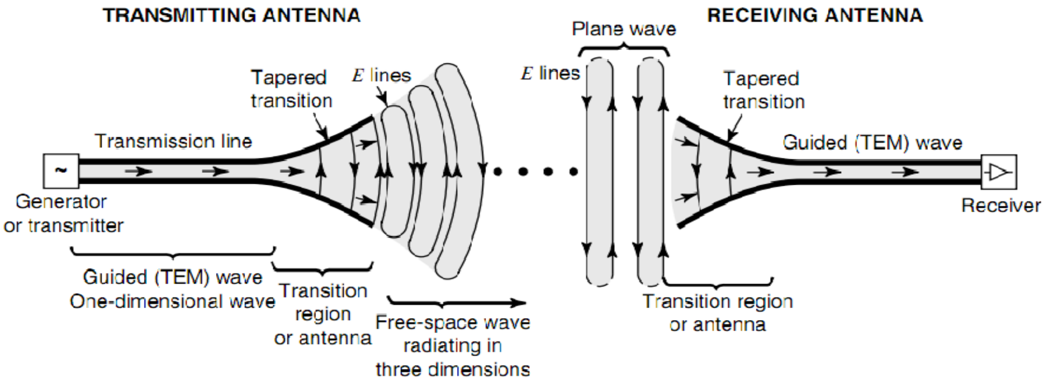


Figure (2.1): The antenna as a transition structure, for a transmitting antenna and for a receiving antenna.(Kraus, Marhefka 2002).

As shown above, for both antennas, the transmission line has the form of a coaxial line or a waveguide. The latter, when a transmitting antenna is considered, is connected to a transmitter that generates radio-frequency (RF – see section 2.2) energy that is guided through the uniform part of the line as a plane. Transverse Electromagnetic (TEM) wave with little loss, transformed into a signal that is amplified, modulated and applied to the antenna; otherwise, when a receiving antenna is considered, the transmission line is connected to a receiver which collects the alternating currents that resulted from the transformation process of the received radio waves by the antenna(Kraus and Marhefka, 2003).

Antenna characteristics concerning to radiation are basically the same regardless of its type. Therefore, if a time-changing current or an acceleration (or deceleration) of charge occurs, the radiation will be created in a certain length of current element. This can be described by (Balanis, 2005).

$$l.\frac{dl}{dt} = l.q_l.\frac{dv}{dt}\left(A.\frac{m}{s}\right) \qquad (2.1)$$

Where:

l - Length of the current element in meters (m);

di/dt Time-changing current in ampere per second (A/s).

$_l$ qi $_l$Charge per unit length (coulombs/m). Note that q = I. t = 1.602×10-19 Q.

Furthermore, the radiation is always perpendicular to the acceleration and its power is proportional to the square of both parts of the equation (2.1). It is important to refer that the spacing between the two wires of the transition line is just a small part of a wavelength (see section 2.2); therefore, the more the transition curve of the antenna opens out the more the order of a wavelength or more is reached; consequently, the more the wave tends to be radiated and launched into the free-space(Kraus and Marhefka, 2003).

Looking at the antenna structure as a whole, the transition region of the antenna is like a radiation resistance (R_r) to the transmission line point of view, which represents the radiation that the antenna emits, analyzing it as a circuit. Figure 2.2 shows the complete circuit of an antenna; where the source is an ideal generator with a tension V_g(or V_s) and with an impedance Z_g (or Z_s); the transmission line is a line with characteristic impedance Z_c (or Z_o), and the antenna itself is represented by a load impedance Z_A [$Z_A=(R_L+ R_r) + jX_A$] connected to the transmission line. The load resistance R_L is used to represent the conduction and dielectric losses associated with the antenna structure while

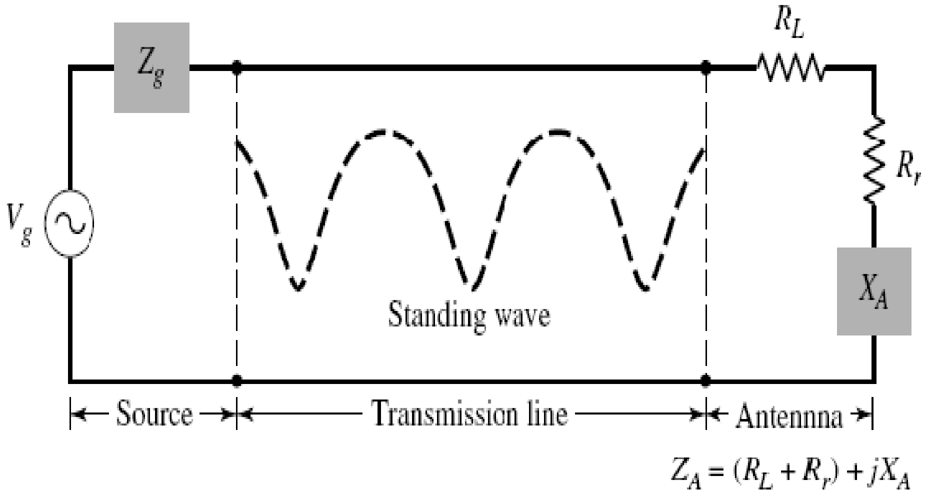


Figure (2.2): Circuit representing antenna as whole structure.(Balanis 2005).

R_r, referred to as the radiation resistance, is used to represent radiation by the antenna. The reactance X_A is used to represent the imaginary part of the impedance associated with radiation by the antenna. Therefore, if ideal conditions are applied, the radiation resistance R_r, which is used to represent radiation by the antenna, will get all the energy that is generated by the transmitter (Balanis, 2005).

2.2 Radio Frequency

EM waves are a type of electromagnetic radiation which is organized according to the frequency (f) of its waves. Frequency counts the number of incidences that a repetition of an event occurs per unit of time. Usually, a frequency is given in Hertz (Hz) which means the number of cycles per second. Each cycle is also mentioned, as a period (T) .There for, frequency is the reciprocal of period:

$$F=1/T \tag{2.2}$$

EM waves cover the whole spectrum; radio waves and optical waves are just two examples of EM waves. We can see light but we cannot see radio waves. The Whole spectrum is divided into many frequency bands. Some radio frequency bands are listed in Table 2.1.

Table 2.1 EM spectrum and applications.

Frequency	Band	Wavelength	Applications
3-30 kHz	VLF	100 – 10 km	Navigation, sonar, fax
30-300 kHz	LF	10 – 1 km	Navigation
0.3-3 MHz	MF	1 – 0.1 km	AM broadcasting
3-30 MHz	HF	100 – 10 m	Tel, fax, CB, ship communications
30-300 MHz	VHF	10 – 1 m	TV, FM broadcasting
0.3-3 GHz	UHF	1 – 0.1 m	TV, mobile, radar
3-30 GHz	SHF	100 – 10 mm	Radar, satellite, mobile, microwave
30-300 GHz	EHF	10 – 1 mm	Radar, wireless communications
0.3-3 THz	THz	1 – 0.1 mm	THz imaging

Although the whole spectrum is infinite, the useful spectrum is limited and some frequency bands, such as the UHF, are already very congested. Normally, significant license fees have to be paid to use the spectrum, although there are some license-free bands: the most well-known ones are the industrial, science and medical (ISM) bands (Huang and Boyle, 2008).

Another very important parameter is the wavelength (λ), which is the distance between two consecutive points of the same phase, given in meters. Figure 2.3 shows the plot of wavelength and Figure 2.4 the difference between highest and lowest frequencies.

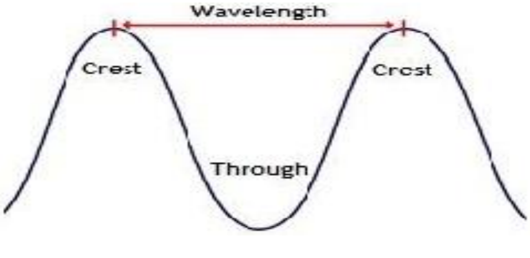


Figure (2.3): Wavelength measurement.

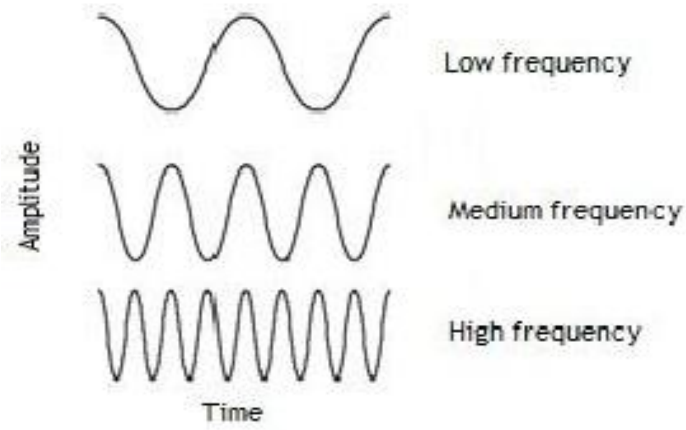


Figure (2.4): Frequency quality.

The *wave velocity, v,* is linked to the frequency, *f* , and wavelength, λ, by this simple equation:

$$V=\beta f \tag{2.3}$$

It is well known that the speed of light (an EM wave) is about 3×10^8 m/s in free space. The higher the frequency, the shorter the wavelength is.

2.3Types of Antennas

There are several types of antennas which were developed since the past times due nowadays. In this section, a brief discussion of the different antennas according to their physical structures will be presented. The following types of antennas are Wire antennas; aperture antennas; micro strip antennas; array Antennas; reflector antennas; and lens antennas(Balanis, 2005).

2.3.1 Wire Antennas

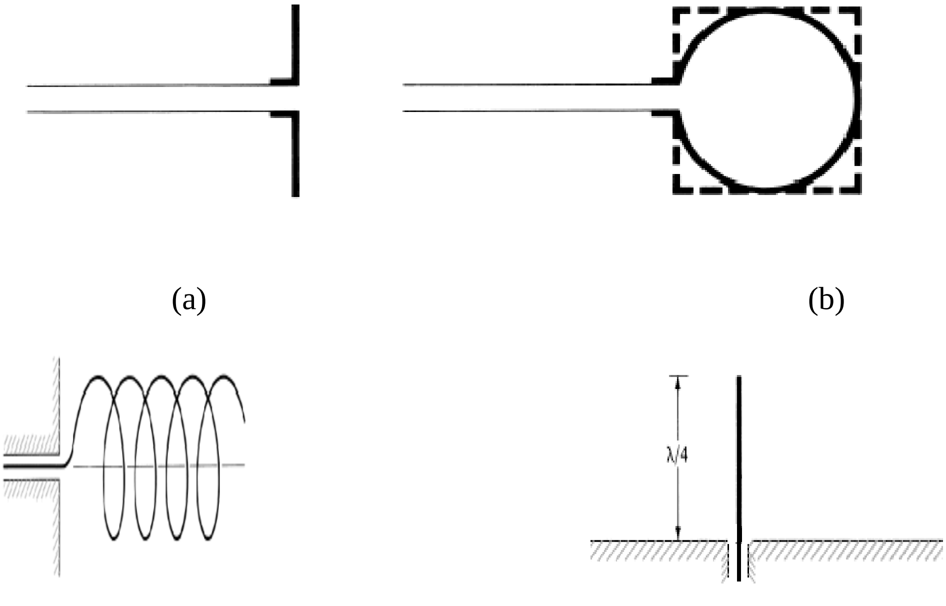
Wire antennas are between the most used antennas. Basically, they are very simple and cheap, with linear or curved forms. Examples include dipoles, monopoles, loops, helices, Yagi–Uda and log-periodic antennas (Huang and Boyle, 2008). They are:

Dipole antennas: Dipoles are one of the simplest but most widely used types of antenna. As shown in Figure 2.5 (a), a dipole can be considered a structure evolved from an open-end, two-wire transmission line. Atypical structure of a dipole consists of two metal wires, which are normally of equal length.

Monopole antennas: The monopole antenna is half of the dipole antenna as shown in Figure 2.5 (d), there are a lot of similarities between them, but there are also some differences which will be discussed thoroughly in chapter3.

Loop antennas: It can be a circular, square, triangle, rectangular or elliptical form. In the past they were used in pagers. While the dipole is considered to be a configuration evolved from an open-end transmission line, the loop can be viewed as a configuration evolved from a short-end transmission line, as shown in Figure 2.5 (b).

Helical antennas: with a shape defined by helices, similarly to a spring shape. Those antennas are used for space telemetry as shown in Figure 2.5(c).



(a) (b)

(c) (d)

Figure(2.5): Types of wire antennas (a) Dipole (b) Loop (c) Helix (d) Monopole.(Balanis 2005).

2.3.2 Aperture Antennas

These types of antennas are utilized at high frequencies. Aperture antennas largely depend on their aperture, because this property is directly related to gain. A notable example of an aperture antenna is the horn antenna. Although another well-liked aperture antenna is the slot antenna. Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft. Both are described as follows(Balanis, 2005).

Horn antennas: Horn antennas are the simplest and one of the most widely used forms of microwave antenna – the antenna is nicely integrated with the feed line (waveguide) and the performance can be controlled easily. They are mainly used for standard antenna gain and field measurements feed elements for reflector antennas and microwave communications.

Slot antenna: Usually, frequencies up to 24 GHz can be reached. Another interesting property of these antennas is their almost inexistent directivity, allowing omnidirectional radiation.

2.3.3 Micro strip Antennas

Micro strip antennas or micro strip patch antennas are usually very cheap and small, with an easier manufacture. They are printed directly onto a printed circuit board (PCB), and they are made of a metallic patch with a rectangular or circular shape, embedded on a grounded substrate, which will be discussed in detail in chapter 3 (Huang and Boyle, 2008).

Different feed configurations, including aperture coupled, micro strip line feed and coaxial feed can be used as shown in Figure 2.7.

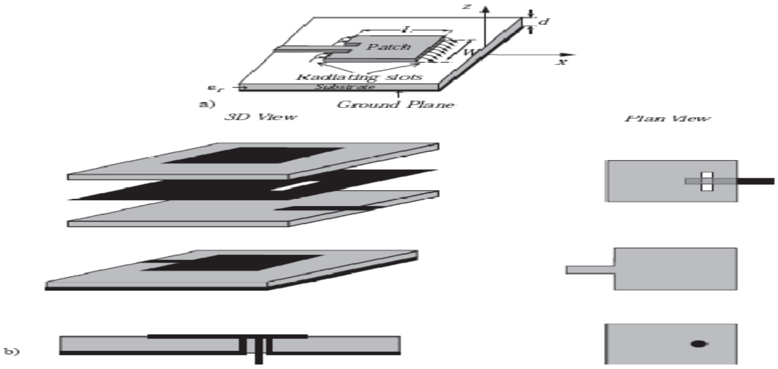
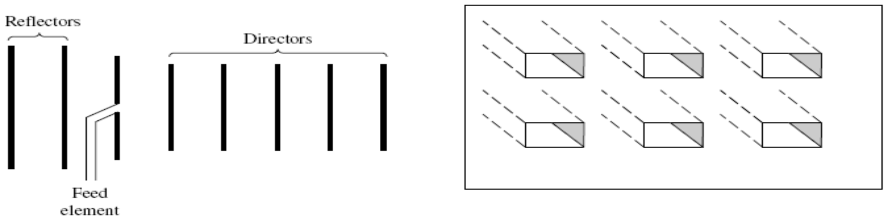


Figure (2.7): Microstrip antennas and their feeds (a) a microstrip antenna with its coordinates, (b) Three feeding configurations: coupling feed, microstrip feed and coaxial feed respectively.(Huang , Boyle 2008).

2.3.4 Array Antennas

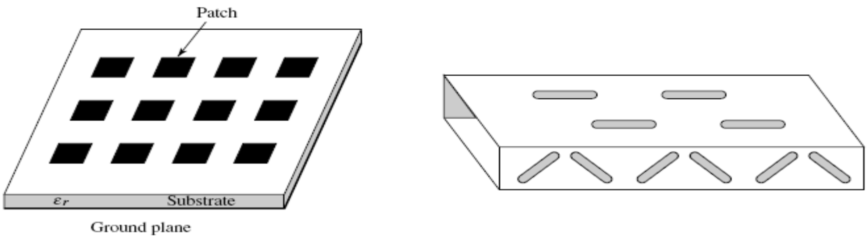
Sometimes we need to be able to control the antenna radiation pattern, for example for tracking or anti-jamming/interference applications. A single-element antenna is not good enough to meet such a requirement. In this case, an antenna array could be a good solution.

The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction, minimum in others, or otherwise as desired. Typical examples of arrays are shown in Figure 2.8. Usually the term *array* is reserved for an arrangement in which the individual radiators are separate as shown in Figures 2.8 (a–c). However the same term is also used to describe an assembly of radiators mounted on a continuous structure, shown in Figure 2.8(d). The major advantages of an array are the flexibility to form a desired radiation pattern, the high directivity and gain (Balanis, 2005).



(a) Yagi-Uda array

(b) Aperture array



(c) Microstrip patch array

(d) Slotted-waveguide array

Figure (2.8): Typical wire, aperture, and micro strip array configurations.

2.3.5 Reflector Antennas

Reflector antennas, also known as satellite dish antennas, are a specific type of antennas for long distance communications. They are probably the most widely used antennas for high frequency and high-gain applications in radio astronomy, radar, microwave and millimeter wave communications and satellite tracking and communications(Balanis, 2005) (Huang and Boyle 2008).

2.3.6 Lens Antennas

As reflector antennas, lens antennas can convert a spherical wave into a plane wave to produce high gains. They are suitable for high-frequency >4 GHz applications. There are of many types but the most important two types are delay lenses, in which the electrical path length is increased by the lens medium (using low-loss dielectrics with a relative permittivity greater than one, such as Lucite or polystyrene), and fast lenses, in which the electrical path length is decreased by the lens medium (using metallic or artificial dielectric switch a relative permittivity small earth an one) (Huang and Boyle, 2008).

2.4 Antenna Fundamentals

Antennas are defined by several parameters according to their constitution and shape. In this section, the most important are considered and explained, and an overview of each is essential to describe antenna’s performance.

2.4.1 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as “a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization(Balanis, 2005).

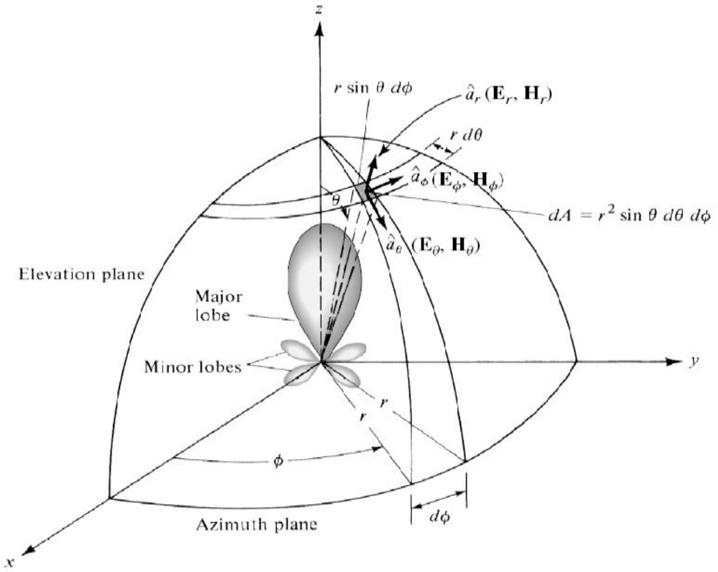


Figure (2.9): Coordinate system for antenna Analysis.(Balanis 2005).

A trace of the received electric (magnetic) field at a constant radius is called the amplitude field pattern. On the other hand, a graph of the spatial variation of the power density along a constant radius is called an amplitude power pattern, Often the *field* and *power* patterns are normalized with respect to their maximum value, yielding normalized field and power patterns. In addition, the power patterns usually plotted on a logarithmic scale or more commonly in decibels (dB) (Balanis, 2005). Various parts of a radiation pattern are referred to as lobes, which may be sub- classified into major or main, minor, side, and back lobes as shown in figure 2.10. A radiation lobe is a “portion of the radiation pattern bounded by regions of relatively weak radiation intensity.” (Balanis, 2005). The main lobe (or main beam or major lobe) is the lobe containing the direction of maximum radiation. There is also usually a series of lobes smaller than the main lobe. Any lobe other than the main lobe is called a minor lobe. Minor lobes are composed of side lobes and back lobes. Back lobes are directly opposite the main lobe, or sometimes they are taken to be the lobes in the half-space opposite the main lobe(Stutzman, Thiele, 1998).

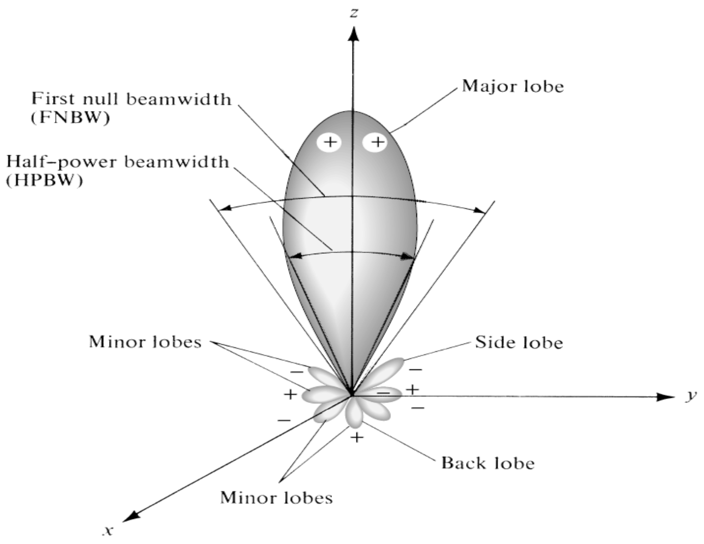


Figure (2.10): Radiation lobes and beam widths of an antenna pattern. .(Balanis 2005).

There are three common radiation patterns that are used to describe an antenna's radiation property:

Isotropic: A hypothetical lossless antenna having equal radiation in all directions.

Directional: An antenna having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others.

Omnidirectional: An antenna having an essentially non-directional pattern in a given plane and a directional pattern in any orthogonal plane.

Directional or omnidirectional radiation properties are needed depending on the practical application. Omnidirectional patterns are normally desirable in mobile and hand-held systems (Balanis, 2005).

2.4.2 Beam width

The beam width of a pattern definition is the angular separation between two identical points on opposite side of the pattern maximum. In an antenna pattern, there are a number of beam widths. One of the most widely used beam widths is the *Half*- Power Beam width (*HPBW*), which is defined by IEEE as: “In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam". The angular separation between the First nulls of the pattern is referred to as the First-Null Beam width (*FNBW*) as shown in figures 2.10 and 2.11 (Balanis, 2005).

The beam width of an antenna is a very important issue and often is used as a trade-off between it and the side lobe level; that is, as the beam width decreases, the side lobe increases and vice versa. In addition, the beam width of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets (Balanis, 2005).

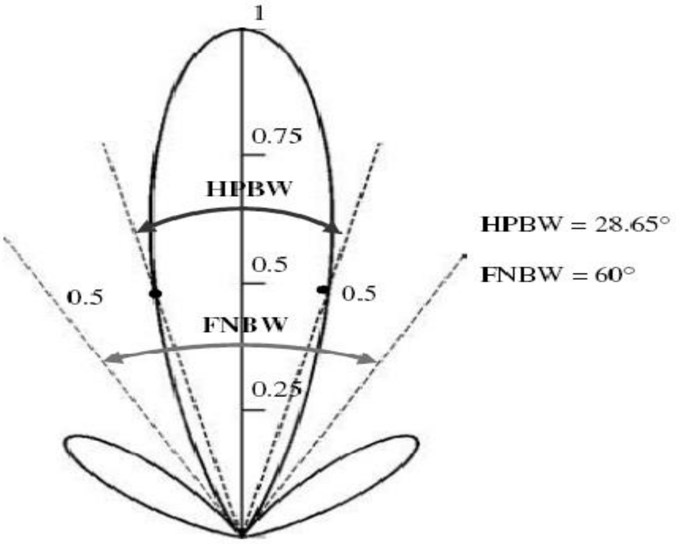


Figure (2.11): Beam widths of a directional antenna power pattern.(Balanis 2005).

2.4.3 Directivity

The directivity of an antenna is defined as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.” In other words, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction, over that of an isotropic source(Stutzman, Thiele, 1998).

Radiation intensity is the power radiated in a given direction per unit solid angle and has units of watts per square radian (or steroidal, sr). The advantage of using radiation intensity is that it is independent of distance *r* (Stutzman, Thiele, 1998).

$$\mathcal{D} = \frac{U}{Ui} - 4\frac{\pi U}{Pr} \tag{2.4}$$

where D is the directivity of the antenna; U is the radiation intensity of the antenna; U_i is the radiation intensity of an isotropic source; and P_r is the total power radiated. Sometimes, the direction of the directivity is not specified. In this case, the direction of the maximum radiation intensity is implied and the maximum directivity is given as

$$\mathcal{D}\max = \left(\frac{U\max}{Ui}\right) = \left(4\frac{\pi U\max}{Pr}\right) \tag{2.5}$$

Where $\mathcal{D}_{\max}$ is the maximum directivity and $U_{\max}$ is the maximum radiation intensity. The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity than the one that has abroad main lobe; hence, this antenna is more directive.

2.4.4 Antenna Efficiency

Antenna efficiency is the measure of the antenna's ability to transmit the input power into radiation. Antenna efficiency is the ratio between the radiated power to the input power (Stutzman, Thiele, 1998).

$$\mathrm{e} = \frac{\mathrm{P_r}}{\mathrm{P_i}n} \tag{2.6}$$

There are a number of antenna efficiencies; the total antenna efficiency e_0 is used to take into account losses at the input terminals and within the structure of the antenna as shown in Figure 2.12. Such losses may be due to (Balanis, 2005).

1. Reflections because of the mismatch between the transmission line and

the antenna.

2. I^2R losses (conduction and dielectric)

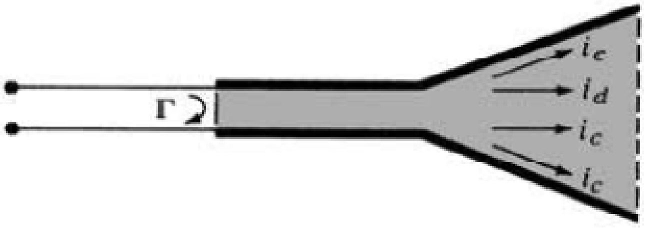


Figure (2.12): Antenna losses (Reflection, conduction and dielectric).(Balanis 2005).

In general, the overall efficiency can be written as:

$$e_o = e_r e_c e_d \tag{2.7}$$

Where

e_o= total efficiency

e_r= reflection (mismatch) efficiency

e_c= conduction efficiency

e_d= dielectric efficiency

2.4.5 Gain

The gain of an antenna (referred to a lossless isotropic source) depends on both its directivity and its efficiency. If the efficiency is not 100 percent, the gain is less than the directivity (Kraus, 1988). Thus, the gain

$$G = e_O D \tag{2.8}$$

Where k = efficiency factor of antenna ($0<e_o < 1$).

Gain of an antenna (in a given direction) is defined as “the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropic. The radiation intensity corresponding to the isotropic radiated power is equal to the power accepted (input) by the antenna divided by 4n.” (Balanis, 2005).

2.4.7 Polarization

The polarization of an antenna is the polarization of the wave radiated in a given direction by the antenna when transmitting. When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain. The polarization of a radiated wave is the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector(Balanis, 2005).

If the polarization of the receiving antenna is not the same as the polarization of the incoming (incident) wave, there is polarization mismatch resulting in power loss. The requirement of the antenna polarization depends on the applications(Stutzman, Thiele, 1998). Polarization can be categorized as linear, circular and elliptical as shown in Figure 2.13.

Linear polarization: If the electric field vector moves back and forth along a line it is assumed to be linearly polarized. A linearly polarized wave is considered as horizontally polarized if the electric field is parallel to the earth and vertically polarized if the electric field is perpendicular to the earth. For a linearly polarized antenna, the radiation pattern is taken both for ace-polarized and cross-polarized response.

Co polarization represents the polarization the antenna is intended to radiate (receive); Cross polarization represents the polarization orthogonal to a specified polarization (co polarization).

Circular polarization: If the electric field vector remains constant in length but rotates around in a circular path then it is considered circularly polarized. For circular polarization, the field's components have same magnitude and the phase between two components is 90degree.

Elliptical polarization: describes an antenna when its electric field vector at a far field point is such that traces elliptical curves constantly with time. Moreover, both the circular and elliptical polarizations are characterized for being right-hand (RH) or left- hand (LH) polarized, depending on the sense of the field; if the field is flowing in the clockwise direction, the field will be right hand polarized; otherwise it will be left hand polarized(Balanis, 2005).

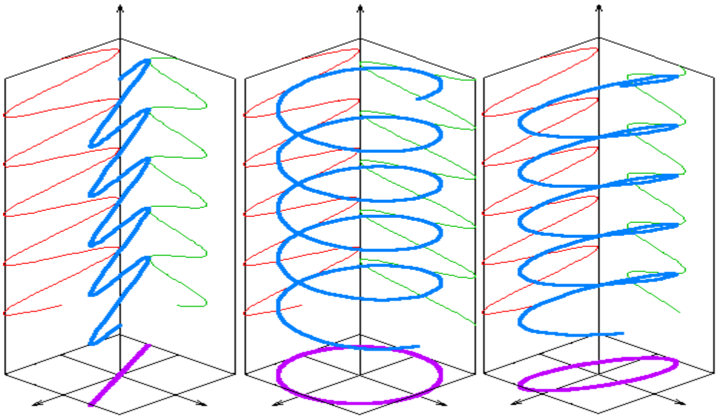


Figure (2.13): Three types of polarization (linear, circular and elliptical).(Huang, Boyle 2008).

2.4.8 Input Impedance

Input impedance is defined as “the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point.” (Balanis, 2005). The input impedance will be affected by other antennas or objects that are nearby, but we assume that the antenna is isolated. Input impedance is composed of real and imaginary parts (Stutzman, Thiele, 1998).

$$Z_{in} = R_A + jX_A \tag{2.9}$$

The input resistance R_A represents dissipation, which occurs in two ways.

Power that leaves the antenna and never returns (i.e., radiation) is a form of dissipation. There are also ohmic losses associated with heating on the antenna structure, but on many antennas, ohmic lossek2s are small compared to radiation losses. However, ohmic losses are usually significant on electrically small antennas, which have dimensions

much less than a wavelength. The input reactance X_A represents power stored in the near field of the antenna. As a consequence of reciprocity, the impedance of an antenna is identical during reception and transmission (Stutzman, Thiele, 1998).

Frequency makes the impedance vary constantly with its value. For lower frequencies (higher wavelengths) the length of the transmission line is not significant when compared to wavelength, so the result is a short line.

Although for higher frequencies where the transmission line is slightly a big fraction of a wavelength, it can be a problem because the input impedance will be influenced in a large scale by the length of the transmission line. Therefore, the term impedance matching becomes important, because in this case the length of a transmission line is not significant when compared to the wavelength. The input impedance of an antenna will be matched with a transmission line if both impedances are the same ($Z_A = Z_O$).

If an antenna is mismatched, the loss of power can be very high, because the power generated by the source will be reflected back. As a measure related with power, input impedance is a crucial quantity for the power that an antenna will receive. Thus, as a definition, a maximum power will be delivered from the source to the antenna, if the input impedance is equal to the conjugate of the impedance generated by the source $Z_A = Z_S^*$. Therefore, no power will be transmitted when Z_A is much smaller or much superior to Z_S as shown in Figure 2.14 (Stutzman, Thiele, 1998).

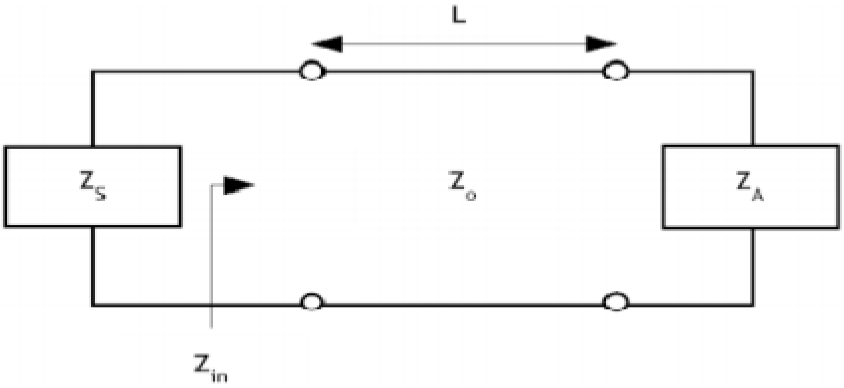


Figure (2.14): Circuit representing input impedance at the entrance terminals of the transmission line.(Balanis 2005).

2.4.9 Bandwidth

The term bandwidth specifies the range of frequencies, which an antenna can achieve, in order to obtain a desirable behavior of a certain characteristic. The bandwidth can be considered to be the range of frequencies, on either side of a center frequency (usually the resonance frequency for a dipole), where the antenna characteristics such as (input impedance, radiation pattern, beam width, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the center frequency (at -10 dB). However, as a range, two boundaries define the lower and upper frequency limits, and the ratio of its size to the center frequency as a percentage define the percent bandwidth for a narrowband antenna , thus occupying a small space quantity on the RF spectrum–given by equation (2.11); otherwise, for a Broad band (or wideband) antenna the bandwidth is defined as the ratio of the upper to lower frequencies as written in equation (2.12). Both expressions are analytically represented as (Eibert and Volakis, 2007).

$$B_f = \frac{(f_H - f_L) \times 100}{f_c} \tag{2.10}$$

$$B_r = \frac{f_H}{f_L} \tag{2.11}$$

Where:

B_f _Fractional bandwidth in Hz percentage.

B_r _ Bandwidth ratio.

f_H_ Upper frequency in Hz.

f_L _Lower frequency in Hz.

Usually, the described parameters of an antenna may have a satisfactory value of those at the center frequency; therefore a bandwidth involving it, for which those parameters are able to have a good performance. In fact, all the parameters can be influenced by frequency in a different way, what gives a different meaning to the bandwidth of each. Especially analyzing the radiation pattern and input impedance bandwidth differences, the useful bandwidth of a designed antenna can be related to both, despite of the disparity on those differences. In some cases the satisfactory bandwidth for radiation pattern goes above the one for input impedance, or vice-versa(Eibert and Volakis, 2007).

2.5 UWB antenna technology

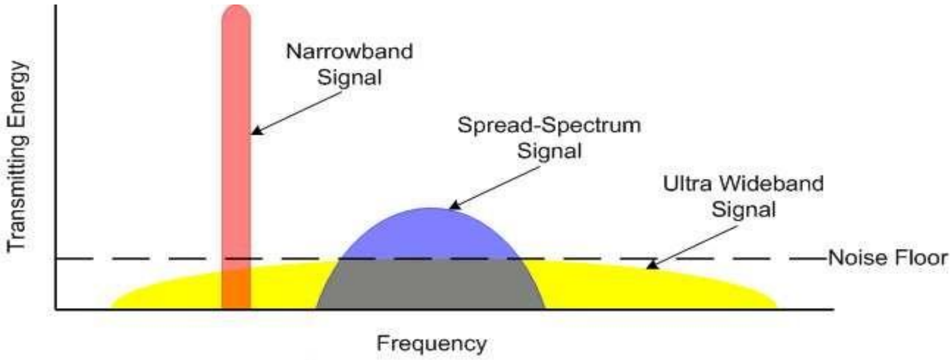
UWB technology has been used in the areas of radar, sensing and military communications during the past 27 years. A substantial surge of research interest has occurred since February 2002, when the Fedral Communications Commission (FCC). issued a ruling that UWB could be used for data communications as well as for radar and safety applications (FCC, 2002).

2.5.1 Advantages of UWB

UWB has a number of encouraging advantages that are the reasons why it presents a more eloquent solution to wireless broadband than other technologies.

Firstly, according to Shannon –Hartley the Orem, channel capacity is in proportion to bandwidth. Since UWB has an ultra-wide frequency bandwidth, it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances of 1 to 10 meters . Secondly, UWB systems operate at extremely low power transmission levels. By dividing the power of the signal across a huge frequency spectrum, the effect upon any frequency is below the acceptable noise floor (Cravotta, 2002).

Currently the field of antennas for Body Area Network BAN has resolved itself into the following categories, narrowband, wideband, implantable, fabric and multiple antennas.



Figure(2.15): spectrum of frequency (Reproduced from). (Cravotta, 2002).

For example, 1 watt of power spread across 1GHz of spectrum results in only 1 nano-watt of power into each hertz band of frequency. Thus, UWB signals do not cause significant interference to other wireless systems. Thirdly, UWB provides high secure and high reliable communication solutions .Due to the low energy density, the UWB signal is noise-like, which makes unintended detection quite difficult. Furthermore, the "noise-like" signal has a particular shape; in contrast (Hamalainen and Iinatti, 2004).

2.5.2 Regulation Issus

Any technology has its own properties and constrains placed on it by physics as well regulations. Government regulators define the way that technologies operate so as to make coexistence more harmonious and also to ensure public safety (Oppermann, Hamalainen and Iinatti, 2004).

Since UWB systems operate over an ultra wide frequency spectrum which will overlap with the existing wireless systems such as global positioning system (GPS), and the IEEE 802.11 WLAN, it is natural that regulations are an important issue. The international regulations for UWB technology is not available now and will be mainly dependent on the findings and recommendations on the International Telecom. Union (ITU).

Currently, United States, with the FCC approval, is the only country to have a complete ruling for UWB devices. While other regulatory bodies around the world have also been trying to build regulations for UWB.

2.5.3 The FCC's Rules in Unites States

After several years of debate, the FCC released its First Report and Order and adopted the rules for Part 15 operation of UWB devices on February 14th, 2002.

The FCC defines UWB operation as any transmission scheme that has a fractional bandwidth greater than or equal to 20% or an absolute bandwidth greater than or equal to 500MHz.(Webb,2006). UWB bandwidth is the frequency band bounded by the points that are 10dB below the highest radiated emission, as based on the complete transmission system including the antenna. The upper boundary and the lower boundary are designated fH sub fL, respectively. Also, the frequency at which the highest radiated emission occurs is designated FM. In addition, it must be contained with this bandwidth. Although UWB systems have very low transmission power level, there is still serious concern about the potential interference they may cause to other wireless services. To avoid the harmful interference effectively, the FCC regulates emission mask which defines the maximum allowable radiated power for UWB devices.

In FCC's First Report and Order, the UWB devices are defined as imaging systems, vehicular radar systems, indoor systems and hand-held systems. The devices of indoor systems are intended solely for indoor operation and must operate with a fixed indoor infrastructure. It is prohibited to use outdoor antenna to direct the transmission outside of a building intentionally. The UWB bandwidth must be contained between 3.1GHz and 10.6GHz (Webb, 2006).

2.5.4 UWB Standards

A standard is the precondition for any technology to grow and develop because it makes possible the wide acceptance and dissemination of products for multiple manufacturers with an economy of scale that reduces costs to consumers. Conformance to standards makes it possible for different manufacturers to create products that are compatible or interchange able with each other (Siwiak, and McKeown, 2004).

The IEEE 802.15.3 at ask group is aimed at developing high rate alternative physical layer for WPANs (Siwiak, and McKeown, 2004).802.15.3A is proposed to support a data rate of 110Mbps with a distance of 10 meters. When the distance is further reduced to 4 meters and 2 meters, the data rate will be increased to 200Mbps and 480Mbps, respectively. There are two competitive proposals for 802.15.3a, i.e. the Direct Sequence UWB (DS-UWB) and the Multi band Orthogonal Frequency Division Multiplexing (MB-OFDM). DS-UWB proposal is the conventional impulse radio approach to UWB communication; i.e. it exploits short pulses, which occupy single band of several GHz for transmission. This proposal is mainly backed by Free scale and Japanese and its proponents have established their own umbrella group, namely, the UWB Forum(Cravotta, N. 2002). The concept to direct sequences spread spectrum (DSSS) is illustrated in Figure2.10. The input data is modulated by a pseudo –noise (PN) sequence which is a binary sequence that appears random but can be reproduced at the receiver. Each user is assigned a unique PN code, which is approximately orthogonal to those of other users. The receiver can separate each user based on their PN code even if they share the same frequency band. Therefore ,many users can simultaneously use the same band width without significantly interfering one another (Theodore, 1996).

2.5.5 UWB Applications

Firstly, sensors of all types also offer an opportunity for UWB to flourish (Karacolak, Cooper,Topsakal, 2009).Sensor networks is comprised of a large number of nodes within geographical area.

These nodes may be static, when applied for securing home, tracking and monitoring, or mobile, if equipped on soldiers, firefighters', automobiles, or robots in military and emergency response situations (FCC, 2002). The key requirements for sensor networks include low cost, low power and multi functionality, which can be well met by using UWB technology. High data rate UWB systems are capable of gathering and disseminate ting or changing a vast quantity of sensory data in a timely manner. The cost of installation and maintenance can drop significantly by using UWB sensor networks due to being devoid of wires. This merit is especially attractive in medical applications because a UWB sensor network frees the patient from being shackled by wires and cables when extensive medical monitoring is required. In addition, with a wireless solution, the coverage can be expanded more easily and made more reliable. (Siwiak, K. 2004).

Secondly, positioning and tracking is another unique property of UWB. Because of the high data rate characteristic in short range, UWB provides an excellent solution for indoor location with a much higher degree of accuracy than a GPS. Furthermore, with advanced tracking mechanism, the precise determination of the tracking of moving objects within an indoor environment can be achieved with an accuracy of several centimeters (Alomainy, Hao and Pasveer, 2007).

UWB systems can operate in complex situations to yield faster and more effective communication between people. They can also be used to find people or objects in a variety of situations, such as casualties in a collapsed building after an earth quake.

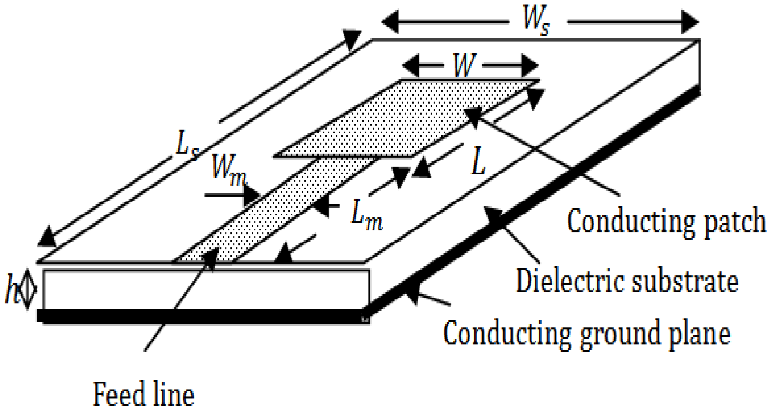
Lastly, UWB can also be applied to radar and imaging applications. It has be ensued in military applications to locate enemy objects behind walls and around corners in the battlefield. It has also found value in commercial use, such as rescue work where a UWB radar could detect a person's breath beneath rubble, or medical diagnostics where X-ray systems may be less desirable.

2.6 Feeding Techniques

The role of feeding is very important in case of efficient operation of antenna to improve the antenna input impedance matching.(Jagdish 2010).

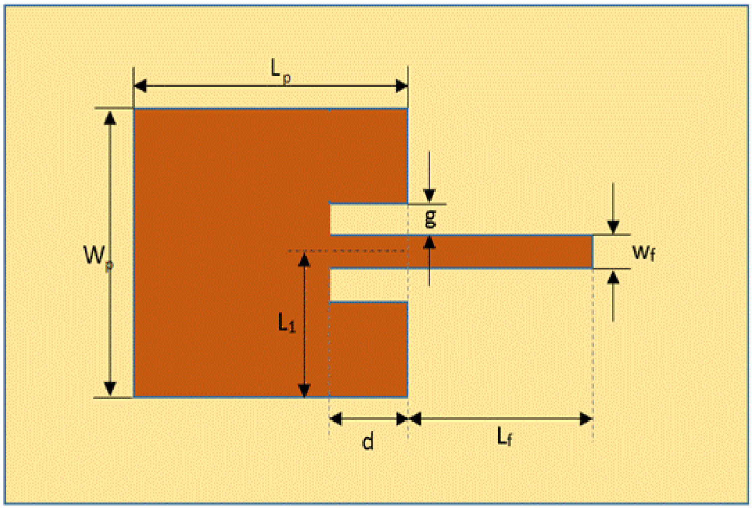
The various types of feeding techniques are:

Microstrip line Feed : In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.(Gurdeep 2012).



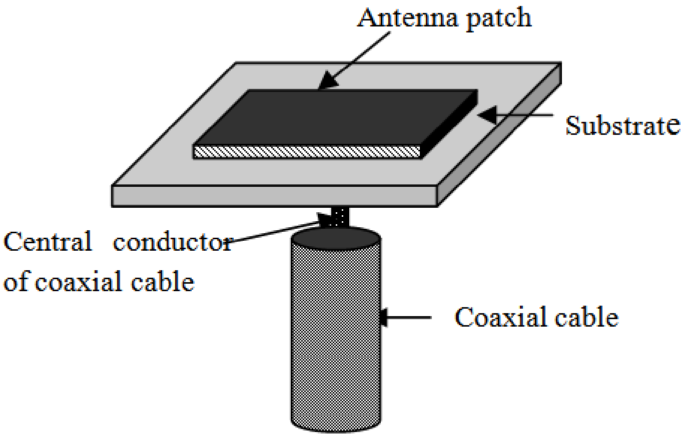
Figure(2.16): Microstrip line Feed. (Ndujiuba, Oloyede 2015).

Inset Feed : In is a type of microstrip line feeding technique, in which the width of conducting strip is small as compared to the patch and has the advantage that the feed can provide a planar structure. (Pattnaik, Gianluca 1998) . The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch input impedance without the need for any additional matching element. This can be achieved by properly adjusting the inset cut position and dimensions. (Mahesh, Gadag, Dundesh, Kamshetty 2010).



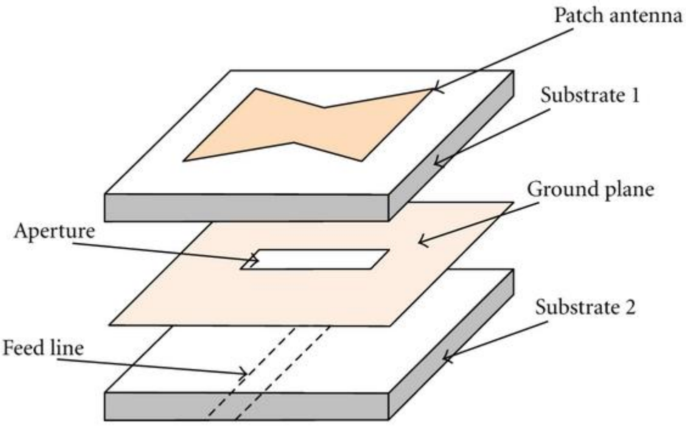
Figure(2.17): Inset line Feed. (Ndujiuba, Oloyede 2015).

Coaxial Feed : The Coaxial probe feeding is a very common technique used for feeding microstrip patch antennas. The inner conductor of the coaxial cable extends through the dielectric and is soldered to the radiating metal patch, while the outer conductor is connected to the ground plane. The advantage of this feeding scheme is that the feed can be placed at any desired location on the patch in order to match cable impedance with the antenna input impedance.(Balanis 2009).The main aim to use probe feeding is it enhances the gain, provides narrow bandwidth and impedance matching. (Mahesh, Gadag, Dundesh, Kamshetty 2010).



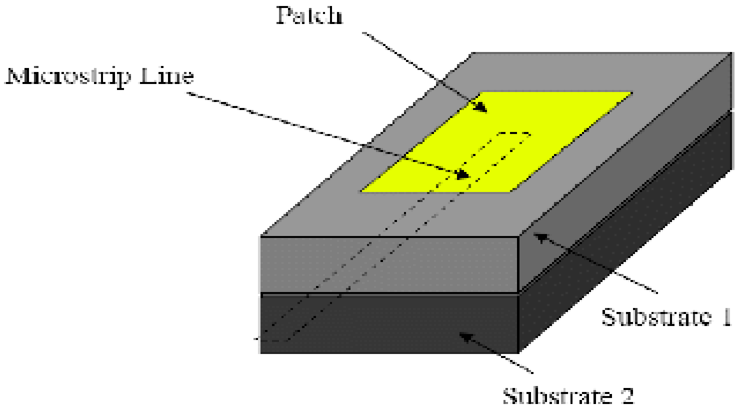
Figure(2.18): Coaxial Feed. (Ndujiuba, Oloyede 2015).

Aperture coupled Feed : In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.



Figure(2.19): Aperture coupled Feed. (Ndujiuba, Oloyede 2015).

Proximity coupled Feed : This type of feed technique is also called as the electromagnetic coupling scheme. 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. (Jagdish 2010).



Figure(2.20): Proximity coupled Feed. (Ndujiuba, Oloyede 2015).

Chapter 3

Design of Frequency and Pattern Reconfigurable Antenna

Chapter 3

Design of Frequency and Pattern Reconfigurable Antenna

Introduction

This chapter presents deign of frequency and pattern reconfigurable antenna. There are conditions that must be acted upon when working to reconfigurable antennas. One of these conditions is that when we change one of the antennas parameters the other parameters must not change. i.e. changing the pattern should keep the return loss acceptable. The antenna is able to switch from ultra-wideband operation to narrowband operation with multiple different radiation pattern configurations. Working on this concept, a novel antenna design is proposed here that can achieve both frequency and pattern re-configurability. Here the work is divided into two parts, the first part is the frequency reconfiguration, and the other part is radiation pattern reconfiguration. PIN diodes are utilized in the design and by changing state of these switches between OFF and ON modes, the proposed antenna is able to switch between the UWB and NWB. Also the proposed antenna is able to switch between the directional and omnidirectional pattern. This design proposes a reconfigurable radiation pattern antenna and reconfigurable frequency antenna that operates across the (3-10) GHz band.

3.1 Antenna Design and Configuration

Fig. 1 Shows the structure of the proposed antenna with its design parameters. The final values of the design sizes are presented in table 1.GHz unit used to express the frequency and millimeter unit used to express dimensions. As shown in Fig.1 there are two circular-shaped microstrip layouts have been added on the proposed antenna. Each one of these shapes divided into eight sections. The first circular-shaped layout is added on the transmission line(Top of substrate), and the distance between each section is 1 mm. The other circular-shaped is placed behind the antenna (Bottom of the substrate) and its epicenter was in the middle of substrate , and the distance between each section is 1.5 mm. Twenty-five switches are inserted to connect the sections with each other ,and in some states of pattern reconfigurable, connect the sections with ground plane. These switches are numbered from D_1 to D_{25},(10 switches used in the first circular-shaped to control the frequency , 15 switches used in the second circular-shaped near the feed-line to control the pattern).

The switches in this design are modeled as copper in simulation when the switch is “ON”. In case of ”OFF” state for the switches, it is left empty space at the location of the switch.

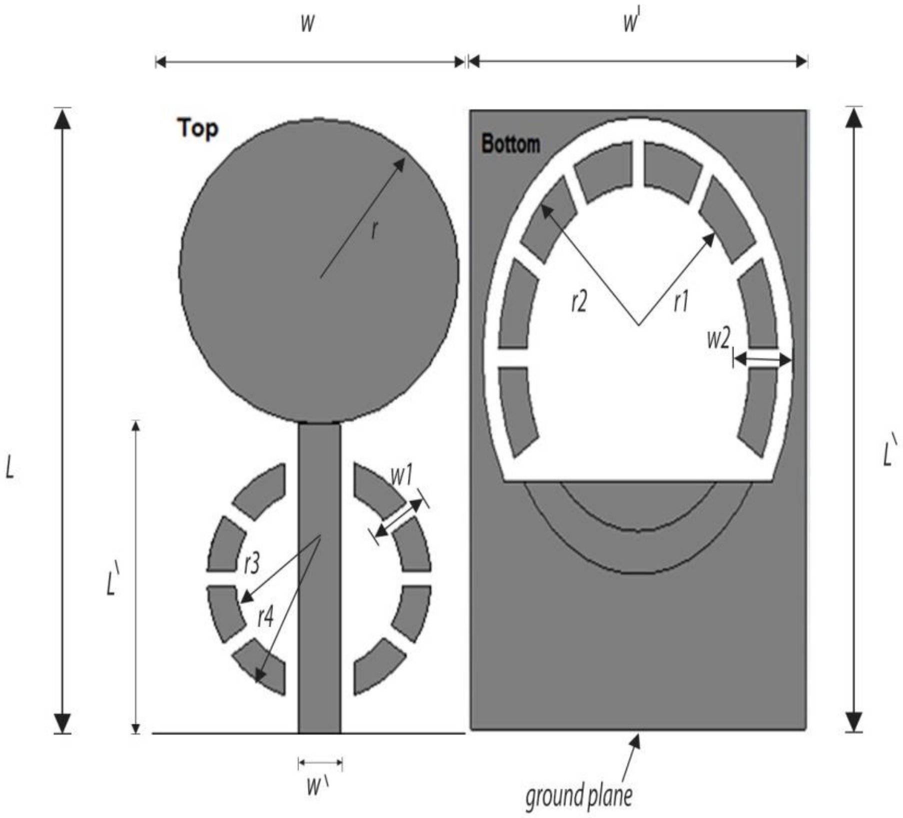


Figure (3.1): Structure of the proposed antenna.

The antenna is designed on FR4 (lossy) substrate with permittivity 4.3 and thickness 1.6 mm . The final dimensions of the proposed antenna are listed in Table 3.1

Table(3.1): Dimensions of the proposed reconfigurable antenna

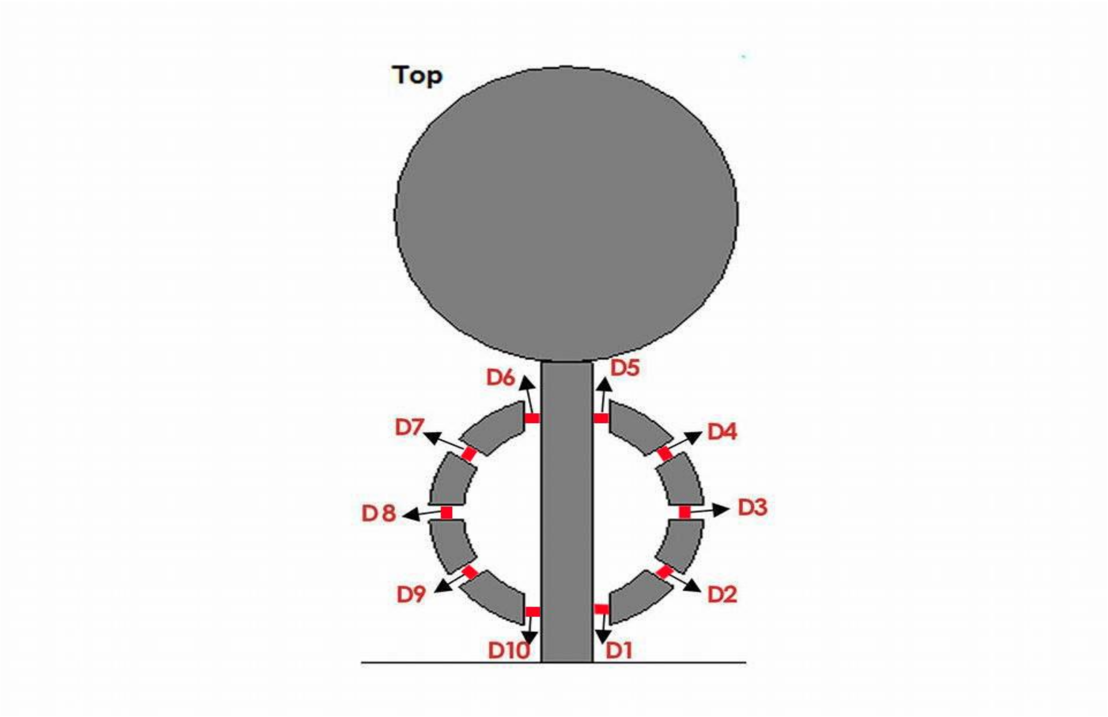
Dimensions	**(mm)**
Substrate width (W)	42
Substrate length(L)	50
Circular disk radius (r)	10
Feed line width(W')	3
Feed line length(l')	20
Ground plane width(W'')	50
Ground plane length(L'')	42
Inner radius of top circular reflector(r3)	6
Outer radius of top top circular reflector(r4)	8
Inner radius of bottom circular reflector(r1)	14
Outer radius of bottom circular reflector(r2)	17.5
width of top circular Reflector(w1)	2
width of bottom circular Reflector(w2)	3.5

3.2 Simulation Results

The simulations were performed using the CST Microwave Studio package ,which utilizes the finite integration technique for computation. CST provides Complete Technology for High Frequency 3D EM Field Simulation, simulation of return loss, radiation pattern, E-Field ,H-Field, 3D far field and S-parameters. In this section, I will show the results obtained for both parts ,the frequency and radiation pattern with analysis.

3.2.1 Simulation results and analysis of frequency re-configuration

Figure3.2. describes the shape of the antenna from the front, where there are 10 switches. Several simulations have been done to get the best results were cases of State0 –to- State 6 are the best, and the On-OFF states are shown in a table 3.2.



Figure(3.2): Diodes Punctuation on Frequency structure

Table (3.2): Switch states for each of the reconfigurable frequency bands.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
State0	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
State1	On	On	On	Off	Off	Off	Off	On	On	On
State2	On	On	On	On	Off	Off	On	On	On	On
State3	On	On	On	On	On	On	On	On	On	On
State4	On	Off	Off	Off	On	On	Off	Off	Off	On
State5	On	On	Off	Off	Off	Off	Off	Off	On	On
State6	On	On	Off	Off	Off	On	On	Off	Off	Off

Frequency simulation results presented in three Figures for clarity. S11 curve compared with all states S11 (every two states with state 0), these three parts of return loss covered all frequencies from 3-10 GHz. Figure 3.3 presents (state0,state1,state2), in table 3.2.

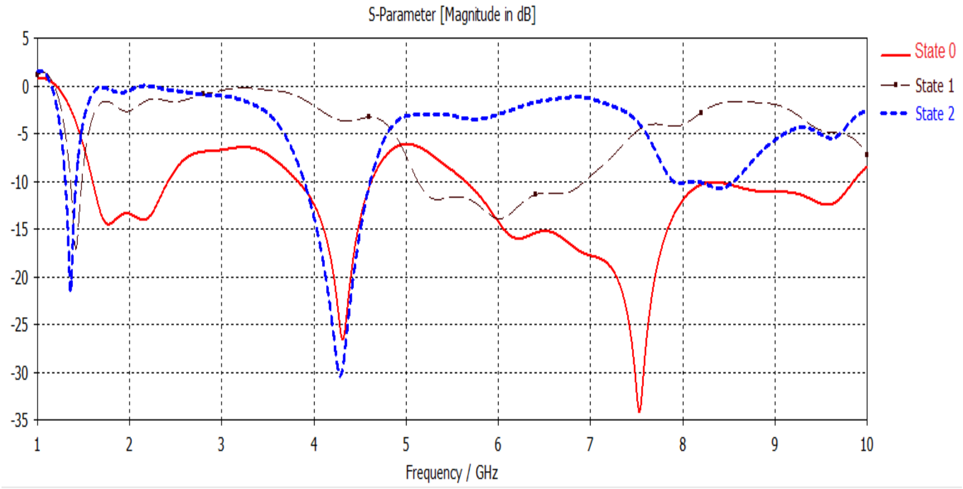


Figure (3.3): simulated return loss curves for different states 0,1,2.

Although the return loss curve of an optimal design of the antenna for covering the Federal Communications Commission (FCC) defined UWB bandwidth is -10 dB ,but the simulated return loss was under the -6dB, which is considered acceptable here in the current work.(Zhang, PP192 ,2011).

As shown in figure 3.3, the reconfigurable frequency is achieved ,this is illustrated by comparison the return loss of the state (1) and state (2) with the return loss of the original UWB (state 0). Here the antenna can be turned from UWB to NWB antenna. In the first case an original state(0) transmission was 3-10 GHz, in state (1) the transmission is in the range [5-7] GHz, in state (2) the transmission is in the range [4-4.5] and [7.5-9] GHz. Figure 3.4 presents (state0,state3,state4), in table 3.2

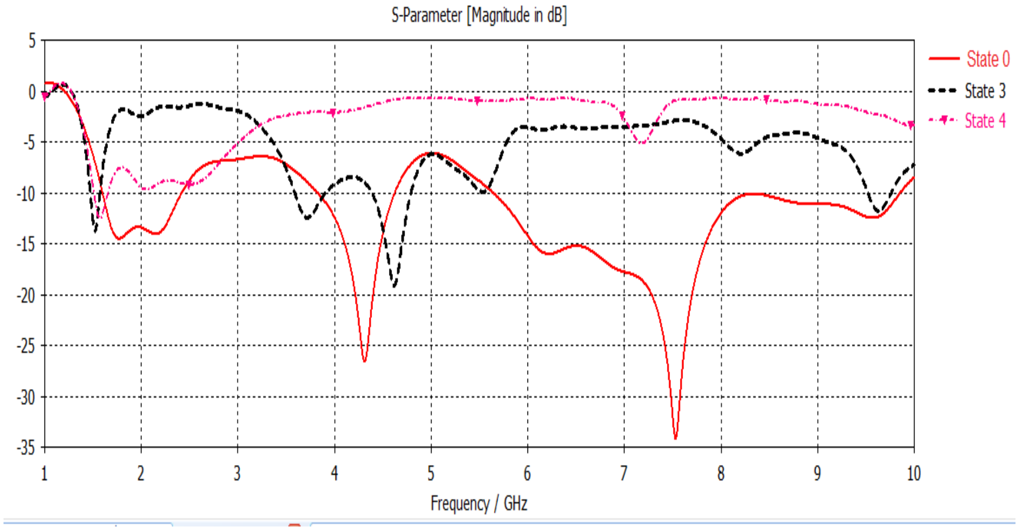
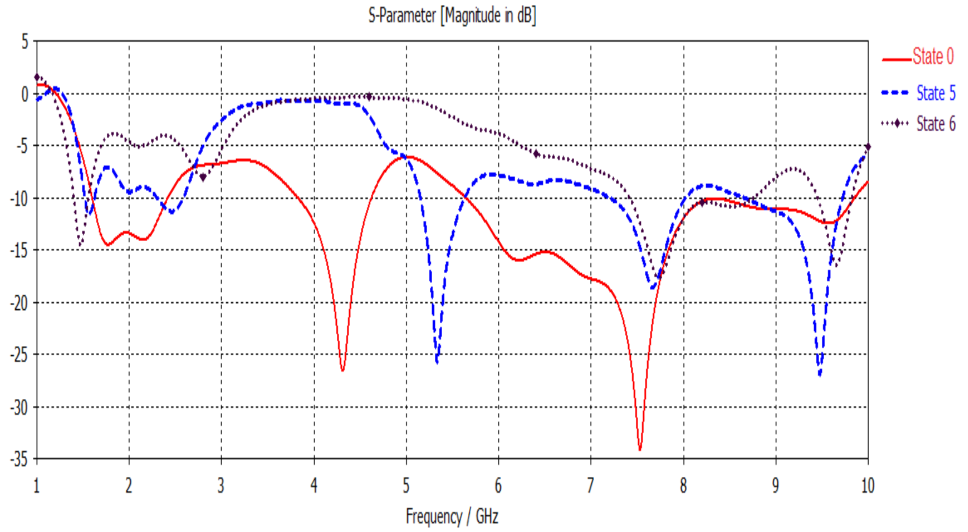


Figure (3.4): simulated return loss curves for different states 0,3,4.

As shown in figure 3.5, the reconfigurable frequency is achieved ,this is illustrated by comparison the return loss of state (3) with the return loss of the original UWB state(0). In state(3) the transmission is in the range [3.5- 5.5] and [9.5-10] GHz. In state(4) the transmission is in the range [1.5-3] GHz which mean that it's below UWB frequency. Figure 3.5 presents (state0,state5,state6), in table 3.2



Figure(3.5): simulated return loss curves for different states 0,5,6.

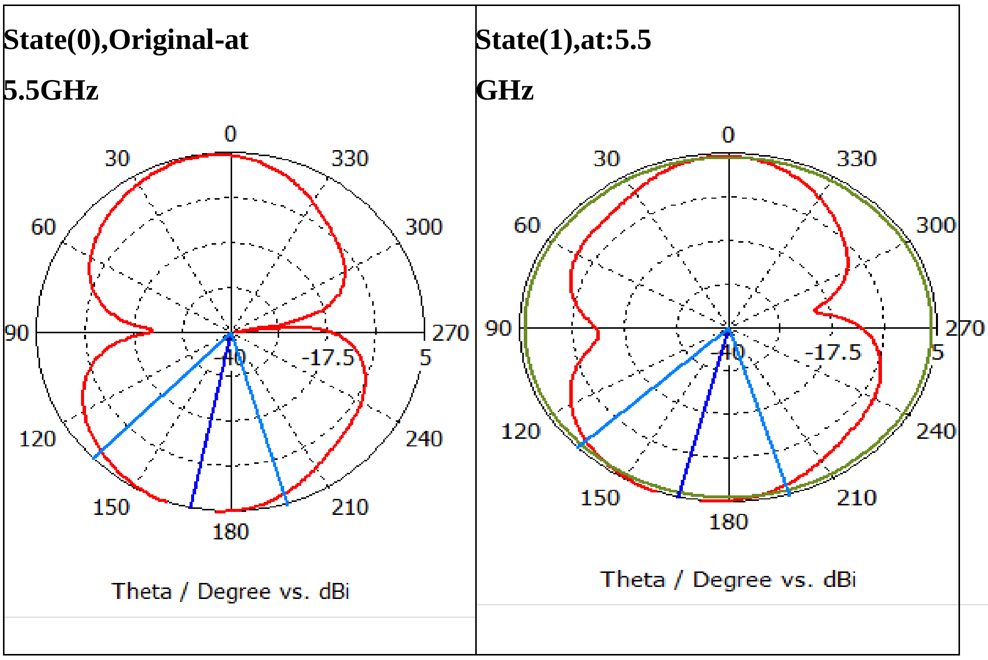
As shown in figure 3.5, the reconfigurable frequency is achieved ,this is illustrated by comparison the return loss of the state (5) and state (6) with the return loss of the original UWB state(0). In state (5) the transmission is in the range [6.5-10]Ghz, and in state (6) the transmission is in the range [5-10]GHz.

After the results at the frequency reconfiguration were offered, we have to check the basic requirement of the concept of re-configuration antenna, which is that when frequency is re-configured, the radiation pattern of antenna does should not change. Now, the radiation pattern of each state in the frequency reconfiguration results will be compared to the original radiation pattern at some operating frequencies.

For example, in the state(1),operating frequency range is in the region of [5-7]GHz, and the radiation pattern in this region is presented at 5.5 GHz and compared with the radiation pattern of the original at the same frequency.

Now and through these figures, radiation pattern is showed for six states and compared to the original [state (0)] The comparisons are shown in Figures.

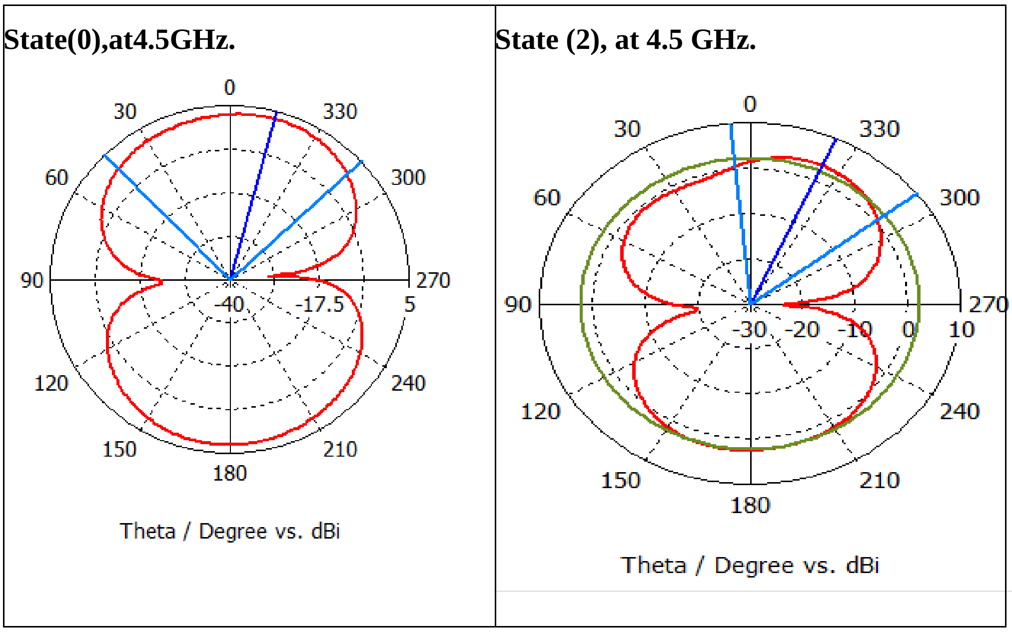
The 1st comparison


State(0),Original-at 5.5GHz

State(1),at:5.5 GHz

Figure(3.6) : Radiation pattern of state (0,1) at 5.5 GHz.

The 2nd comparison

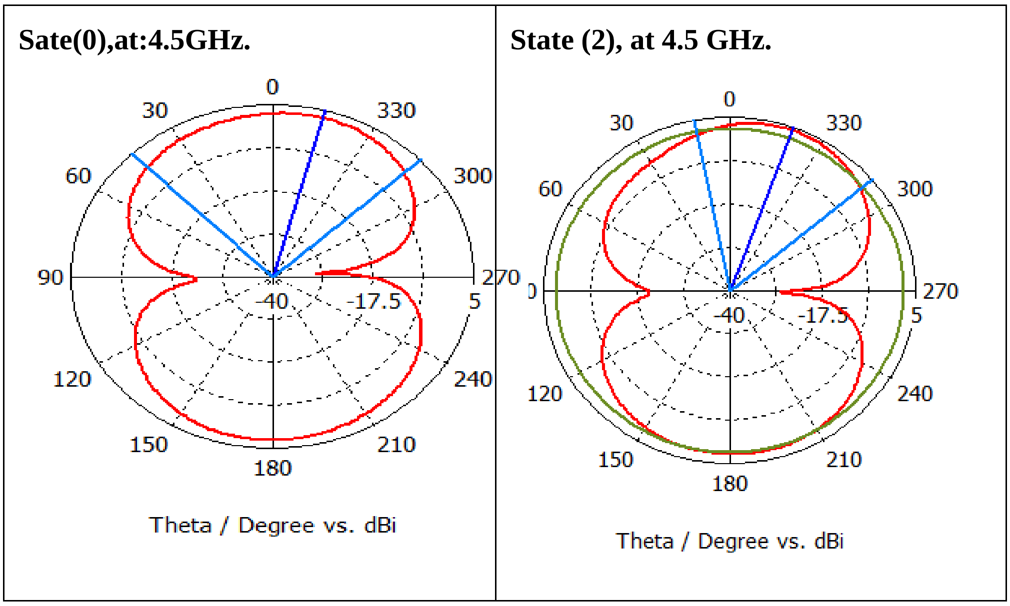


State(0),at4.5GHz.

State (2), at 4.5 GHz.

Figure (3.7) : Radiation pattern of state (0,2) at 4.5 GHz.

The 3rd comparison

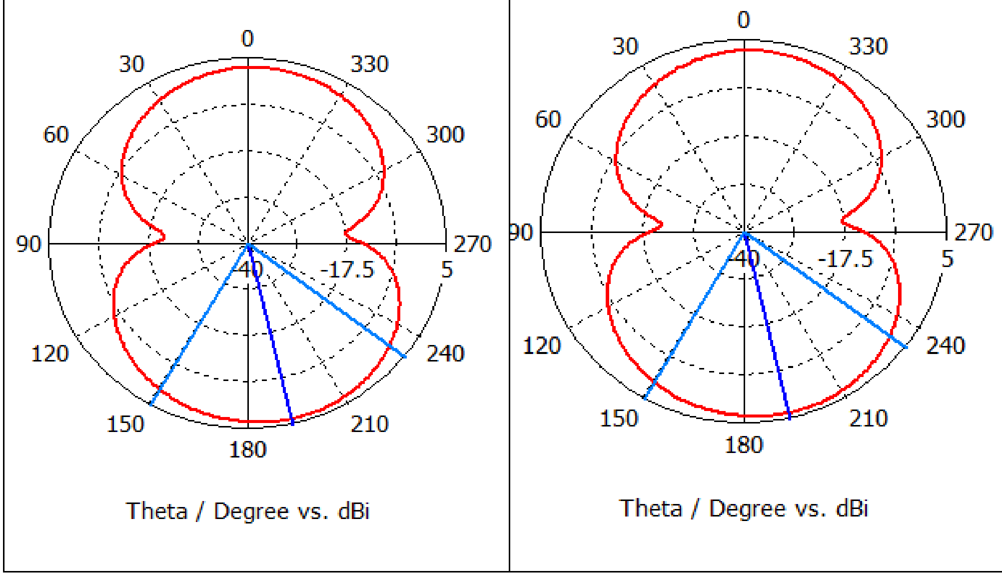


Sate(0),at:4.5GHz.

State (2), at 4.5 GHz.

Figure (3.8): Radiation pattern of state (0,3) at 4.5 GHz.

The 4th comparison

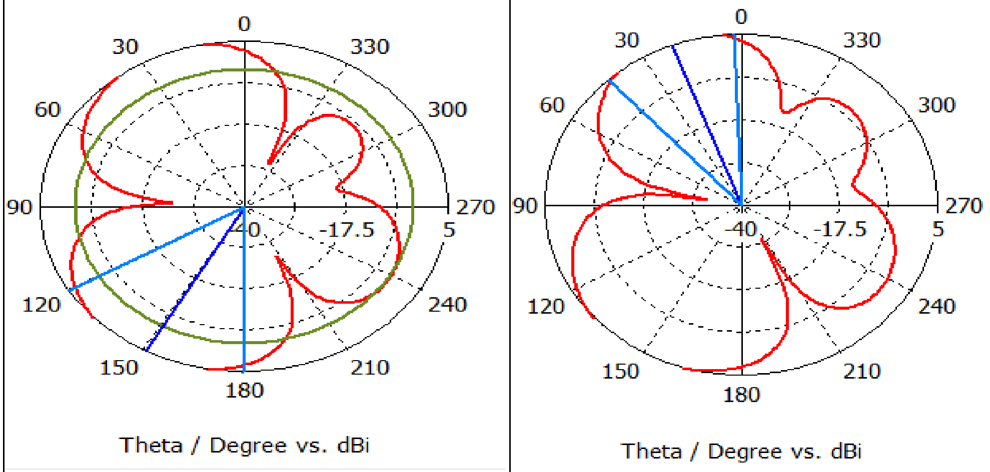


Sate (0), at 2.5 GHz.

State (4), at 2.5 GHz , Below UWB Freq.

Figure (3.9): Radiation pattern of state (0,4) at 2.5 GHz.

The 5th comparison

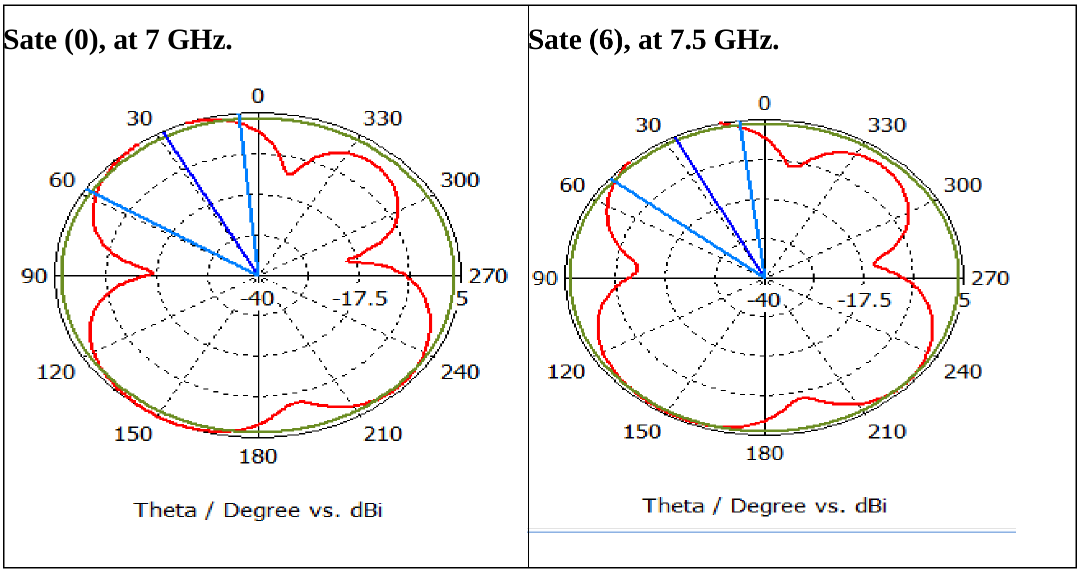


Sate (0), at 7 GHz.

Sate (5), at 7 GHz.

Figure(3.10): Radiation pattern of state (0,5) at 7GHz.

The 6th comparison


Sate (0), at 7 GHz.

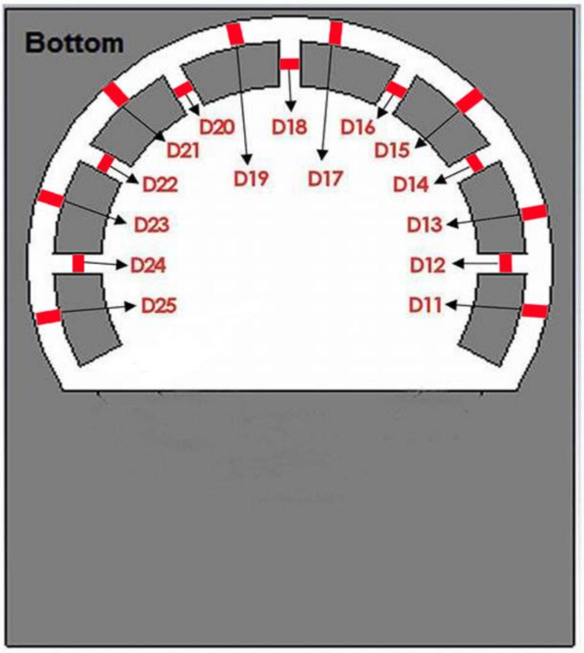
Sate (6), at 7.5 GHz.

Figure(3.11): Radiation pattern of state (0,6) at 7.5GHz.

Following the results in previous comparison figures, the directional pattern has not changed compared to the original pattern and thus the re-configuration requirement is satisfied.

3.2.2 Simulation results and analysis of Pattern Re-configuration

Figure3.7 describes the shape of the antenna from the back, where there are 15 switches. several simulations have been done to get the best results were cases of State0 –to- State 5 are the best. The results are listed in a table 3.

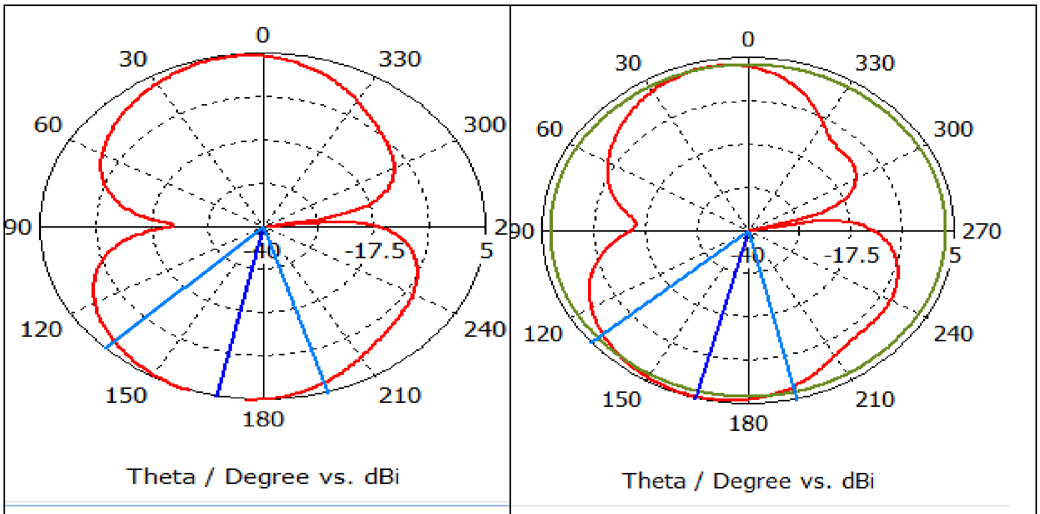


Figure(3.12): Diodes Punctuation on Pattern structure

Table(3.3): Switch states for each of the reconfigurable pattern bands.

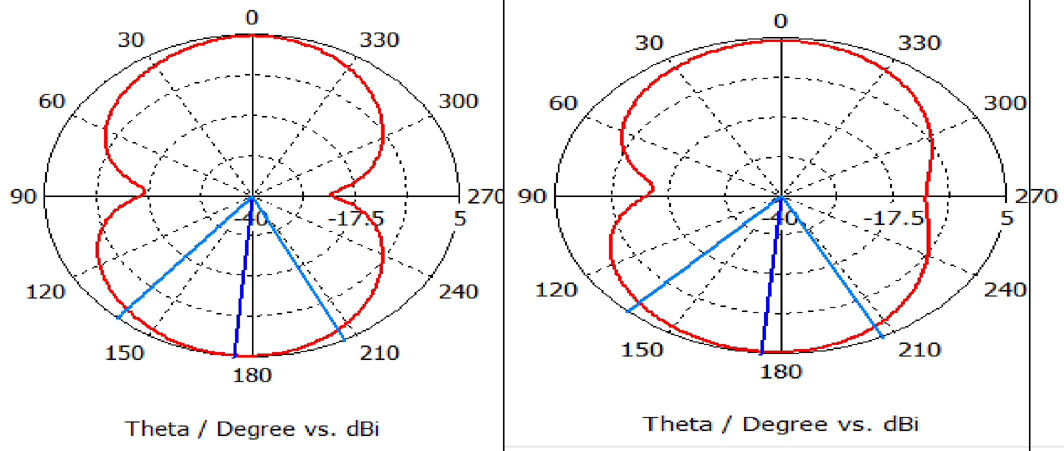
	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25
State0	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
State1	Off	Off	Off	Off	On	On	On	Off	On	On	On	Off	Off	Off	Off
State2	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	Off	Off
State3	Off	Off	Off	Off	On	On	On	On	On	Off	Off	Off	Off	Off	Off
State4	On	On	On	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off
State5	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On

The simulated results of pattern at different states are presented in this section. Figure 3.13 depicts the results at frequency 55 GHz and it can be noticed that pattern changed when going through different states.



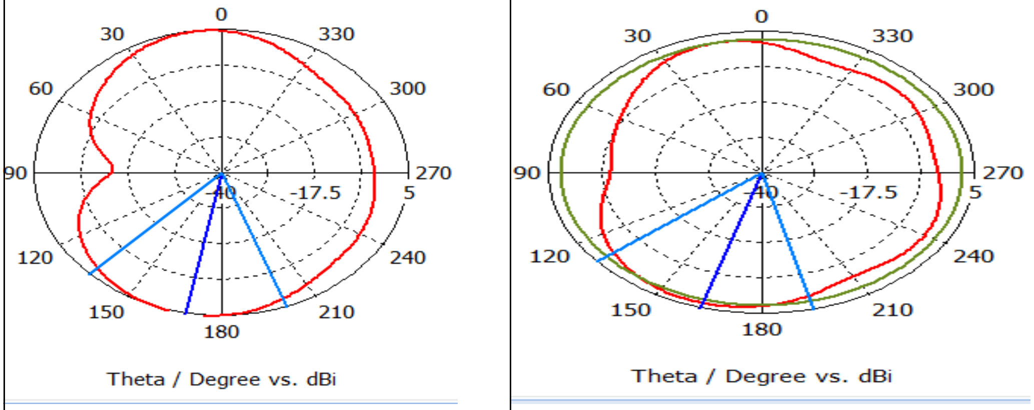
State 0, at f=5.5 GHz

State 1, at f=5.5 GHz



State 2, at f=5.5 GHz

State 3, at f=5.5 GHz



State 4, at f=5.5 GHz

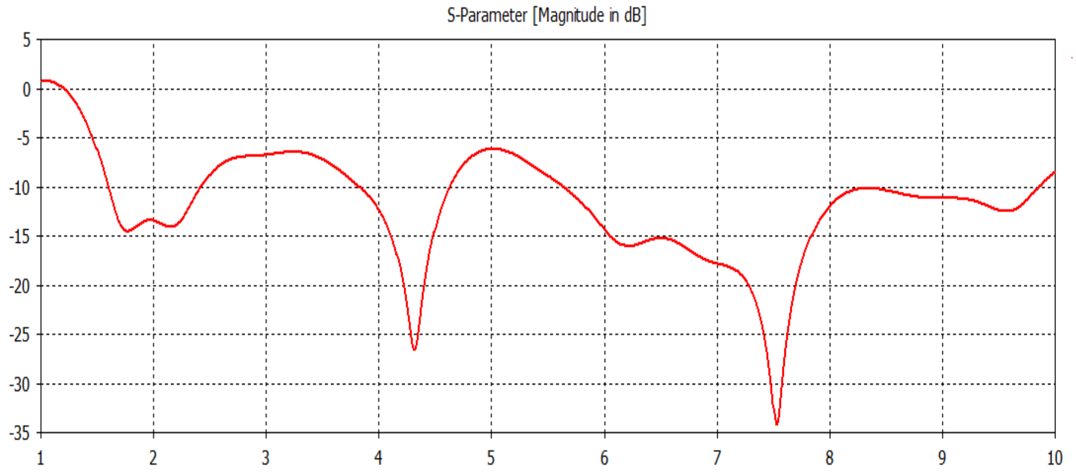
State 5, at f=5.5 GHz

Figure (3.13) : simulated radiation pattern of different states for pattern reconfigurable.

The results in Figure 3.14 shows that the original pattern of state 0 is directional pattern, and the simulated gain is 5.18 dBi at 5.5 GHz. In state 1, the gain is 4.34 dBi at 5.5 GHz and the power level at θ=90 and θ=270 becomes different compared to the original pattern. In state 2, at 5.5GHz , power level increase from right sides, and gain become 4.55 dBi. In state 3,at 5.5GHz, the radiated power is changed from directional to omnidirectional on the right side, power level increase from left sides, gin is 4.32 dBi. In state 4,at 5.5GHz, completely changed the direction of the radiation from the right side and become a broadcast in all directions, is larger than all of the previous cases, as shown in the figure, power level remains constant as it was in the case before, gain is 5.1 dBi. In the last state, also at 5.5GHz,here the radiation pattern completely changed from both sides, so that the null disappears, and increases radiating power to become a broadcast in all directions, and this will be achieved reconfigurable of the antenna from directional to omnidirectional, gain is 3.31dBi.

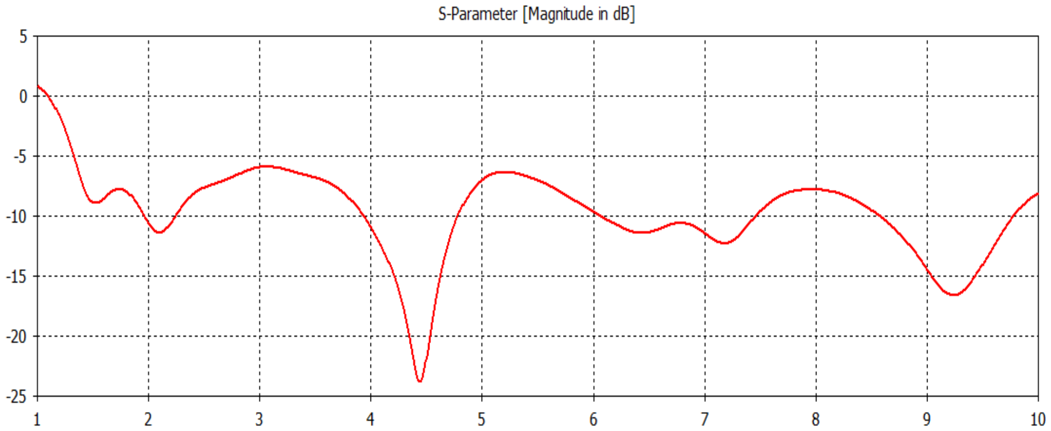
After the results at the radiation pattern reconfiguration were presented, we have to check the basic requirement of the concept of re-configuration antenna, which is that when the radiation pattern is reconfigurable, the frequency of antenna should not change. The results are shown in Figures.

S-parameter of original state (0).



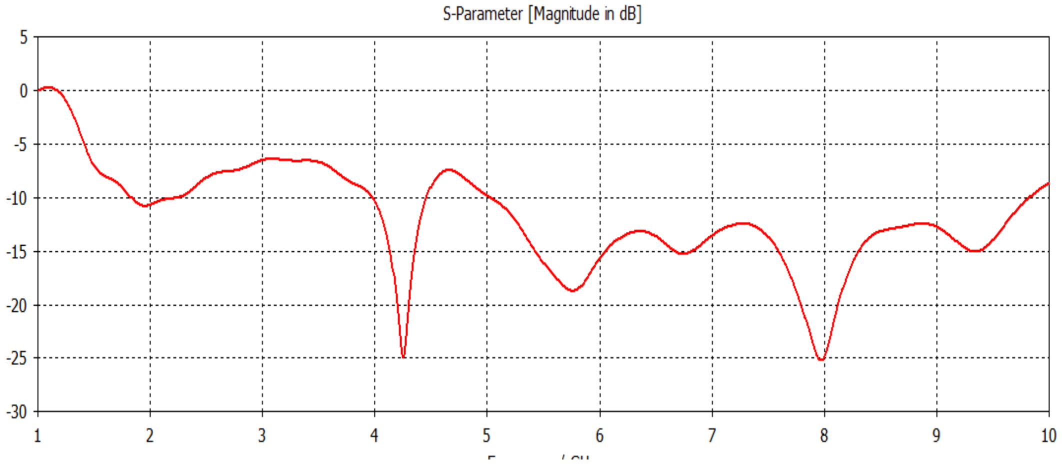
Figure(3.14): return loss of state (0).

S-parameter of radiation pattern reconfiguration, state (1).



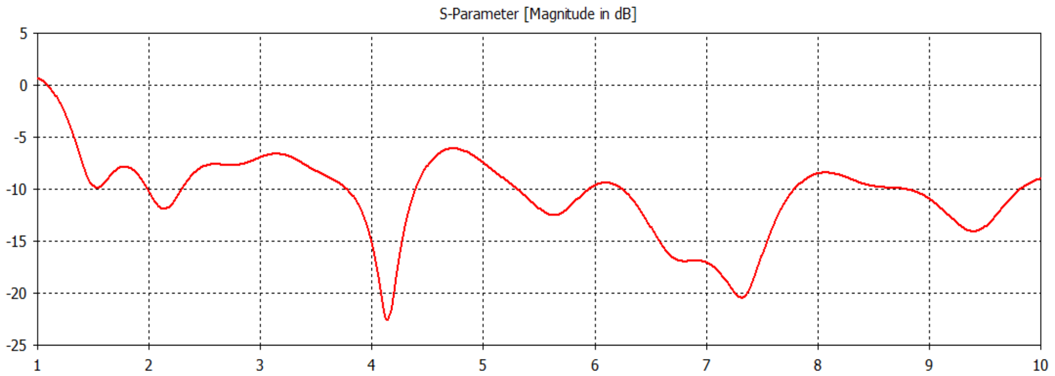
Figure(3.15): return loss of state (1).

S-parameter of radiation pattern reconfiguration, state (2).



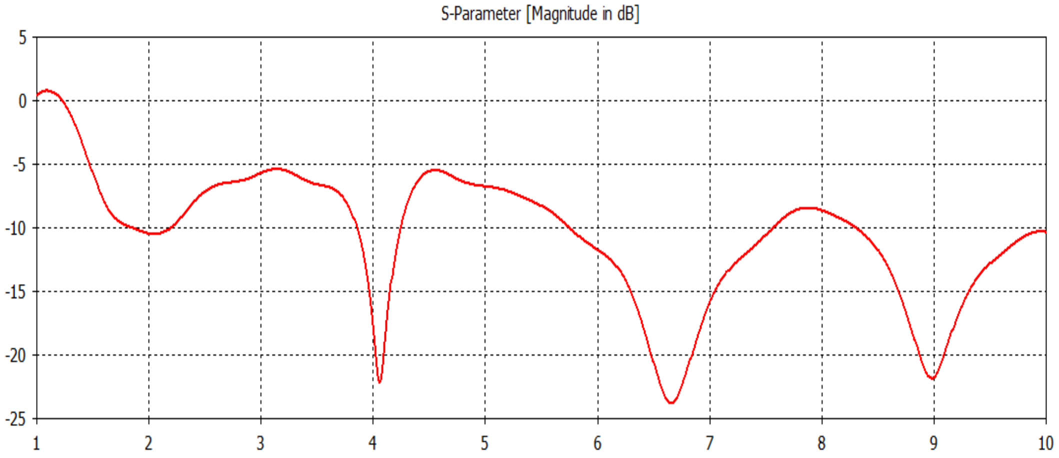
Figure(3.16): return loss of state (2).

S-parameter of radiation pattern reconfiguration, state (3).



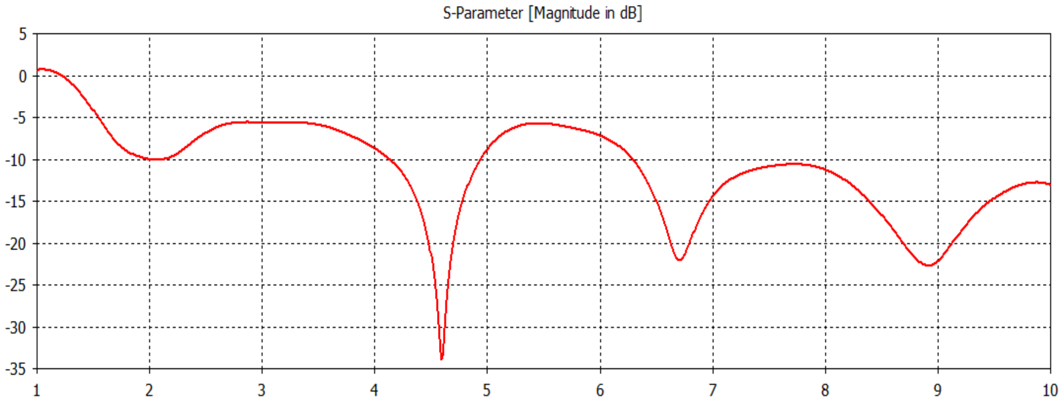
Figure(3.17): return loss of state (3).

S-parameter of radiation pattern reconfiguration, state (4).



Figure(3.18): return loss of state (4).

S-parameter of radiation pattern reconfiguration, state (5).

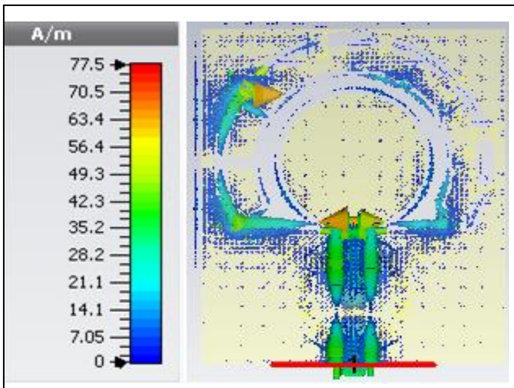


Figure(3.19): return loss of state (5).

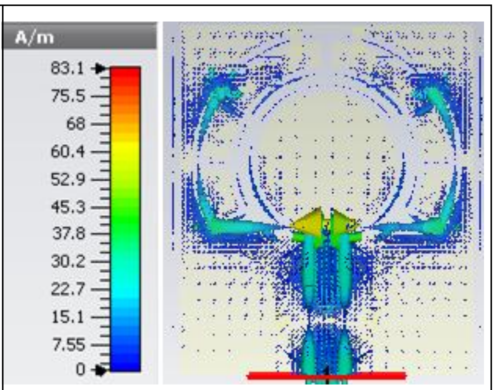
Clearly, from the previous it can be noticed that frequency has not changed in all cases, which means that the condition of reconfigurable frequency is achieved and the antenna remains operating in UWB and does not change to NWB.

The simulation current distribution of proposed antenna at different states are plotted in figure3.20.

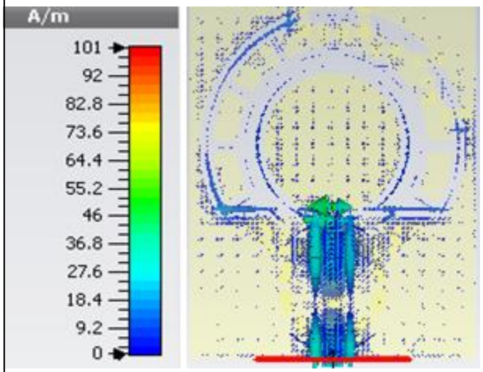
3.2.3 Current distribution



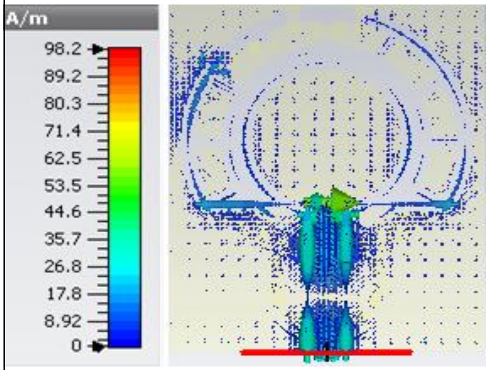
Frequency: state (0), Pattern : state (0)



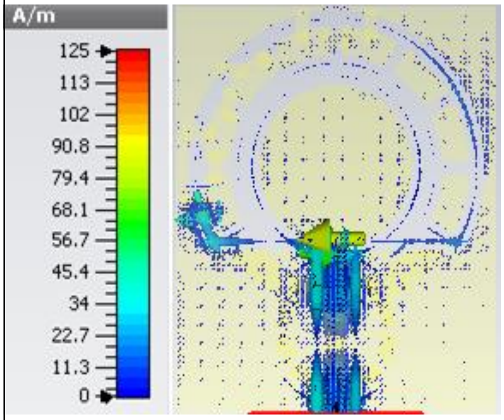
Frequency: state (0), Pattern : state(1)



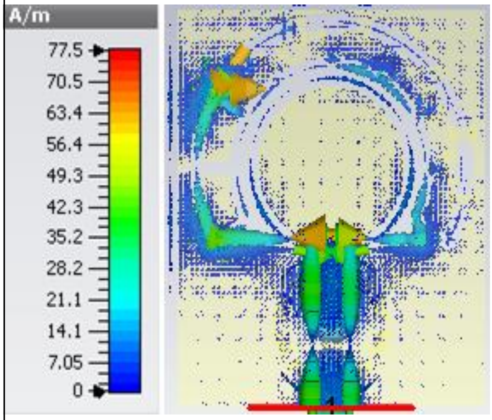
Frequency: state (0), Pattern : state (2)



Frequency: state (0), Pattern : state(3)



Frequency: state (0), Pattern : state (4)



Frequency: state (0), Pattern : state(5)

Figure (3.20): The simulation current distribution of proposed antenna.

3.3 Conclusion

Re configurability is introduced by switching different length of sections. These micro strip sections can be connected together and several low loss switches can change the length of the sections. The results above proved that the frequency reconfigurable not affect on other antenna specifications, similarly, pattern reconfigurable also not affect on antenna specifications. In this we achieve the reconfigurability condition.

Chapter 4

Conclusions and Future Work

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Conclusions

A novel single element reconfigurable ultra-wideband antenna design was presented. The antenna was simply reconfigured by employing circular stubs to support multiple frequency ranges. The antenna return loss, radiation patterns and gain were simulated. Using these circular stubs to reconfigure the antenna allow for more compact design compared to using microstrip rectangular stubs. The proposed antenna can be turned from UWB to NWB . In the UWB case the antenna bandwidth was from 3 to 10 GHz. In the NB case state (1) the bandwidth was in the range from 5 to 7 GHz. When reconfiguring to NB case state (2) the bandwidth was in the range from 4- 4.5 and 7.5-9 GHz. When reconfiguring to NB case state (3) the bandwidth was in the range from 3.5-5.5 and 9.5-10.5 GHz. When reconfiguring to NB case state (4) the bandwidth was in the range from 1.5-3 GHz. When reconfiguring to NB case state (5) the bandwidth was in the range from 6.5- 10 GHz. When reconfiguring to NB case state (6) the bandwidth was in the range from 5-10 GHz.

The reconfiguration process did not affect the original radiation patterns of the ultra-wideband antenna.

Reconfigurable pattern capability has been added to the antenna by employing multiple circular patches on the back of the antenna. The antenna’s radiation patterns can be shaped to concentrate energy in specific directions while minimizing the gain in other unwanted directions, without significantly affecting the bandwidth of the antenna. In our design, we have the omnidirectional mode and 6 multiple directional modes. When reconfiguring the patterns of the antenna the antenna realized gain ranges in the 6 cases were from 4-6 dBi. The designed antenna is highly recommended for providing future smart radio front-end with spatial flexibility by adding the benefits of pattern diversity (through pattern reconfiguration) and interference mitigation through frequency reconfirmation.

To overcome most of the difficulties encountered in using and simulating p-i-n diodes to frequency/Pattern reconfigure ultra-wideband antennas copper switched (ideal switches) were used instead of p-i-n diodes.

Future Work

Fabricate and test a prototype using ideal switches (copper tapes).

The reconfigurable antenna element designs presented in this thesis can be enhanced by using MEMS switches instead of p-i-n diodes, this is due to the low losses they introduce in the antenna and to their inherent low dc power consumption and good linearity.

Ssignificant additional degree of freedom is achieved if the previously designed reconfigurable single-element antennas are arranged in an array. Reconfigurable arrays can enhance the performance of future wireless networks at fraction of the cost of using complex phased arrays.

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