University of Mohamed Khider Biskra
faculty of sciences and Technologies
Department of Electrical and Engineering

Master's Degree

Sciences et Technologies
Field: Telecommunication
Option: Network and Telecommunication

Ref: ....

Presented by :
Ghamri Maroua

On: 30 September 2020

Design a Multiband Micro-strip Patch Antenna

Jury :

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Academic Year : 2019 - 2020

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Favorable opinion of the supervisor:
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Favorable opinion of the President Jury:

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Proposed by: Ms. Ameid Sofiane

Directed by: Ms. Ameid Sofiane

Summarize (English and Arabic)

This project presents a design of micro-strip antenna which is an inseparable part of the wireless networks .Therefore, our work is focused on three techniques applied in patch and ground of the antenna that are used to obtain a multiband and broadband monopole antenna which can radiate in WLAN and WiMAX bands. The first one is DGS technique to impose a monopole antenna and to enhance the bandwidth so that it can be used in mobile phone. The second technique is inverted U-slots in which one inverted U-slot is used to enhance the bandwidth and a 3 inverted U-slot to get a multiband antenna. The last technique is CSRR metamaterial to improve a multiband and to enhance the gain of the antenna. The results are obtained by using the HFSS simulator.

Keywords: Micro-strip, DGS, Inverted U-slot, Monopole, Mobile, CSRR, WiMAX, WlAN.

يقدم هذا المشروع تصميمًا للهوائي المطبوع الذي يعد جزءًا لا يتجزأ من الشبكات اللاسلكية ، ولهذا الغرض يركز عملنا على ثلاث تقنيات مطبقة على تصحيح و أرضية الهوائي والتي تستخدم للحصول على هوائي أحادي القطب متعدد النطاقات وعريض النطاق حيث يمكن ان يشع في نطاقات WLAN و WiMAX. التقنية الأولى هي تقنية DGS لفرض هوائي أحادي القطب بالإضافة إلى تحسين عرض النطاق الترددي بحيث يمكن استعمال الهوائي في الهاتف المحمول . التقنية الثانية هي فتحات U مقلوبة بحيث فتحة Uواحدة معكوسة تستعمل لتعزيز عرض النطاق و

3 فتحات U معكوسة للحصول على هوائي متعدد النطاقات. التقنية الأخيرة هي تقنية الميتامواد CSRR لتحسين النطاقات المتعددة وتعزيز كسب الهوائي. النتائج تم الحصول عليها باستخدام المحاكي HFSS.

كلمات مفتاحية : مطبوع , DGS, فتحات U مقلوبة , CSRR , احادي القطب ,محمول ,WLAN,WiMAX.

Dedication

I dedicate my dissertation work to:

my family and many friends

A special feeling of gratitude to my loving parents

whose words of encouragement and push for tenacity ring in my ears

I dedicate this work and give special thanks to my teachers

Acknowledgments

I wish to express my sincere appreciation to my supervisor Mr.Ameid Sofiane who convincingly guided and encouraged me to be professional and do the right thing even when the road got tough. With many thanks to the jury members to criticize my work.

I would like to thank the following people for helping with this research project: Tarek Menesy from Egypt and Dr.Sajjad Rahim in Shanghai University who took their time to contribute so thoroughly through their further comments and emails.

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I would like to thank all my friends and my colleagues with whom we passed good memories and time and acknowledgment.

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1G: **F**irst **G**eneration

2G: **S**econd **G**eneration

3DES: **T**riple **D**ata **E**ncryption **S**tandard

3G:**T**hird **G**eneration

4G: **F**ourth **G**eneration

AES: **A**dvanced **E**ncryption **S**tandard

ARPT: **T**elecommunications and **P**ostal **A**uthority

BRS: **B**roadband **R**adio **S**ervice

CAT: **A**ir **T**ransport **C**ompany

DGS: **D**efected **G**round **S**tructure

EBG: **E**lectromagnetic **B**and-**G**ap

EM: **E**lectro **M**agnetic

FDD: **F**requency **D**ivision **D**uplex

GPS: **G**lobal **P**ositing **S**ystem

GSM: **G**lobal **S**ystem **M**obile

HFSS: **H**igh **F**requency **S**tructure **S**imulator

IEEE: **I**nstitute of **E**lectrical and **E**lectronics **E**ngineers

ISM: **I**ndustrial **S**cientific and **M**edical

LC (ELC): **C**ombination of **E**lectric **R**esonators

LHMs: **L**eft-**H**and **M**etamaterials

LTE: **L**ong **T**erm **E**volution

MICs: **M**icrowave **I**ntegrated **C**ircuits

NII: **N**ational **I**nformation **I**nfrastructure

OFDM: **O**rthogonal **F**requency **D**ivision **M**ultiplexing

OFDMA: **O**rthogonal **F**requency **D**ivision **M**ultiple **A**ccess

PC: **P**ersonal **C**omputer

QAM: **Q**uadrature **A**mplitude **M**odulation

QPSK: **Q**uadrature **P**hase-**S**hift **K**eying

RSA: **R**ivest **S**hamir **A**dleman

SLC: **S**mart **L**ink **C**ommunications

SRRs: **S**plit **R**ing **R**esonators

TDD: **T**ime **D**ivision **D**uplex

TDM: **T**ime **D**ivision **M**ultiplexing

TDMA: **T**ime **D**ivision **M**ultiple **A**ccess

U-NII band: **U**nlicensed **N**ational **I**nformation **I**nfrastructure

LIST OF ABBREVIATIONS

VoIP: Voice **O**ver **I**nternet **P**rotocol

VPNs: Virtual **P**rivate **N**etwork

WiFi: Wireless **F**idelity

WiMAX: Worldwide **I**nteroperability for **M**icrowave **A**ccess

WLAN: Wireless **L**ocal **A**rea **N**etwork

WMAN: Wireless **M**etropolitan **A**rea **N**etwork

WPAN: Wireless **P**ersonal **A**rea **N**etwork

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INTRODUCTION

General Introduction

The use of the wireless technology covered most of the human needs which have appeared in many areas in our life. Wireless Network is a method of delivering data from a point to another without using physical wires and by means of radio and cellular networks. It increases mobility which allows mobile users to access to real time information such as mobile phone and different application networks (Bluetooth, WiFi and WiMAX).The most important component in wireless communication is the antenna which is responsible of transmitting and receiving the electromagnetic waves. The development of the wireless technology depends on the performance of the antenna.

There are many types of antennas and the most used nowadays is the micro-strip patch antenna for its many benefits like easy fabrication and low cost. The types of applications of MSAs are restricted by the antennas ,inherently narrow bandwidth (BW).Accordingly, increasing the BW of the MSA has been a primary goal of research in the field. This is reflected in the large number of papers on the subject published in journals and conference proceedings. In fact, several broadband MSA configurations have been reported in the last few decades [1].Therefore, we want to design a broadband micro-strip patch antenna in our project.

The remarkable progress in mobile communication systems has proportionally led to the advancement of the antenna systems in the recent decade. The typical mobile communication system has rapidly evolved, emerging from analogue systems to integrated digital systems fully capable of multimedia transmission over several frequency bands. It has become feasible to bring together numerous different applications operating at different channels within only one single wireless device. Accordingly, having multiband antennas capable of covering several wireless signal standards is now a pivotal design requirement. Wireless device terminology considers the antenna that covers more than one of the wireless communication bands as a multi-band antenna[2].

Thesis's objective:

The objective of this project is to design a multiband and broadband monopole antenna with a small geometry (Width and Length) that can radiate in different bands such as L-Band (GSM,UMTS,GPS...), S-Band (WiFi, Bluetooth, Zeegbi and WIMAX....), C-band (WIMAX , WLAN, ...), X-band (Satellite applications) for which the antenna can be usable in cell phones (mobile).The High Frequency Structure Simulator (HFSS)Version 15 is used for the study and the design the proposed antenna.

Thesis outline:

This thesis is divided into three chapters organized as follows:

The first chapter: an introduction to the wireless technologies (WPAN,WLAN,WMAN)and their spectrums**.** Also we introduce the antenna and its basics parameters like frequency, bandwidth, antenna impedance, VSWR, RL, smith chart and impedance matching, Radiation Pattern, Directivity, gain, efficiency and polarization.

The second chapter: an overview of the micro-strip antenna (definition**,** advantages and disadvantages, application, feeding techniques and methods of analysis of MSA's) and the fundamental theories of the working context of the MSA concerning the enhancement techniques for obtain a broadband and multiband antenna designs.

The last chapter: a multiband and broadband monopole antenna designs were modeled and simulated by using the HFSS v15 simulator. The designs of broadband monopole antenna were achieved by the use of DGS technique in the ground and the one inverted U-slot in the patch. The models designs of multiband monopole antenna were obtained by the integration of 3 inverted U-slots and CSRR's in the patch, and DGS technique in the ground.

Finally, we conclude our study with a general conclusion, perspectives and future scope of our work.

CHAPTER I:

WIRELESS NETWORKS AND ANTENNA FUNDAMENTALS PROPRIETIES

Chapter I

Wireless Networks

And Antenna Fundamentals Proprieties

I.1 Introduction:

The demand of mobile and internet is increasing day by day, they are becoming the preferred means of personal and professional communication, giving a new dimension to the telecom industry. To meet up the users request, more and more advancement is being done in the field of communication [3].For that reason we need the wireless networks which we can use it in wireless devices. We will talk about the important of this network by introducing the important wireless networks WPAN (Bluetooth) ,WLAN (WiFi) and WMAN (WiMAX) and we will give a brief comparison between them. As we know that the most important component in wireless network is the antenna which we will define and we will talk about its basic proprieties (frequency, bandwidth, antenna impedance, VSWR, RL, smith chart and impedance matching, Radiation Pattern, Directivity, gain, efficiency, polarization).

I.2 Wireless Network:

I.2.1 Why Are Wireless Devices Important?

There are many reasons. The first one is quite obvious both freedom from wires and mobility. Most such devices, particularly mobile devices, are composed of small mobile terminals or ultra-mobile PCs. Wireless devices are better suited for video sharing (such as via YouTube™), media downloading, gaming, or transferring photographs to processing labs than getting tied to a wired internet point. An example is the BluOynx, which is a mobile server that can store media information and, through its WiFi connectivity, can serve as a gateway to the external world. Users do not need a PC to use the server; it connects using a mobile phone [4].

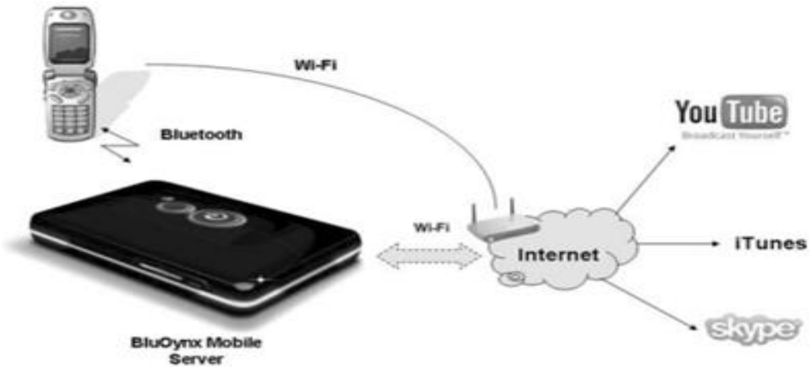


Figure I.1: Example of a wireless device BluOynxTM [4]

I.2.2 Introduction of evolution 1G to 4G:

The evolution of wireless network technologies from 1G to 4G commonly known as first generation (1G), second generation (2G), third generation (3G) and the fourth generation (4G). The first generation mobile communication provided the basic voice communication facility, whereas the second generation supports both the voice and data services. Then the third generation came into existence which gave a boom to the telecommunication industry as it offers subscribers for a wide range of data services, such as mobile Internet access, video conferencing and multimedia applications. But as the demand increased the communication industry moved towards a new generation known as fourth generation with much more advanced features in addition to the usual voice and other services of 3G. The 4G provides mobile ultra broadband Internet access and provides users with much faster data transmission rates. Priorities for this standard include better reception, with less dropped data, IP interoperability for seamless mobile internet, faster information exchanges and much more [3].

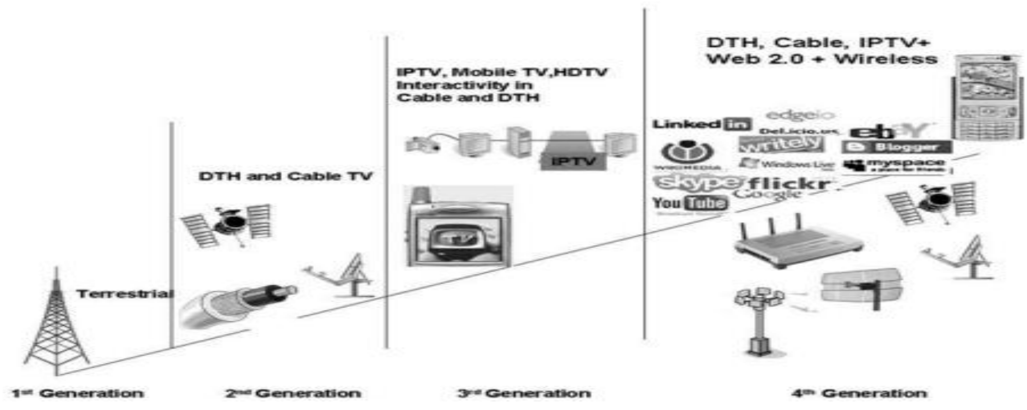


Figure I.2: Evolution 1G to 4G [4]

I.2.3 Wireless Personal Area Network (WPAN):

The market for wireless personal area networks is expanding rapidly. As people use more electronic devices at home and in the office, and with the proliferation of peripherals, a clear need for wireless connectivity between these devices has emerged. Examples of the devices that need to be networked are desktop computers, laptops, printers, microphones, amplifiers, pagers, mobile phones, and sensors. Using cables to connect PC's and with each others can be a difficult task in a fixed location. The most realistic scenario for WPAN technology is cable replacement. This provides a compelling reason to use WPAN technology, and will open the door for more advanced applications in the future. WPAN have a many features like short-range communications, low energy consumption, low cost, small personal networks and connect devices within a personal space. One of wireless standard is leading the way for WPANs: Bluetooth which allows users to connect a wide variety of devices without having to buy, carry or connect cables. They also provide a way to create ad hoc networks among the abundance of mobile devices in the market [5].

a. Bluetooth:

Bluetooth is a standard for enabling wireless communication between laptops, mobile phones, and handheld devices. Bluetooth does not require a line of sight between devices to be effective. It is able to communicate through physical barriers, and usually has a range of up to 10 meters, although with power amplifiers it is possible 100 meters. Bluetooth uses an 2.4Ghz or 2.5Ghz unlicensed band for communication [5].

b. The unlicensed bands:

The Industrial Scientific and Medical (ISM) unlicensed bands are 915 MHz, 2.5GHz and 5GHz. In USA there is an additional U-NII band (unlicensed national information infrastructure) which comprises 300 MHz bandwidth allocated in the 5GHz band. With the anticipated growth of Wireless LAN transmissions in the 2.5GHz band, interference with Bluetooth may become an increasing problem, fortunately, the newer WLAN activity is moving to the 5GHz band, which will help the Bluetooth environment [6].

I.2.4 Wireless Local Area Network (WLAN):

In the early 1990s, WLANs were very expensive and were only used when wired connections were strategically impossible. By the late 1990s, most WLAN solutions and proprietary protocols were replaced by IEEE 802.11 standards in various version which each new advancement is defined by an amendment to the standard that is identified by a one or two letter suffix to "802.11".WLAN prices also began to decrease significantly. WLAN should not be confused with the Wi-Fi Alliance's Wi-Fi trademark. Wi-Fi is not a technical term, but is described as a superset of the IEEE 802.11 standard and is sometimes used interchangeably with that standard. We provide a brief overview of the WLAN standards [7][8].

a. IEEE 802.11b:

In September 1999, the IEEE released the specifications of the 802.11b standard, which provided 11 Mbps transmission in the 2.4Ghz band. This placed its use in the same range of speeds that could be handled on the Ethernet at that time (10 Mbps). This standard is the most widely used standard for wireless LAN access and is used in a majority of WiFi enabled devices [4][9].

b. IEEE 802.11a:

In October 1999, the IEEE also released another variant of the 802.11 standard. The 802.11a standard is designed to operate in the 5 GHz band (typically 5.15 to 5.35 and 5.725 to 5.825 GHz). This band also forms a part of the National Information Infrastructure (NII) in the United States. The band is not unlicensed, although the devices operating in a majority of countries may not require a license. The devices operating with 802.11a are sometimes called WiFi5 to denote the frequency band of operation. In 802.11a, an operation is possible up to a maximum of 54 Mbps as shared bandwidth making possible its use in high-bandwidth applications such as video. The data rate can be reduced to 48, 36, 24, 18, 12, 9 then 6 Mbit/s if required. The band of 5 GHz is characterized by high loss with distance from the transmitter and the inability of signals to pass through obstructions such as walls. In order to overcome these, the 802.11a standard made a major improvement in the physical layer by using the OFDM modulation [4][9][10].

b.1 OFDM:

OFDM "Orthogonal Frequency Division Multiplexing" is a form of signal waveform or modulation that provides some significant advantages for data links. Accordingly, OFDM is used for many of the latest wide bandwidth and high data rate wireless systems including Wi-Fi, cellular telecommunications and many more. The fact that OFDM uses a large number of carriers, each carrying low bit rate data, means that it is very resilient to selective fading, interference, and multipath effects, as well providing a high degree of spectral efficiency[11].

c. IEEE 802.11g:

IEEE 802.11g is an extension to IEEE 802.11 which offers wireless transmission over relatively short distances at 10-54 Mbps in the 2.4 GHz .The IEEE 802.11g use the OFDM modulation and is compatible with IEEE 802.11 a [9].

I.2.5 Wireless Metropolitan Area Network (WMAN):

Wireless Metropolitan Area Network (WMAN) like WLAN and WPAN, is a generic term for networking confined to a geographical area and a set of specific networking technologies that provide wireless communication in metropolitan area .Although WMANs provide city-wide coverage, the area may be as small as a university campus or even a group of buildings. WMAN's belong to a network operator or service provider. The area of coverage of WMAN falls between WLAN/WPAN which are customer premises networks and Wireless Wide Area Networks(WMAN) that are associated with cellular radio mobile networks; Conceptually, WMAN networks provide services to urban or regional areas, both urban and rural, within a 50 km radius. They can be used to connect WLANs / WPANs and provide access to data, voice, video and multimedia services. WMAN is a new technology that will be a supplement to well-known wired technologies. In the meantime, the metropolitan area wireless networks (MANs) development work was progressing under the IEEE 802.16 committee. Standards for Fixed WiMAX (IEEE 802.16-2004) were announced as final in 2004, followed by Mobile WiMAX (IEEE 802.16e) in 2005. The WiMAX Forum, an industry body founded in 2001 to promote conformance to standards and interoperability among wireless MAN networks, then brought forth the WiMAX as it is commonly known today. In Europe, the standards for wireless MANs were formalized under the ETSI as HiperMANs. WiMAX systems (both fixed and mobile), and will be used in the next generation of the long-term evolution of cellular technologies (4G-LTE) [4][12].

a. IEEE 802.16e-2005 standard: [4]

- Frequency Band: 2–6 GHz.
- Multiplexing Schemes: TDM/TDMA and OFDMA.
- Modulation Schemes: QPSK, 16 QAM or 64 QAM (adaptive).
- Duplexing Schemes: TDD and FDD.

b. Spectrum Bands used in WiMAX:

Mobile WiMAX is based on the use of scalable OFDMA and can operate in different frequency bands and has three allocated frequency bands. The low band (2.5-2.69 GHz), the middle band (3.2-3.8 GHz) and the upper band (5.2-5.8 GHz). The frequency band would be either a licensed band or an unlicensed one. However, the availability of various bands (whether unlicensed or otherwise) is country-specific. In general, license-exempt bands, such as 5 GHz (5.25–5.85 GHz) in United States, give an option of fast rollout without awaiting spectral resources. The cost of such systems can also be lower because of the standard frequency band being used rather than a customized country specific band. On the other hand, the unlicensed bands can present higher levels of interference due to other unlicensed systems in use. The licensed bands are the only ones currently recommended for use for Mobile WiMAX as per details in figure I.3. In Europe and many other countries, the 3.5 GHz band is being licensed for Mobile WiMAX applications. The band of 2.495 to 2.690 which is used in the United States is called the Broadband Radio Service (BRS). The type of spectrum required also depends on the technology selected (i.e., FDD or TDD). In the frequency division duplex mode a paired spectrum is needed for the uplink and the downlinks. The most of the initial implementation profiles of WiMAX are based on the use of the time-division duplexing (TDD)[4][13].

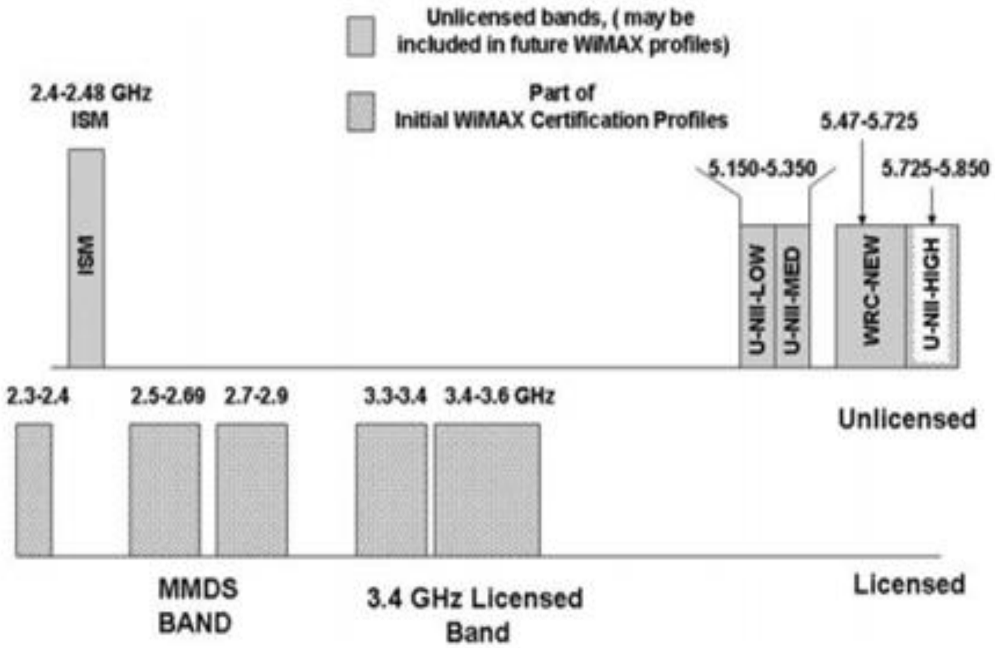


Figure I.3: Spectrum bands and WiMAX certification profiles [4]

c. WiMAX in Algeria:

A WiMAX-based multi-services network was launched in Algeria in July 2005, making it the first country in North Africa to offer such a service. The services are provided by SLC (Smart Link Communications) and provide VoIP, broadband wireless access, and data connectivity (VPNs). The WiMAX network has proved especially advantageous in this case owing to an effective coverage of large areas in mountainous terrain. The ARPT has granted WiMAX authorizations to the fixed telephony operators (Algerian Telecom and CAT) and the VoIP operators (Smart link communications, LastNet, EEPAD, Icosnet, Wataniya, Anouar Net, and Vocalone)[4].

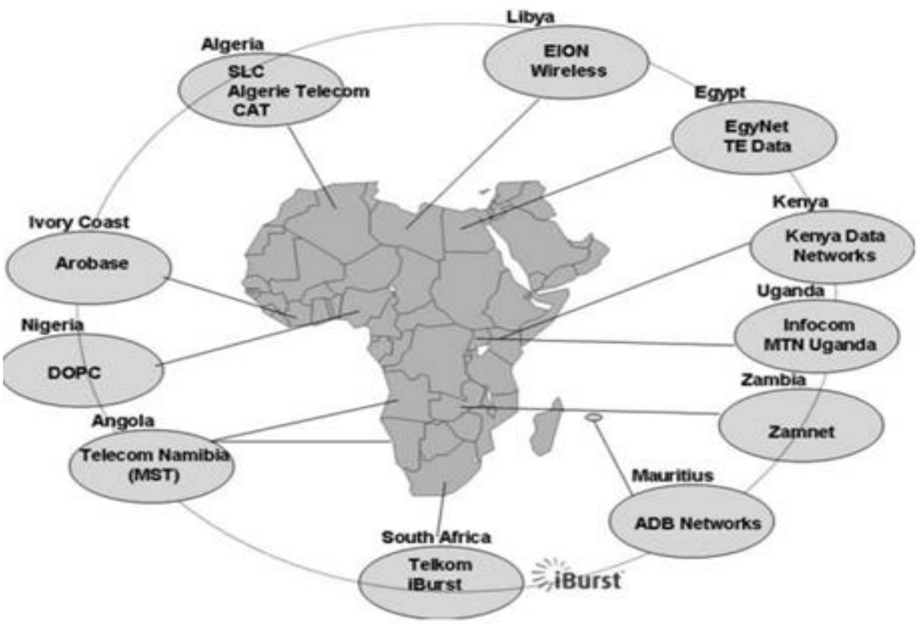


Figure I.4: WiMAX in Africa [4]

d. WiMAX network for interconnecting WiFi hot-spots:

WiMAX networks are seen as ideal methods of interconnecting thousands of hot- spots which exist in a city. In this model of implementation, the WiFi hotspots can be embedded anywhere in the coverage area of a WiMAX base station. The WiFi hotspots can have external high-gain antennas which would enable them to use the most dense modulation schemes and high data rates. In such cases, the data rates will be limited by the capacity of the WiMAX system [4].

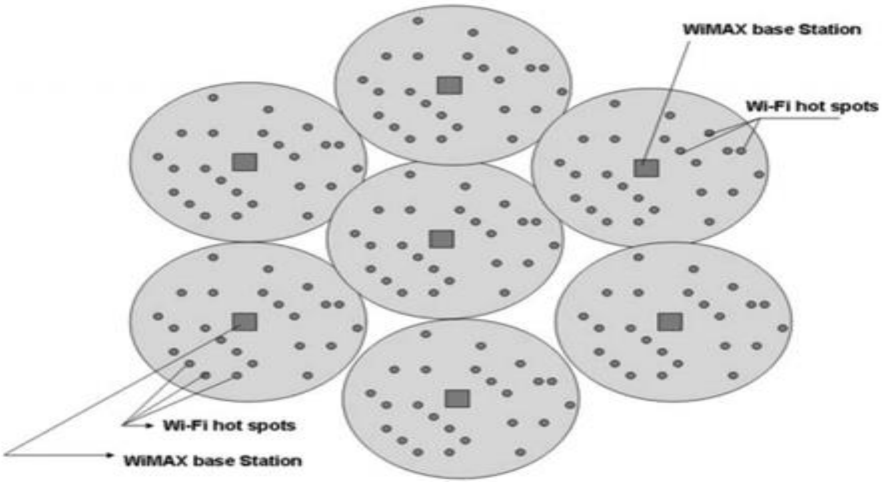


Figure I.5: WiMAX network with WiFi as last time [4]

I.2.6 Performance Comparison between Bluetooth, WiFi and WiMAX:

The table below gives a few differences between Bluetooth, WiFi and WiMAX [4] [14] [15].

Features	Bluetooth	WiFi	WiMAX
Area of operation	10-100 m	10-100 m	More than 20 km
Frequency of operation	Unlicensed band 2.4Ghz or 2.5Ghz	Unlicensed band 2.4Ghz and 5Ghz	Due to a large area of operation Licensed and Unlicensed band 2.486Ghz-2.69Ghz 3.2Ghz-3.8Ghz 5.2Ghz-5.8Ghz
Standards	IEEE802.15.1	IEEE802.11a/b/g	IEEE802.16d/e
Security(Encryption)	Low (using RSA algorithm for encryption)	Medium (using AES Advanced Encryption Standard algorithm for encryption)	High(using 3DES Triple Data Encryption Standard Algorithm and AES for encryption)
Service cost	Low	Medium	High

Table I.1: Performance Comparison between Bluetooth, WiFi and WiMAX

I.3 Antenna fundamentals proprieties:

I.3.1 Definition of Antenna:

An antenna is defined by Webster's Dictionary as a usually metallic device (as a rod or wire) for radiating or receiving radio waves, and The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines them as a means for radiating or receiving radio waves. Electromagnetic Waves (EM)are made up of Electric Fields (E-field) measured by Newtons/Coulomb [N/C] and Magnetic fields (H-field) measured in Amps/Meter[A/m] which both of them are a vector quantity(in every point in space they have magnitude and a direction). The spatial variation (EM vary with space) and the temporal (time) variation (EM vary with time) are given in figures I.6 and I.7 [16][17].

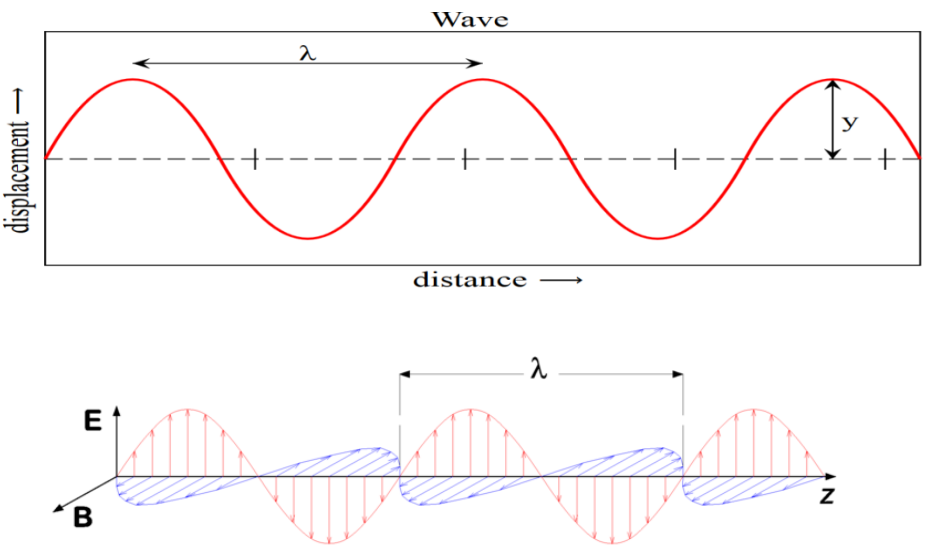


Figure I.6: The spatial variation [18][19]

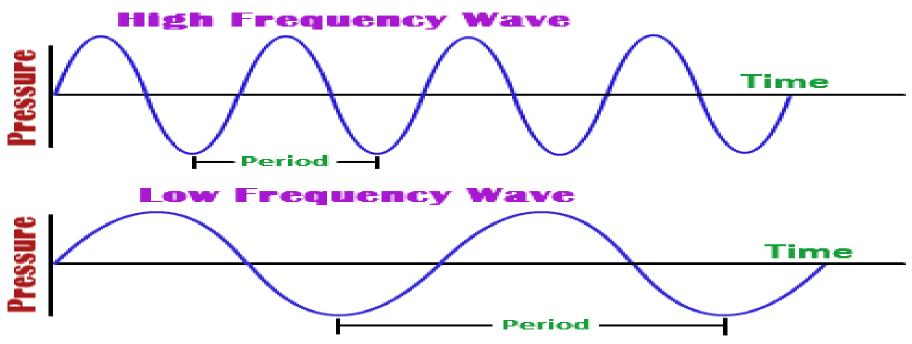


Figure I.7: The temporal variation [20]

Most fundamentally, an antenna is a way of converting the guided waves present in a waveguide, feeder cable or transmission line into radiating waves travelling in free space, or vice versa. Figure I.8 shows how the fields trapped in the transmission line travel in one dimension towards the antenna, which converts them into radiating waves, carrying power away from the transmitter in three dimensions into free space. The art of antenna design is to ensure that this process takes place as efficiently as possible, with the antenna radiating as much power from the transmitter into useful directions, particularly the direction of the intended receiver, as can practically be achieved [21].

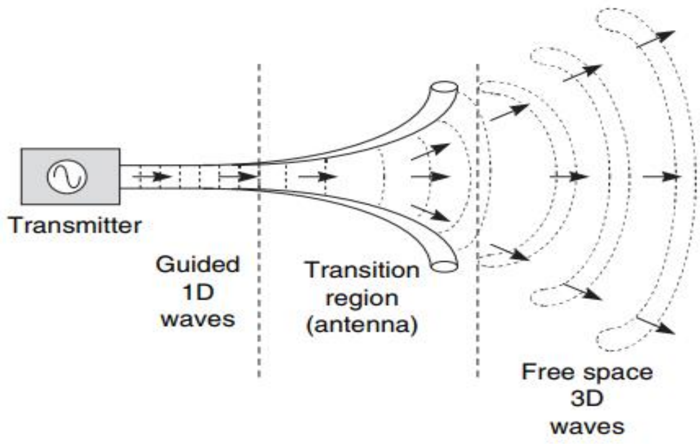


Figure I.8: The antenna as a transition region between guided and propagating waves [21]

I.3.2 Antenna basics:

a. Frequency:

The frequency (written f) is simply the number of complete cycles the wave completes (viewed as a function of time) in one second (two hundred cycles per second is written 200Hz or 200 "Hertz") [16].

Mathematically this is written as:

$$f = \frac{1}{T} \qquad \textbf{(I.1)}$$

Basically the frequency is just a measure of how fast the wave is oscillating and since all EM waves travel at the same speed, the faster is oscillates the shorter the wavelength. And a longer wavelength implies a slower frequency [16].

Mathematically this is written as:

$$f = \frac{c}{\lambda} \quad \textbf{(I.2)}$$

Where f, T, c, λ are represent**:**

f:frequency in Hertz

T:periodic wave in second

c:speed of Light in meters/second

λ:wavelenght in meters

b. Bandwidth:

Bandwidth describes the range of frequencies over which the antenna can properly radiate or receive energy. Also the bandwidth is often specified in terms of its Fractional Bandwidth(FBM) or percentage bandwidth. The FBW is the ratio of the frequency range (highest frequency minus lowest frequency) divided by the center frequency. Wideband antennas typically have a Fractional Bandwidth of 20% or more. Antennas with a FBW of greater than of 50% are referred to as ultra-wideband antennas .The bandwidth once allotted, cannot be used by others. The whole spectrum is divided into bandwidths to allot to different transmitters. A method for judging the efficiency of the antenna which operates over the entire frequency range is the measurement of the VSWR. A VSWR < 2 (RL>-9.54dB) ensures performance [16][22] [23].

Mathematically this is written as:

$$\text{FBW} = \frac{\text{absolute bandwidth}}{\text{center frequency}} = \frac{fH - fL}{fc} \quad \textbf{(I.3)}$$

fH: the highest frequency

fL : the lowest frequency

fc : the center frequency or resonant frequency

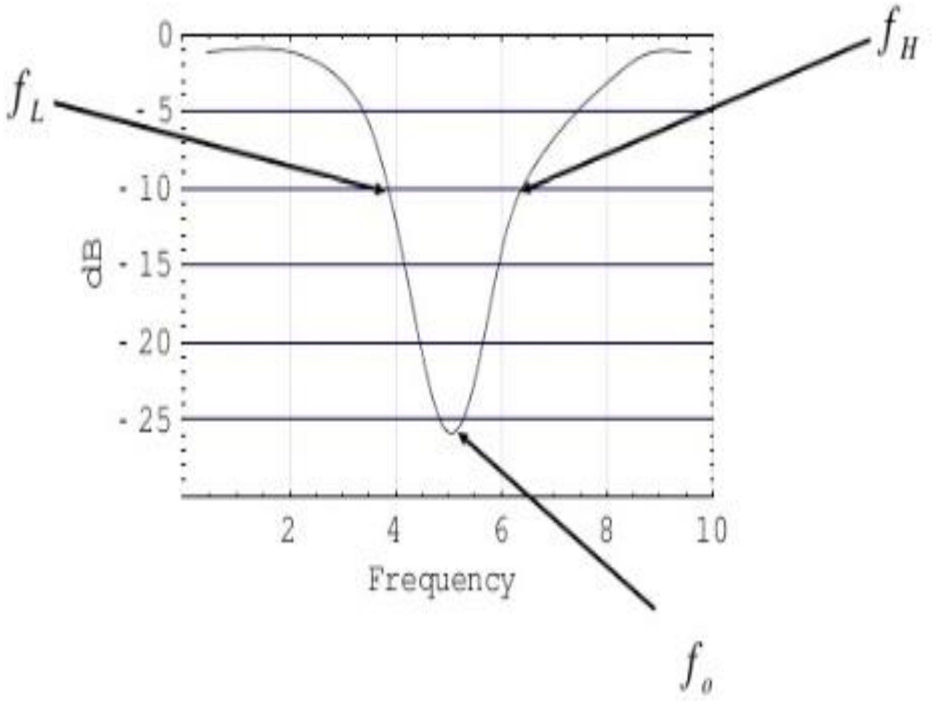


Figure I.9: measure of bandwidth from the Return Loss plot [18]

c. Antenna impedance:

Antenna impedance is a simple concept. Impedance relates the voltage and the current at the input to the antenna .The real part of the antenna impedance represents power that is either radiated away or absorbed within the antenna and the imaginary part represents power that is stored in near field of the antenna (non-radiated power) .An antenna with a real input impedance (zero imaginary part)is said to be resonant .Imaginary numbers are there to give phase information .So; if the impedance is entirely real then the voltage and current are exactly in time-phase and if it is entirely imaginary then the voltage leads the current by 90 degrees in phase. The impedance of an antenna will vary with frequency which the table I.2 below resume the relationship between antenna impedance and frequency for more understanding the important of the antenna impedance[16].

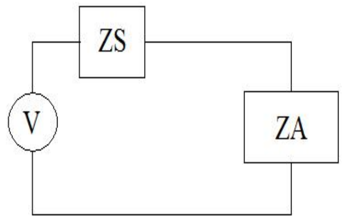
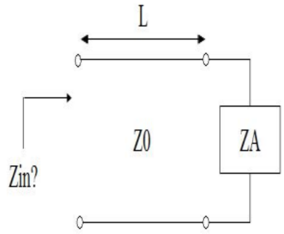
Features	Low frequency	High frequency
Circuit model of the antenna connected to source		
For maximum power to be Transferred from the Generator to the antenna	Z_A=Z_s*	$Zin = Z_0\left[\frac{Z_A+jZ_0\tan(\beta L)}{Z_0+jZ_A\tan(\beta L)}\right]$
Wavelength λ	The length of the line is les than tenth of wavelength L<1/10 λ	L= λ/4
Transmission line	Not important	Important

Table I.2: The relationship between antenna impedance and frequency [16]

$\boldsymbol{Z_S}$: source impedance

$\boldsymbol{Z_A}$: antenna impedance

$\boldsymbol{Z_0}$: characteristic impedance of transmission line

$\boldsymbol{Z_{in}}$: input impedance of the transmission line

$\boldsymbol{\beta}$: wave numbers and mathematical formula is : $\boldsymbol{\beta = \frac{2\pi f}{c} = \frac{2\pi}{\lambda}}$ **(I.4)**

c.1 The calculation of the Characteristic impedance in high frequency:

Step 1: When λ is take to be a quarter :

$$\mathbf{Zin}\left(\mathbf{L} = \lambda/_{\mathbf{4}}\right) = \mathbf{Z_0}\left[\frac{\mathbf{Z_A+jZ_0\tan(\frac{2\pi}{\lambda}\frac{\lambda}{4})}}{\mathbf{Z_0+jZ_A\tan(\frac{2\pi}{\lambda}\frac{\lambda}{4})}}\right] \quad \textbf{(I.5)}$$

Step 2: The simplifies formula is :

$$\boldsymbol{Zin}\left(\boldsymbol{L} = \lambda/_{\mathbf{4}}\right) = \frac{\boldsymbol{Z_0}^2}{\boldsymbol{Z_A}} \quad \textbf{(I.6)}$$

Step 3: The antenna impedance Z_A in higher frequency is generally :

$$Z_A = \frac{Z_0^{\,2}}{Zin} \qquad \textbf{(I.7)}$$

Step 4: The Characteristic Impedance of the transmission line is :

$$Z_0 = \sqrt{Z_{in}\, Z_A} \qquad \textbf{(I.8)}$$

If the antenna is matched to the transmission line (Z_A=Z_0) than the input impedance Zin doesn't depend on the length of transmission line L and makes think much simpler [16].

d. VSWR (adaptation):

In order for the antenna to operate efficiently, maximum transfer of power must take place between the transmission line and the antenna. Maximum power transfer can only take place when the impedance of the antenna is matched to that of the transmitter. If the matching condition is not satisfied, some of the power will be reflected back and this leads to the creation of standing waves, which can be characterized by voltage standing wave ratio (VSWR). The parameter can be expressed by formula I.9 .VSWR is a real number that is always greater than or equal to 1. A VSWR of 1 indicates no mismatch loss(the antenna is perfectly matched) .Higher values of VSWR indicate more mismatch loss. The VSWR is a function of the Γ(the reflection coefficient) describes the power reflected from the antenna. If the reflection is given by Γ, then the VSWR is defined by the formula I.1 [16][23][24].

$$\Gamma = \frac{V_r}{Vi} = \frac{Z_A - Z_s}{Z_A - Z_s} \qquad \textbf{(I.9)}$$

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \textbf{(I.10)}$$

Γ: is the reflection coefficient.

V_r: is amplitude of reflected wave.

V_i: is amplitude of incident wave.

A practical antenna design must have an input impedance equal to 50Ω or 75Ω and most radio equipment is built for this impedance [23].

e. Return Loss:

The Return Loss is a parameter which indicates the amount of energy lost to the load when the impedance of the transmitter and the antenna are not equal. From where RL is a parameter similar to VSWR that can be thought of as a measure of how close the actual input/output impedance of the network is to the antenna impedance value [23][25].

$$\boldsymbol{RL = 10\log_{10}\left|\frac{1}{\Gamma^2}\right| = -20\log_{10}|\Gamma|\ \mathrm{dB}} \qquad \textbf{(I.11)}$$

For a perfect match between the transmitter and the antenna , $\boldsymbol{\Gamma = 0}$ and **RL = - ∞** means that there will be no reflected energy; while that $\boldsymbol{\Gamma = 1}$ and **RL = 0** dB which implies that all the incident power is reflected. For a two-port device there are four S parameters S11, S21, S12, and S22 .The S11 and S22 are simply the forward and reverse reflection coefficients, with the opposite port terminated in Z_0 (usually 50 ohms.) ;S21 and S12 are simply the forward and reverse gains assuming a Z_0 source and load (again usually 50ohms) [23][26].

f. Smith chart and impedance matching:

The Smith Chart is a fantastic tool for visualizing the impedance of a transmission line(the wires that connect the wall outlet to the device) and antenna system as a function of frequency . It is also extremely helpful for impedance matching which is the process of removing mismatch loss to minimize the reflection coefficient .To achieve perfect matching ,we want the antenna impedance to match the transmission line $\boldsymbol{(Z_L(Z_A)=Z_0)}$; In Smith Chart terms we want to move the impedance $Z_L$towards the center of the Smith Chart , where reflection coefficient $\boldsymbol{\Gamma = 0}$ and **VSWR=1**.Series Inductor and Series Capacitor are some of the basic building blocks to make this happen which it is resume in the table I.2 [16].

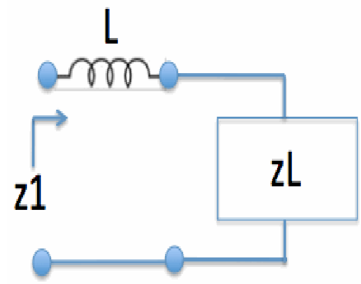
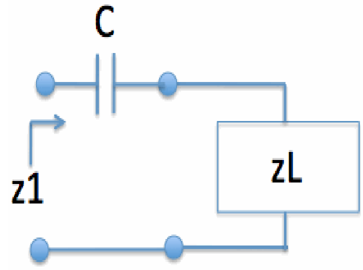
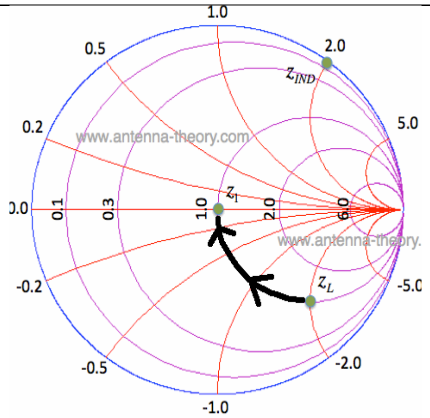
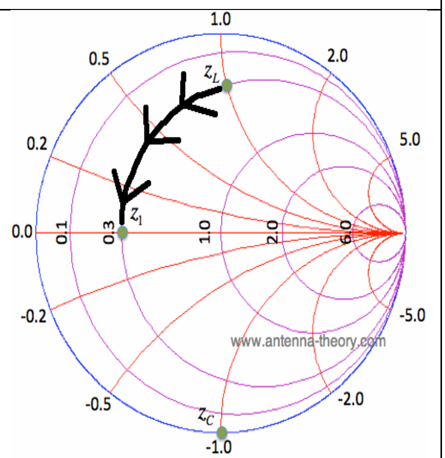
	Series Inductor	Series capacitor
A normalized impedance	$Z_{IND} = \frac{i2\pi fL}{Z_0}$	$Z_c = \frac{1}{Z_0 i2\pi fC} = \frac{-i}{Z_0 2\pi fC}$
Series Inductor and Series Capacitor with Load impedance		
Mathematically ,the series impedance will add	$Z_1 = Z_L + Z_{IND}$ $= R + i(X + \frac{i2\pi fL}{Z_0})$	$Z_1 = Z_L + Z_c$ $= R + i(X - \frac{1}{Z_0 i2\pi fC})$
Series Conductor and Series Capacitor matching Load impedance Z_L		

Table I.3: Series Conductor and Series Capacitor matching Load impedance Z_L

g. 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 .The Rays from any point on the antenna on far field are approximately parallel. The fields surrounding an antenna are divided into 3 principle regions reactive near field , radiative near field and far field which they are represented in the Figure I.9 [16][27].

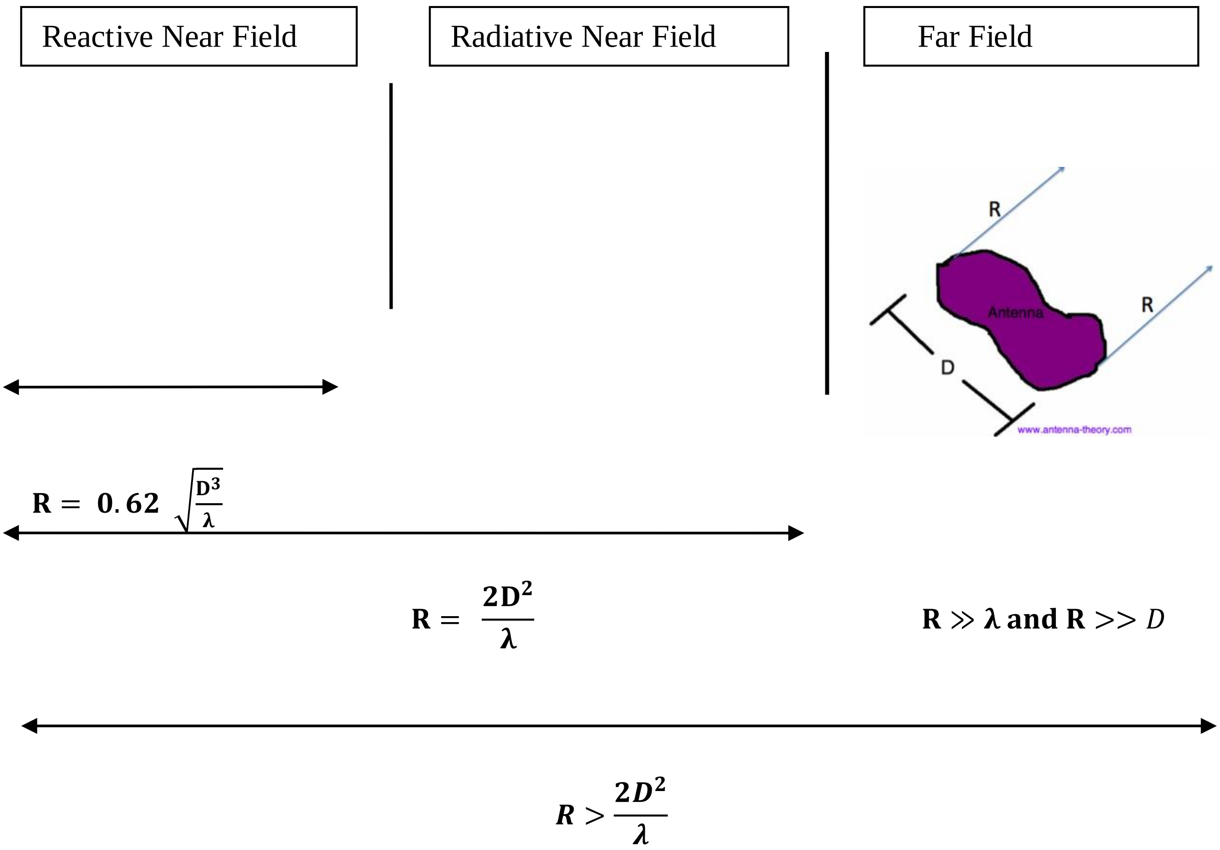


Figure I.10: Regions Field of an antenna [16][27]

D: the maximum linear dimension of the antenna

g.1 Radiation Pattern Lobes:

The Figure I.10 below show the radiation pattern of directive antenna.

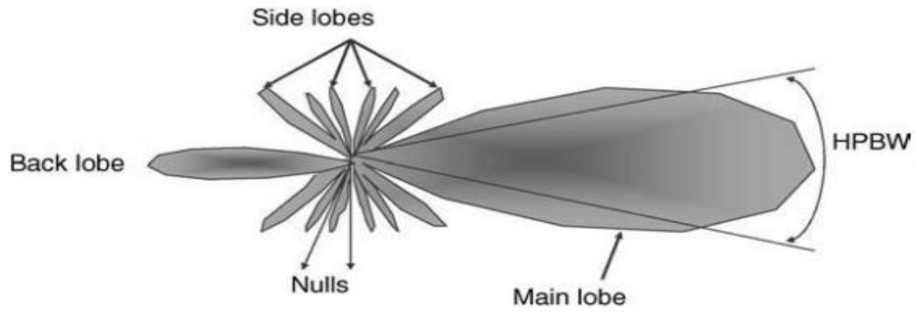


Figure I.11: Radiation Pattern Lobes for generic directive antenna [24]

Main lobe: is the radiation lobe containing the maximum of energy and the direction of the maximum of radiation [23].

HPBW(the Half Power Beam-Width): is the direction angle for which the radiated power is the half of the radiated power in the most favorable direction [23].

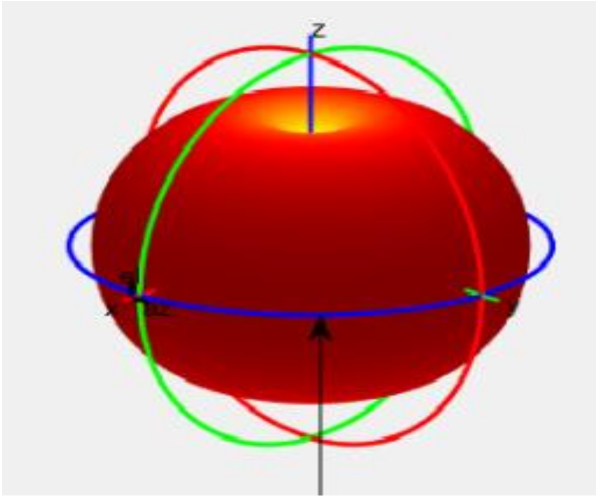
Side lobes :all other lobes are called minor lobes or secondary lobes .They represent the radiation from the antenna in unwanted directions [23].

Back lobe: it is the secondary lobe or minor lobe present in the opposite direction at 180° from the main lobe [23].

g.2 Isotropic, Directional, and Omnidirectional Patterns:

g.2.1 Isotropic Pattern:

A pattern is isotropic if the radiation pattern having equal radiation in all directions. Antenna with isotropic radiation patterns doesn't exist in practice, but are sometimes discussed as a means of comparison with real antennas. The surface area of the ball represents the total available power radiated by an ideal isotropic antenna over its sphere of radiation like shown in the figure I.11 [16][27][28].



FigureI.12: Isotropic Pattern Antenna [29]

g.2.2 Directional Pattern:

The antenna typically has a single peak direction in the radiation pattern; this is the direction where the bulk of the radiated power travels [16].

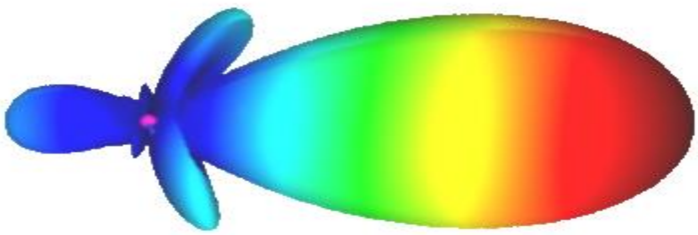
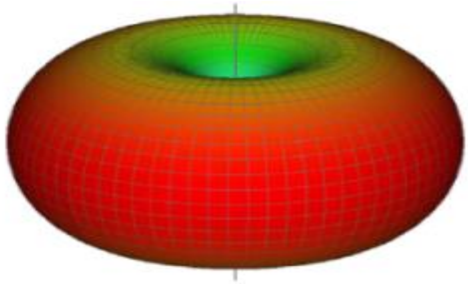


Figure I.13: Directional Pattern Antenna [30]

g.2.3 Omnidirectional Pattern:

An Omnidirectional antenna is designed to provide a 360 ° radiation pattern . This type of the antenna is used when coverage in all direction from antenna is required .It is one of the most popularly used antennas in wireless application which achieves a greater coverage distance in the horizontal direction at the expense of coverage in the vertical areas of the radiating sphere and the figure I.12 shows the Omnidirectional Pattern [28][31][32].



FigureI.14: Omnidirectional Pattern Antenna [30]

h. Directivity:

It is a measure of how 'directional' an antenna's radiation pattern which is an antenna that radiates equally in all directions would have effectively zero directionality. Antennas for cell phones should have a low directivity because the signal can come from any direction, and the antennas should pick it up. In contrast, satellite dish antennas have a very high directivity, because they are to receive signals from a fixed direction. It is important to understand directivity in choosing the best antenna for our specific application. If we need to transmit or receive energy from a wide variety of directions (example: car radio, mobile phones, computer Wifi), then we should design an antenna with a low directivity. Conversely, if we are doing remote sensing or targeted power transfer(example: received signal from a mountain top) we choose a high directivity antenna , to maximize power transfer and reduce signal from unwanted directions. [16] If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed in the formula [27][28]:

$$D_{max} = D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{P_{rad}} \quad \textbf{(I.12)}$$

D **:** directivity (dimensionless)

D_0 **:** maximum directivity (dimensionless)

U_{max}: maximum radiation intensity (W/unit solid angle)

U_0**:** radiation intensity of isotropic source (W/unit solid angle)

P_{rad}**:** total radiated power (W)

i. Efficiency:

The efficiency of an antenna is a ration of the power delivered to the antenna relative to the power radiated from the antenna. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna. The antenna efficiency is quoted in terms of in percentage % or in dB [16].

mathematically written:

$$0 < \varepsilon_R = \frac{Pradiated}{Pinput} < 1 \quad \textbf{(I.13)}$$

ε_R **:** the antenna efficiency radiation

$Pradiated$**:** radiated power

$Pinput$**:** input power of the antenna

j. Gain:

The gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Gain is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur [16].

$$G = \varepsilon_R D \quad \textbf{(I.14)}$$

D **:** directivity

ε_R **:** antenna efficiency (radiation efficiency)

j. 1 Units for Antenna Gain:

The units for antenna gain listed in dB, dBi or dBd and their definitions are [16]:

dB(decibels): number N in dB means N times the energy relative to an isotropic antenna in the peak direction of radiation for example 10dB means 10 times the energy relative to an isotropic antenna in the peak direction of radiation [16].

dBi (decibels relative to an isotropic antenna): means twice(2x) the power relative to isotropic antenna in the peak direction [16].

dBd(decibels relative to a dipole antenna): Note that a half-wavelength dipole antenna has a gain of 2.15 dBi. Hence 7.85dBd means the peak gain is 7.85 dB higher than a dipole antenna [16].

k. Polarization:

The polarization is defined as being the orientation of the electric field of a wave electromagnetic EM. The polarization of a wave is a fundamental data for the study of antennas. According to the constitution of the antenna, it will only receive a certain form of polarization. The polarization state of a plane wave could be expressed in terms of the relative amplitudes of the orthogonal components of the electric field [14][23].

mathematically written:

$$\mathrm{E}=\boldsymbol{E_0}(\boldsymbol{E}_{\theta}\hat{\theta} + \boldsymbol{E_\phi}\,\hat{\boldsymbol{\phi}}) = \boldsymbol{E_0 p_w} \quad \textbf{(I.15)}$$

Where $\boldsymbol{E_0}$ is the electric field amplitude and $\boldsymbol{p_w}$is the polarization vector of the wave. Circular polarization can be described by [21]:

$$\boldsymbol{p_w} = \begin{Bmatrix} \frac{\hat{\theta} - j\hat{\phi}}{\sqrt{2}} \ \textbf{for right} - \textbf{hand circular polarization} \\ \frac{\hat{\theta} + j\hat{\phi}}{\sqrt{2}} \textbf{for Left} - \textbf{hand circular polarization} \end{Bmatrix} \quad \textbf{(I.16)}$$

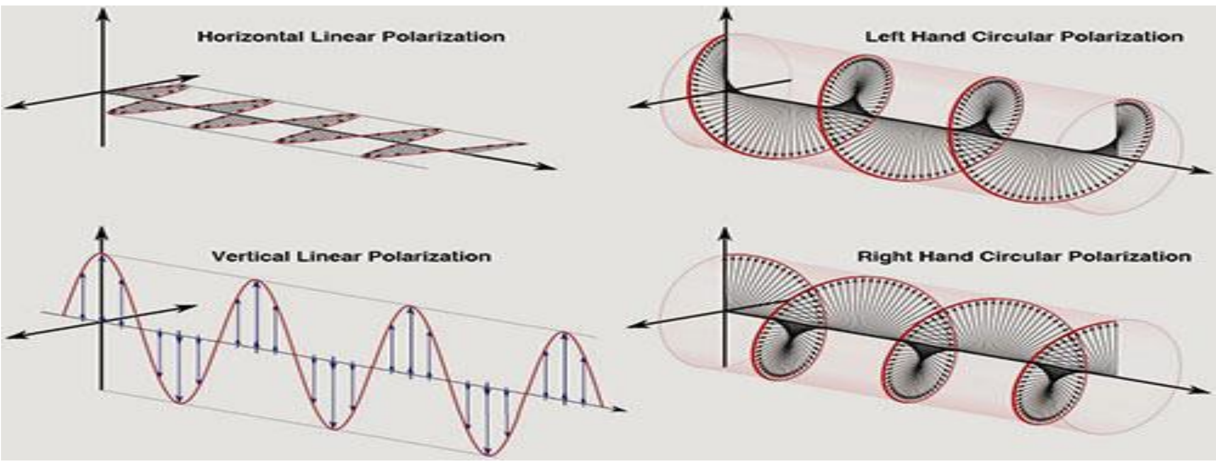


Figure I.15: Antenna Polarization [33]

Polarization may be classified as **linear**, **circular** or **elliptical** depending on the properties of the polarization ellipse. If the ellipse has equal minor and major axis it transforms into a circle. In that case we say that the antenna is circularly polarized. If the ellipse has no minor axis it transforms into a straight line, In that case we say that the antenna is linearly polarized. The various polarization types are graphically demonstrated in figure I.15 [16][34].

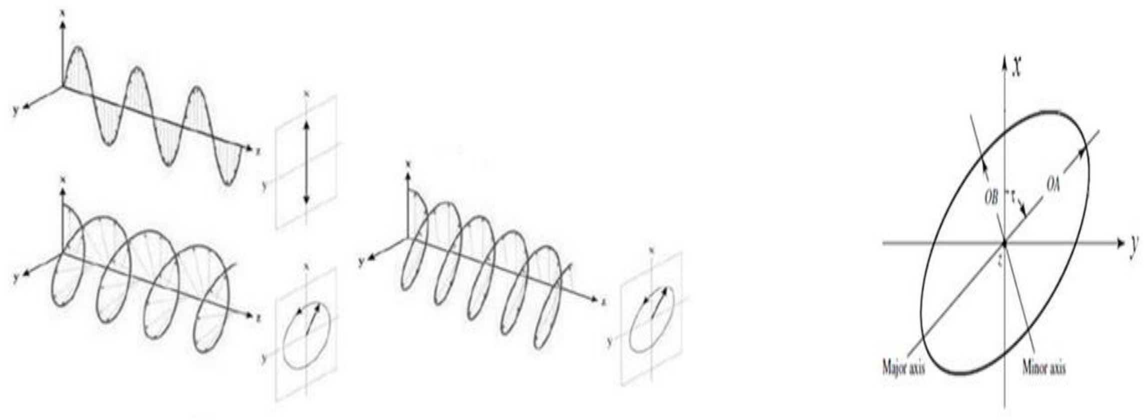


Figure I.16: linear, circular or elliptical polarization [34]

I.4 Conclusion

Because of the human needs for the wireless devices like PC's, cell phones etc… in order to communicate between them and sending files and messages by using wireless technologies like Bluetooth, WiFi, WiMAX. So we explained WLAN (WiFi),WPAN (Bluetooth) and we focused on the WiMAX technology for its many features recently like its high speed and large distance converged. To improve all these technologies in wireless devices like mobile phone we need an antenna that can radiate and pick up the frequencies of this wireless networks. Therefore, we took about the antenna basics and we choose the micro-strip antenna in our study for its easy fabrication and low cost which we will explain more in next chapter.

CHAPTER II:

PATCH ANTENNA BASICS

AND ENHANCEMENT TECHNIQUES

Chapter II

Patch antenna basics

and Enhancement Techniques

II.1 Introduction

Rapid development of modern communication for defense and commercial applications increases the demand of cost effective and easily fabricated antennas which presented in Micro-strip patch antenna. Micro-strip Patch antennas are printed antenna used in different wireless networks like Wireless Local Area Network (WLAN), GPS communication system, Bluetooth, etc... Micro-strip patch antennas are commonly used in satellite, and mobile communication applications due to their attractive advantages.

In this chapter; we will start by detailing patch basics (definition , advantages and disadvantages, application , feeding techniques and methods of analysis of MSA's). After that we will explain the dipole and monopole antenna to obtain omnidirectional pattern. Also, in the recent years; increasing progress in communication system rises the demand of multi-frequency and wide-band antennas and to achieve miniaturization of patch and enhance bandwidth we will use different techniques methods.

II.2 Patch Antenna Basics :

II.2.1 Definition of Micro-strip Antenna:

Micro-strip antenna (MSA) simplest form consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. MSAs are also known as "patch antennas" or "printed antennas" or "planer antennas". The patch is generally made of conducting material such as copper or gold and can take any possible shape such as square, rectangular, circular, triangular, elliptical or some other common shape as shown in the figure II.1 and the figure II.2 [35][36][37].

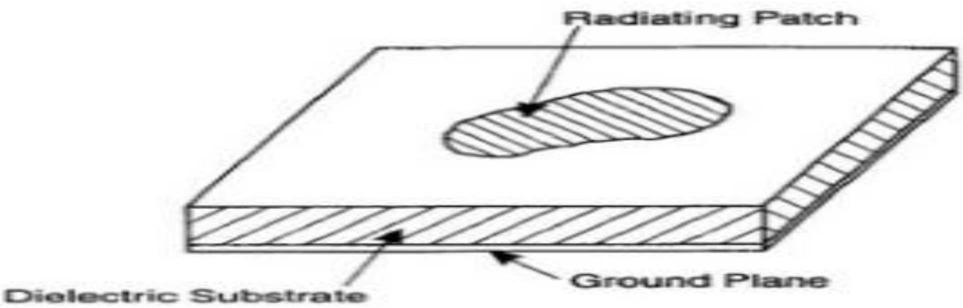


Figure II.1: MSA configuration [38]

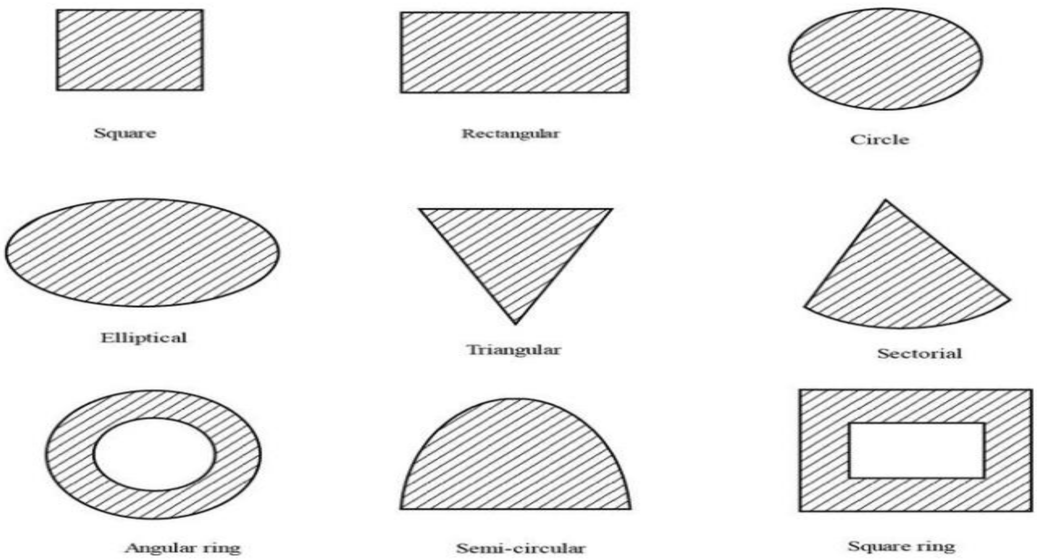


Figure II.2: The Different shapes of micro-strip patches [39]

II.2.2 Basics Characteristics of Rectangular Patch Antenna:

For simplify analysis and performance prediction we choose a rectangular patch which its length L is usually $\lambda_0/3 < L < \lambda_0/2$, where λ_0 is the free-space wavelength. Metallic strip (patch) is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is very small ($h \ll \lambda_0$, usually $0.003\ \lambda_0 \leq h \leq 0.05\lambda_0$). The dielectric constant of the substrate εr is typically in the range of $2.2 \leq \varepsilon r \leq 12$ [27].

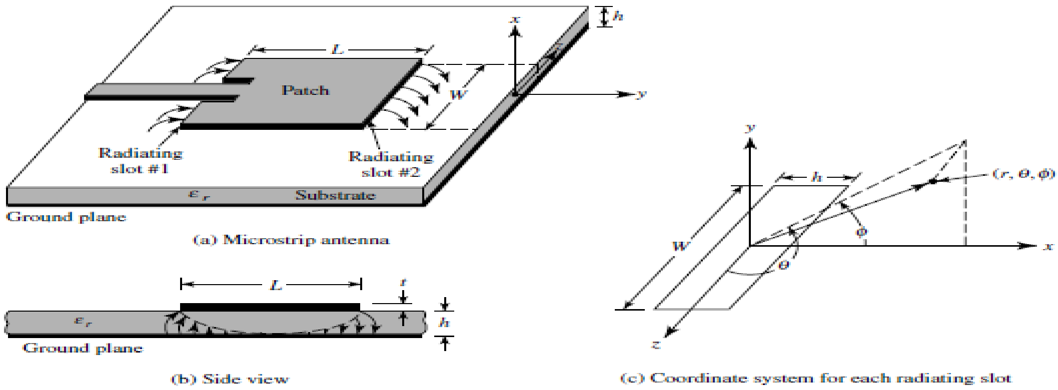


Figure II.3: Micro-strip Patch and Coordinate System [27]

II.2.3 Antenna Geometry:

The material with dielectric constant is used as a backplane conductor to form a micro-strip antenna and the heart of a micro-strip patch antenna is the upper conductor. The patch of finite dimensions can be considered to be an open-ended transmission line of length and width. The amplitude of surface currents becomes significant when the signal frequency is close to resonance by taking only the fundamental mode into account. The resonant frequency can be calculated by the formula II.1 [27][40].

$$f_r = \frac{c}{2(L+2\Delta L)\varepsilon_{eff}} \qquad \textbf{(II.1)}$$

Where ΔL is the equivalent length extension that financial records for the fringing fields at the two open ends and ε_{eff} is the effective relative permittivity. A micro-strip structure is not homogeneous because the electromagnetic field extends over the two media air and dielectric [40].

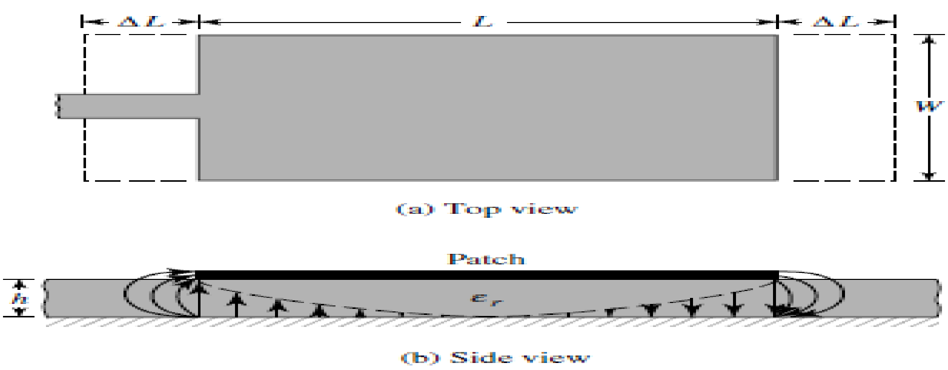


Figure II.4: Physical and effective lengths of rectangular MSA[27]

The dimensions of the MSA are giving by analytical formulae [27][40][41]:

a) Width of metallic patch (W):

$$\mathbf{W} = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad \textbf{(II.2)}$$

$$\mathbf{W} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad \textbf{(II.3)}$$

Where :

c : free space velocity of light

ε_r**:** Dielectric constant of substrate

b) Effective dielectric constant is calculated from:

$$\boldsymbol{\varepsilon_{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \qquad \textbf{(II.4)}$$

c) Length of metallic patch (L):

$$\mathbf{L = L_{eff} - 2\Delta L} \qquad \textbf{(II.5)}$$

Where $\mathbf{L_{eff}} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$

d) Calculation of Length Extension:

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \qquad \textbf{(II.6)}$$

e) Length and width of Ground plane (W_g,L_g):

$$\mathbf{W_g = 6h + W} \qquad \textbf{(II.7)}$$

$$\mathbf{L_g = 6h + L} \qquad \textbf{(II.8)}$$

f) Feed line length (L_f):

$$\mathbf{L_f} = \frac{\lambda_g}{4} \qquad \textbf{(II.9)}$$

where $\boldsymbol{\lambda_g} = \frac{\lambda}{\sqrt{\varepsilon_{eff}}}$ **,** $\boldsymbol{\lambda_g}$ **:**guided wave length **(II.10)**

II.2.4 Advantages and Disadvantages of MSA:

The benefits or advantages of micro-strip antenna are [1][27][42]:

- Lightweight and low profile (volume).
- Capable to design with multi-frequency bands (dual and triple frequency operations).
- Mechanically robust when mounted on rigid surfaces.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- MSA's are easily etched and will also provide easy access for troubleshooting during design and development.

Disadvantages of MSA are[1][27][42]:

- Low efficiency due to dielectric losses and conductor losses.
- MSA offers lower gain and narrow bandwidth.
- MSA structure radiates from feeds and other junction points.
- MSA has low power handling capacity and impedance bandwidth.

II.2.5 MSA's Application:

The advantages of micro-strip antennas make them suitable for numerous applications. Micro-strip patch antennas are a novel antenna that proposed topic with several applications in communication systems like [43]:

- The telemetry and communications antennas on missiles need to be thin and conformal and are often micros-trip antennas.
- Radar altimeters use small arrays of micro-strip radiators.
- Aircraft related applications include antennas for telephone and satellite communications.
- Patch antennas have been used on communication links between ships or buoys and satellites.
- Smart weapon systems.
- The global system for mobile communications (GSM), and the global positioning system (GPS) are major users of micro-strip antennas.

- Medical application.

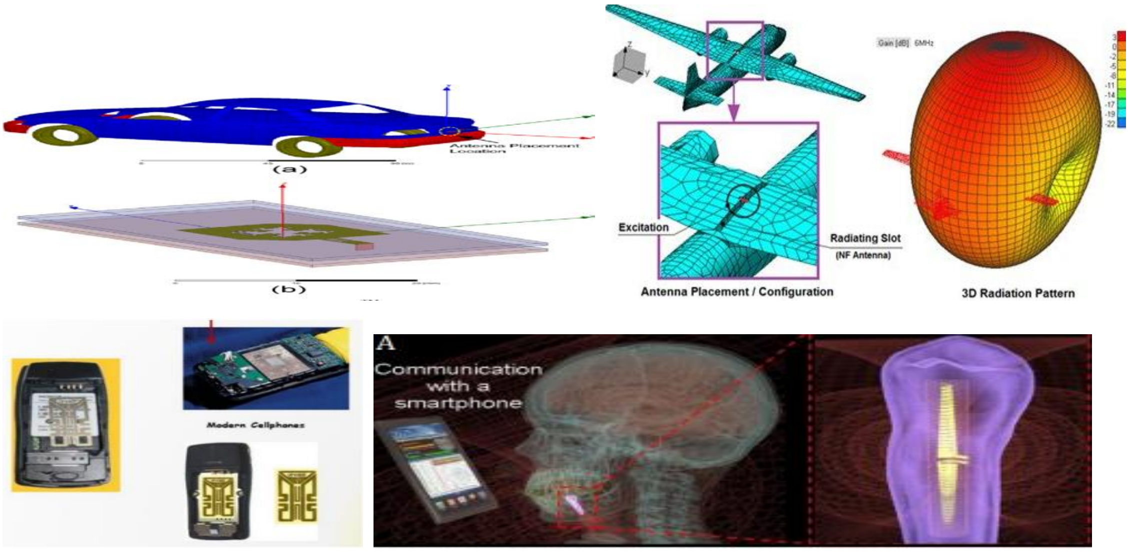


Figure II.5: MSA's application [44][45][46][47]

II.2.6 MSA's Feeding Methods:

A feed line is used to excite to radiate by direct or indirect contact. There are many different methods of feeding and four most popular methods are micro-strip line feed, coaxial cable (probe feed), aperture coupling and proximity coupling [27][43][48].

II.2.6.1 Micro-strip Line Feed:

Micro-strip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be consider as extension of patch such us figure II.6. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position [27][43][48].

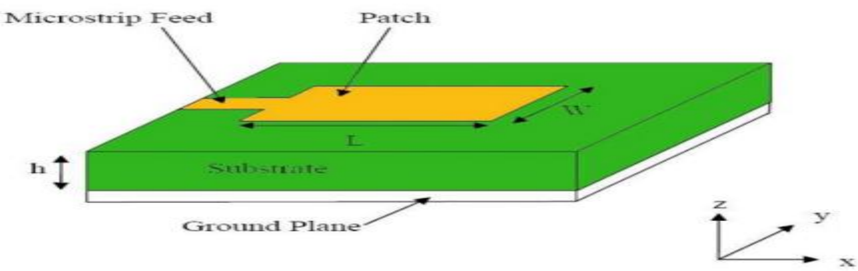


Figure II.6: Micro-strip Line Feed [43]

Advantages:

- Easy to fabricate and to modal [27][43][48].
- Simplicity in modeling as well as impedance matching by controlling the inset position [27][43][48].

Disadvantages:

- As the thickness of the dielectric substrate being used increases, surface waves and spurious feed radiation also increases, which limit the bandwidth of the antenna (typically 3-5%) [27][43][48].
- The feed radiation leads to undesired cross-polarized radiation [27][43][48].

II.2.6.2 Coaxial Cable (probe feed):

The coaxial feed is a very common technique used for feeding micro-strip patch antennas which that the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. As seen in figure II.7 [27][43][48].

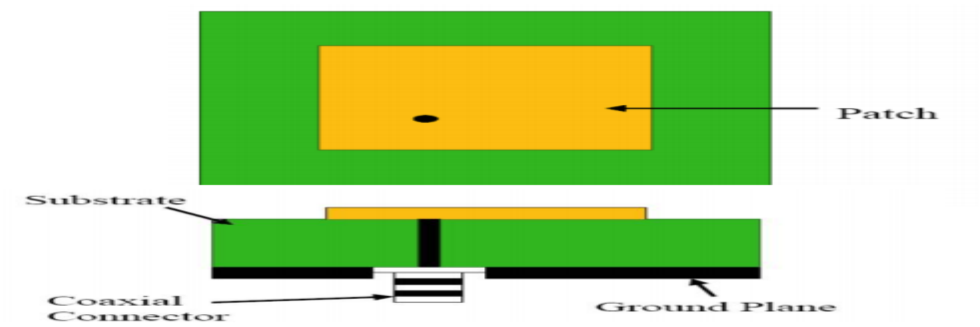


Figure II.7: Probe Feed for MSA [43]

Advantages:

- The feed can be placed at any desired location inside the patch in order to match with its input impedance [27][43][48].
- This feed method is easy to fabricate [27][43][48].
- Low spurious radiation [27][43][48].

Disadvantages:

- Difficult to model specially for thick substrate (h > 0.02λo) [27][43][48].

- It provides narrow bandwidth [27][43][48].
- For thicker substrates, the increased probe length makes the input impedance more inductive [27][43][48].

II.2.6.3 Aperture Coupled Feed:

In this type of feed technique, the radiating patch and the micro-strip feed line is separated by the ground plane coupling between the patch and the feed line as shown in figure II.8. Normally top substrate uses a thick low dielectric constant substrate while for the bottom substrate; it is the high dielectric substrate. The ground plane, which is in the middle, isolates the feed from radiation element and minimizes interference of spurious radiation for pattern formation and polarization purity [27][43][48].

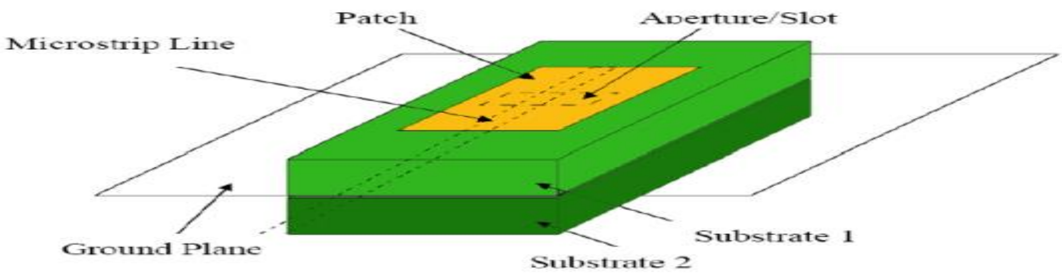


Figure II.8: Aperture Coupled Feed [43]

Advantages:

- Allows independent optimization of feed mechanism element [27][43][48].
- Minimization of spurious radiation [27][43][48].

Disadvantages:

- Feed technique is that it is difficult to fabricate due to multiple layers [27][43][48].
- Increases the antenna thickness [27][43][48].
- This feeding scheme provides narrow bandwidth [27][43][48].

II.2.6.4 Proximity Coupled:

Proximity Coupled Feed This type of feed technique is also called as the electromagnetic coupling scheme. As Shown in figure II.9, 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 [27] [43].

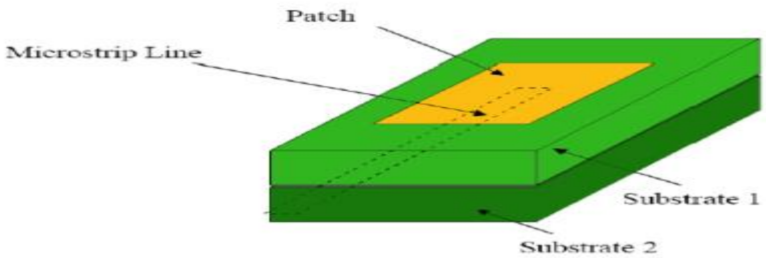


Figure II.9: Proximity Coupled [43]

Advantages:

- Feed technique eliminates spurious feed radiation [27][43].
- Provides very high bandwidth (as high as 13%) [27][43].

Disadvantages:

- Difficult to fabricate because of the two dielectric layers [27][43].
- An increase in the overall thickness of the antenna [27][43].

II.2.7 Methods of analysis MSA:

Several methods of analysis of micro-strip antennas have been proposed. They may be broadly classified into [43]:

II.2.7.1 Analytical model:

The methods are based on equivalent magnetic current distribution around the patch edges which patch antennas with separable geometries such as rectangular, square, circular ....etc used this model. Among this methods [23][27][43]:

a) Transmission line model:

The most popular models for the analysis of micro-strip patch antennas which it represents the micro-strip antenna by two slots of width W and height h, separated by a transmission line of length L. The micro-strip is essentially a non homogeneous line of two dielectrics, typically the substrate and air [23][27][43].

b) The cavity model:

The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. It is more complex in nature [23][27][43].

II.2.7.2 Numerical model:

The methods are based on the electric current distribution on the patch conductor and the ground plane For arbitrary shape of patch antennas. Among this methods [23][43]:

- Methods of moments.
- Finite element method.
- Wire grid model.
- Greens function approach.
- Boundary integral method.
- Finite difference time domain method.

II.3 Dipole and Monopole Antennas:

II.3.1 Dipole Antennas:

The dipole antenna has been developed by Heinrich Rudolph Hertz around 1886 and still remains the most widely used antenna. It owns two identical (same length) and symmetrical metal wires, and its feeding device is connected at the center of the dipole for example connected to the two adjacent wires ends. The dipole working results of a standing wave phenomenon depending on its length. The antenna fundamental mode occurs when the whole antenna is a half-wavelength long [49].

A general purpose dipole antenna (long thin wire antenna) with height h1 = h2 = L/2, where L is the total length of the antenna is shown in figure II.10 [50].

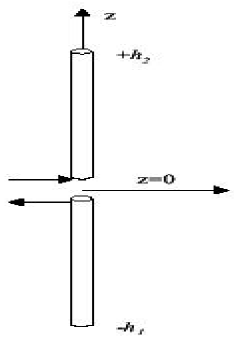


Figure II.10: Thin Linear Antenna of Total Length h2 + h1 [50]

The current of the center fed antenna of length L at any point z on the antenna is [50]:

$$I(z) = I_0 \sin[\frac{2\pi}{\lambda}(\frac{L}{2} - |z|)] \quad \textbf{(II.11)}$$

The peak value of the current I_0 is not reached along the dipole unless the length is greater than half a wavelength as shown in figure II.11 [16].

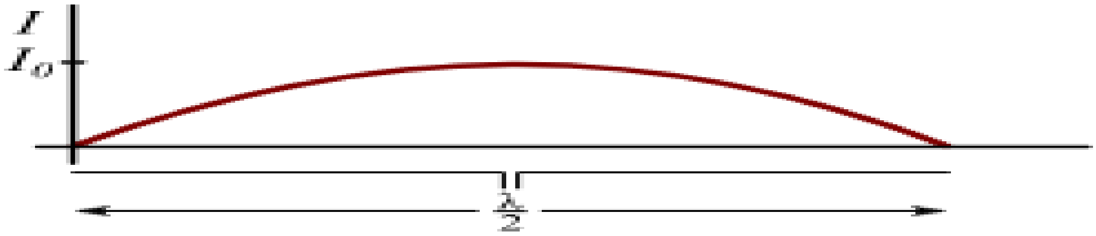


Figure II.11: Current distributions on finite-length dipole antennas [51]

If the dipole antenna's length becomes slightly less than **λ/2** the antenna has zero imaginary component to the impedance(reactance **X=0**), and the antenna is said to be resonant. If the dipole antenna's length becomes close to one wavelength, the input impedance (given by **Z=V/I**) becomes infinite and the current at the terminals is zero. The dipole antenna is an example of an omnidirectional antenna(figure II.12) [16].

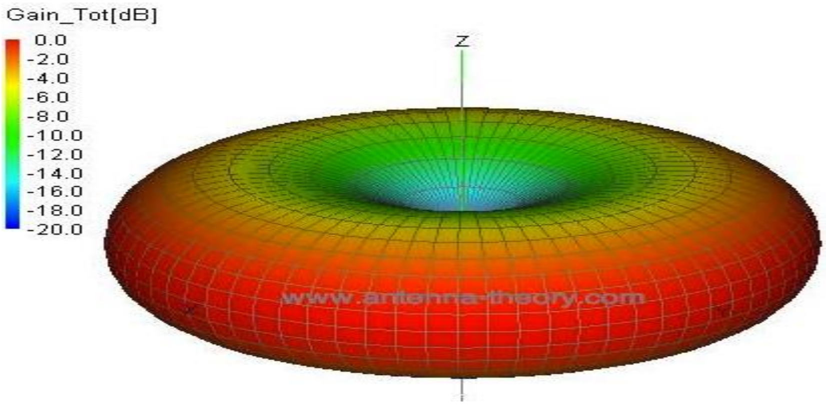


Figure II.12: Normalized 3d radiation pattern for the dipole antenna [16]

II.3.2 Monopole Antennas:

A monopole antenna is one half of a dipole antenna, almost always mounted above some sort of ground plane. A quarter-wave monopole antenna excited by a source at its base as shown in figure II.13 exhibits the same radiation pattern in the region above the ground as a half-wave dipole in free space. This is because, from image theory, the conducting plane can be replaced with the image of a λ/4 monopole. However, the monopole can only radiate above the ground plane. Hence the λ/4 monopole radiates only half as much power as the dipole[50].

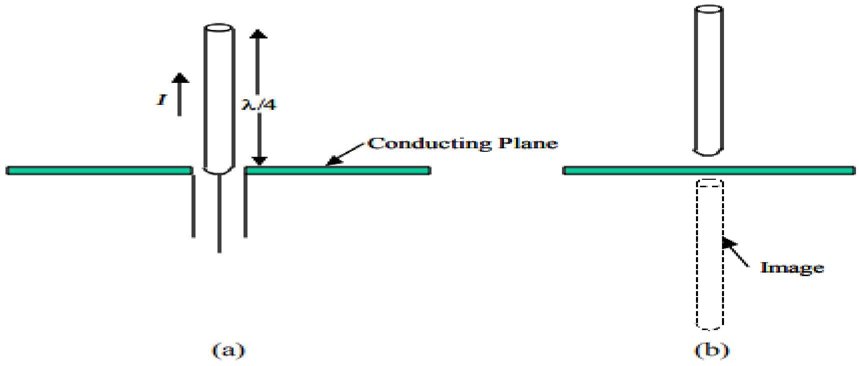


Figure II.13: (a) Quarter-Wave Monopole Antenna. (b) Equivalent Half-Wave Dipole Antenna [50]

The radiation pattern of monopole antennas ,above a ground plane is also known from the dipole result and still omnidirectional as shown in figure II.12. The only change that needs to be noted is that the impedance of a monopole antenna is one half of that of a full dipole antenna. The directivity of a monopole antenna is twice the directivity of a dipole antenna of twice the length. Monopole antennas are half the size of their dipole counterparts, and hence are attractive when a smaller antenna is needed. Therefore it presents a 3 dB gain higher than the dipole antenna. Also antennas on older cell phones were typically monopole antennas. The first mobile phones were using this kind of antennas to receive the Global System for Mobile Communications (GSM) which is presented in figure II.15 [16][49].

Figure II.14: Monopole antenna integrated in cell mobile phone [49]

II.3.2.1 Modification of antenna shape (T-shaped):

The geometry of the proposed T-shaped monopole patch antenna is shown in figure II.16. The antenna has been designed using the rectangular T-shape patch in a monopole configuration. The monopole structure provides impedance matching over the wide range of frequency [52][53].

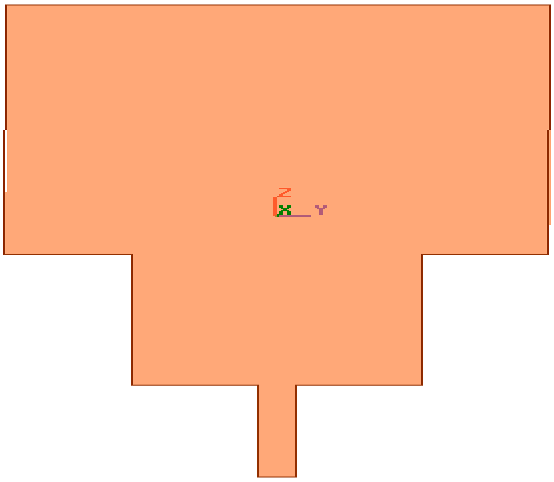


Figure II.15: T-shaped Patch Antenna

II.4 Broadband Antenna:

Micro-strip patch antennas has some drawbacks of low efficiency, narrow bandwidth (3-6) % of the central frequency, its bandwidth is limited to a few percentage which is not enough for most of the wireless communication system. There are several designs have been investigated and reported to decrease the size of antenna and to improve the bandwidth of antenna. Practically bandwidth of micro-strip Patch Antenna is narrow but today wireless communication systems require higher operating bandwidth such as about 7.6% for a global system for mobile communication (GSM890-960 MHz), 9.5% for a digital communication system(DCS;1710-1880 MHz), 5% for a personal communication system (PCS;1850–1990 MHz)And 12.2% for a universal mobile telecommunication system (UMTS;1920-2170 MHz), also the WiMAX technology require a broadband antenna. The BW could be defined in terms of its VSWR or input impedance variation with frequency or in terms of radiation parameters. The BW of the MSA is inversely proportional to its Quality Factor Q and is given by the formula II.11 [40][54].

$$\mathbf{BW = \frac{VSWR-1}{Q\sqrt{VSWR}}} \qquad \textbf{(II.12)}$$

Fortunately, the BW can be increased by decrees Quality Factor Q means of using a thick substrate with a low dielectric constant. Other methods for increasing the BW of MSAs include planar gap-coupled and directly coupled multi-resonators, stacked electromagnetically coupled or aperture-coupled patches, impedance-matching techniques[40][54].

II.4.1 Enhancing the bandwidth by Slot loaded Patch:

As the simple micro-strip antenna has low bandwidth, one technique to improve this is done by cutting a slot in the patch of half wavelength long at desired resonant frequency. Slots are embedded in the printed patch. Their dimensions and positions are properly selected in order to the first two broadside-radiation modes of the patch be perturbed such that their resonance frequencies get close to each other to form a wide impedance bandwidth. Slots cut into the patch are of different types and commonly used slot are U-slot, E-slot H-Slot etc... An U-slot loaded MSA is one of the most promising broadband antennas and the figure II.17 show the inverted u-slot in the rectangular patch [53][54][55][56].

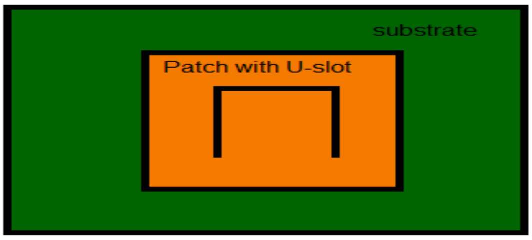


Figure II.16: Rectangle Patch antenna with Inverted U-slot

II.4.2 Enhancing the bandwidth by DGS (Defected Ground Structure):

Recent development of Electromagnetic Band-gap (EBG) has led immense research interest of antenna performance improvements of size reduction gain enhancement and radiation efficiency improvement and so forth. A notable class of EBG structures named Defected Ground Structure (DGS) is recently introduced and it has a controllable finite transmission zero characteristic. Defected ground structure increases the performance of the system by modifying the ground plane metal of micro-strip. DGS is formed by etching off a simple shape on the ground plane that is called as "defect". The different dimensions and shapes of the defect customized the shielded current distribution in ground plane that result in the propagation of the electromagnetic waves and controlled excitation through the substrate layer. This modification will also change the other characteristics of a transmission line such as inductance and line capacitance. In short any defect etched in the ground plane of micro-strip can increases the effective inductance and capacitance. The shape of the defect may be varies from the simple shape to the complex shape for the enhanced performance depending on the shape and configuration of DGS. In order to increase bandwidth DGS has been used. It is noted that within particular area of ground different DGS produces different resonant frequencies and bandwidth as well [17][57].

It was reported that an H-shaped DGS was used to suppress higher order harmonics of a micro-strip patch antenna by more than 20 dB and; a circular DGS reduced the cross-polarized (XP) radiation of a micro-strip patch antenna by 8 dB. Also a U-shaped DGS offers a high order matching network for bandwidth enhancement and etching the DGS underneath the simple micro-strip feed-line, impedance bandwidth broadening can be obtained [17].

DGS is employed to enhance the impedance bandwidth of a micro-strip-fed monopole antenna [17].

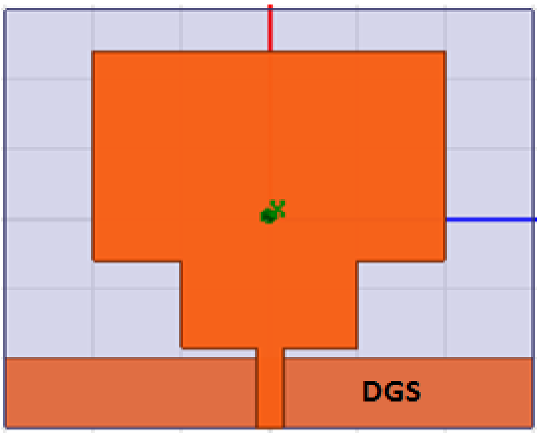


Figure II.17: T-shaped patch antenna with DGS

II.5 Multiband Antennas:

II.5.1 Definition of Multiband Antennas:

A multiband antenna by definition is an antenna which works or more precisely which resounds on at least two frequencies with same requirements (adaptation , the value of the reflection coefficient,....) [24][34]. A multiband antenna is an antenna working in two or several bands of frequency with performance rather similar in its bands [23].

II.5.2 Enhancing by Slot loaded Patch:

Multiband performances at different bands were integrated into one antenna by cutting slots in the patch .Slot radiator or slot antennas are antennas that are used in frequency range from about 300Mhz to 25Ghz. They are often used in wireless communication .The slot behaves according to Babinet's principle as resonant radiator. Jacques Babinet (1794-1872) was a French physicist and mathematician, formulated the theorem that similar diffraction patterns are produced by two complementary screens. This principle relates the radiated field and impedance of an aperture or slot antenna so that of the field of a dipole antenna. It can also provide the low profile, low cost, small size, easier integration with other circuits and conformability to a shaped surface. Micro-strip slot antenna is simple in structure. Furthermore they are capable of producing omnidirectional radiation patterns by simply inserting quarter wave thick foam and reflector. By using different shape of slots we can enhance bandwidth, gain etc . Return loss is reduce. and radiation pattern is also improved. By the use of slot micro-strip antenna can be used in many application [58].

The U-slot patch antennas are widely used in the past in wireless systems. The advantages of the U-slot structure are that linear polarization and circular polarization radiation can be obtained by simply changing the length of the U-slot arm. Recently a new approach, to achieve dual-band and tri-band performances, by cutting U-slots in the patch [59].

II.5.3 Enhancing by Using Metamaterials:

Meta-material (MTM) is a kind of engineering materials which exhibits exotic physical properties that may not be found in nature. MTMs which have negative permittivity and permeability together are also referred to as left-hand metamaterials (LHMs). It provides negative effective refractive index over a certain frequency region(s). These properties of metamaterial provide novel application opportunities to several disciplines, such as microwave and optical cloaking, focusing of images, and sensing of biological and chemical substances. Metamaterials have also many application areas for novel antenna systems. One of the important applications of metamaterials is miniaturization of the micro-strip antennas with different types of artificial materials. The conventional way of reducing the antenna size is to use high permittivity substrate. This approach reduces the wavelength of the signal in the substrate. But, this design results in more energy consumption due to high permittivity, since it decreases the impedance bandwidth of the antenna. Another way is removing the substrate to minimize the effective dielectric constant. This application restricts the wave to travel in the substrate, hence, improving the gain of the patch antenna has been possible. However, the maximum gain enhancement does not exceed to 2 dB with all these techniques and the directionality also does not change too much. Hence, many different solutions have been proposed to overcome these problems, such as utilization of metamaterials with patch antenna [60][61].

II.5.3.1 Left-Handed Metamaterials:

LHMs have a series of fantastic characteristics such as negative refractive index and backward waves, which draw great attention all over the world. MTMs have been successfully employed in many areas such as cloaking, absorbing materials and antenna designs [61].

There are 2 kinds of realizations of metal-based LHMs in the microwave regime. The first kind of metal-based LHMs is implemented with magnetic resonances and arrayed metallic wires. The magnetic resonances, typically the split ring resonators (SRRs), are able to extract negative permeability at a specified frequency band, while the arrayed metallic wires are capable of providing negative permittivity at frequencies lower than their plasma frequency. The other kind of LHMs is realized with the combination of electric LC (ELC) resonators which generate negative permittivity, and magnetic resonator. A common character of both LHMs is that the negative permeability is extracted from magnetic resonators [61].

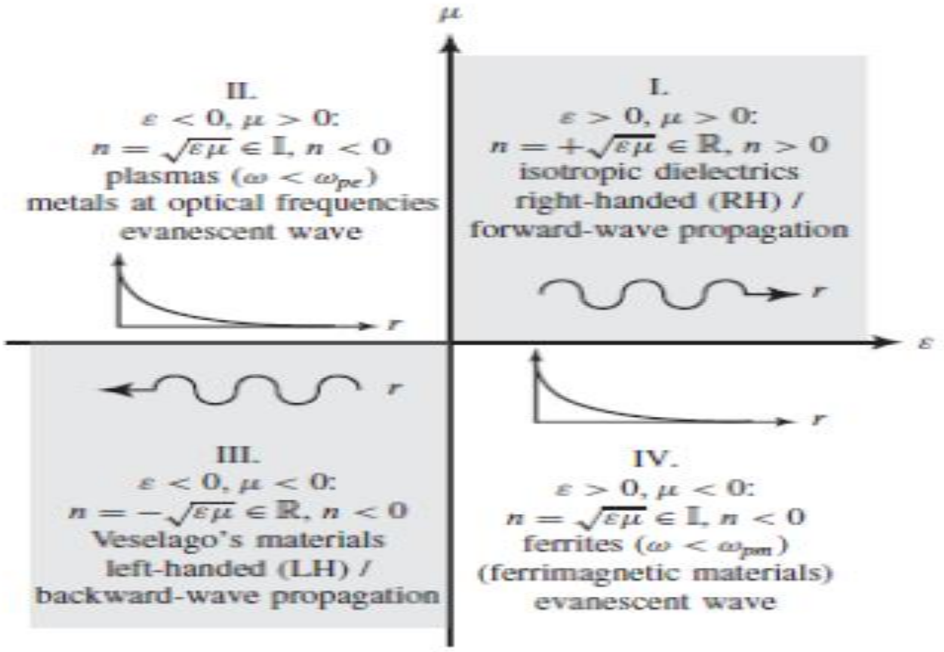


Figure II.18: Permittivity, Permeability and Refractive Index graph [62]

II.5.3.2 CSRR's Metamaterials:

The structural alignment of CSRR alters the current direction and contributes the new resonance frequency with respect to band pass filter. CSRR employs the negative permittivity characteristics through a band pass filter. The application of CSRR becomes more attractive due to sub wavelength resonator, such as miniaturization and gain improvement [63].

The CSRR resonance frequency is analyzed by quasi-static equivalent circuit model, as described in figure II.21. Slit gap plays a major role in creating pass band characteristics. The capacitance of CSRR (C_{CSRR}) is governed by slot among the metal strip and inductance of CSRR (L_{CSRR})) is governed by a metal strip among the slot [63].

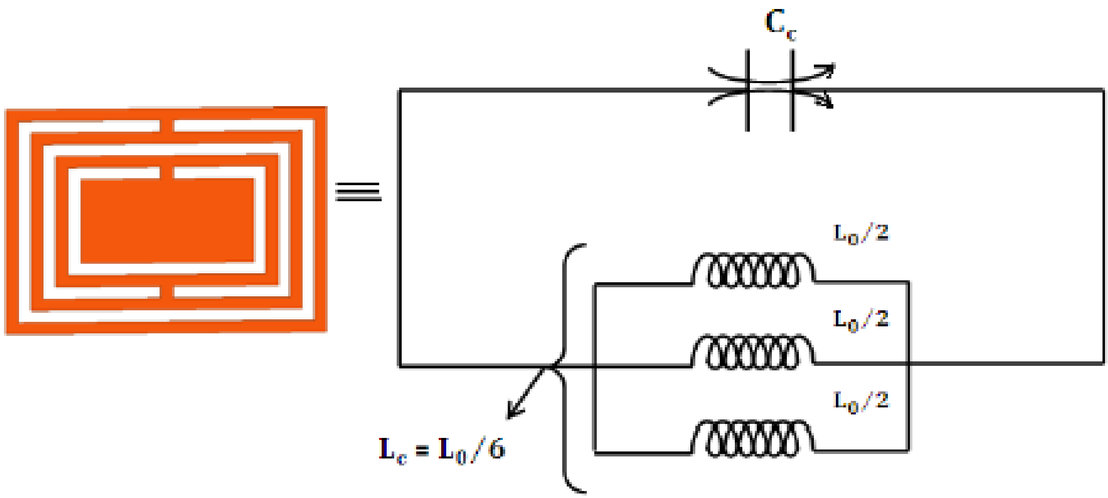


Figure II.19: Proposed CSRR topology and its equivalent circuit model [63]

- The capacitance (C_{CSRR}) and inductance (L_{CSRR})values of CSRR [63].
- It is only suitable for a number of CSRR ring greater than one (N>1) [63].
- If N=1 than C_{CSRR}=L_{CSRR} = 0 [63].

II.6 comparison between multiband and broadband:

A multiband antenna is an antenna working on several frequency bands and it only allows to pass the interest bands but a broadband antenna is an antenna whose performance is independent or almost independent of frequency and these antennas are characterized by the width of their operating band as well as the minimum and maximum dimensions respectively setting the highest and the lowest operating frequency [23].

The table below resume the strengths and weaknesses of multiband and broadband antennas [23].

	Multiband Antenna	Broadband Antenna
Strengths	• high selectivity • simplified post processing	• relatively easy design • less susceptible to manufacturing errors • the antenna can also be used for other applications contained in the broadband covered
Weaknesses	• poor control of operating frequency ratios • limited number of bands to cover • more susceptible to manufacturing errors	• often delicate impedance matching across the width of the band • post processing necessary to separate the bands • low directivity

Table II.1: The strengths and Weaknesses of multiband and broadband antennas [23]

II.7 Conclusion:

In this chapter we present an overview about micro-strip patch antenna to more understand its performance in wireless network which is used in several applications. Also we define a dipole and a monopole antenna to obtain a omnidirectional antenna which is demanded in cell phone applications. Finally we explained a U-slot ,DGS (Defected Ground Structure) and a metamaterial (CSRR) techniques in order to use these techniques for enhancing the bandwidth and to obtain a multiband and broadband antennas which are more demanded in recent years and for that we define each of them to spoke about their strengths and their weaknesses.

CHAPTER III:

DESIGN AND SIMULATION

Chapter III

Design and Simulation

III.1 Introduction:

The design of a multiband and a broadband micro-strip patch antenna with a low profile which can be mounted on a flat surface with its low cost and easy fabrication is very demanded for emission and reception of the wave in wireless network. Our objective is to design a monopole antenna with a small geometry (Width and Length) that can radiate in low frequencies in different bands such as L-Band (GSM,UMTS,GPS...), S-Band (WLAN, Bluetooth, Zeegbi and WIMAX....), C-band (WIMAX , WLAN, ...), X-band (Satellite applications) which the antenna can be usable in cell phones (mobile). Also we want to use it to get WLAN (2.5Ghz or 5Ghz) and WIMAX (low band, middle band or upper band) application using the same antenna. We opted for the design of a T-shaped patch monopole antenna using the HFSS v15 simulator to study his basic parameters like 3D Radiation Pattern, Return Loss, VSWR, Smith Chart and Total Directivity and the Total Gain. For this study we used two types of material FR4 with dielectric constant 4.4 and material Rogers RO4350 with dielectric constant 3.66 in order to choose one that gives the best results. The substrate thickness used is 1.6 mm because it can be found in the Algerian market and it is the mostly used. A DGS structure is added in order to enhance the bandwidth and to make it monopole. Enhanced methods are then used to obtain an antenna with better broadband and multiband. The first method is Inverted U-slots in the patch, the second one is meta-material (CSRR's) in the patch.

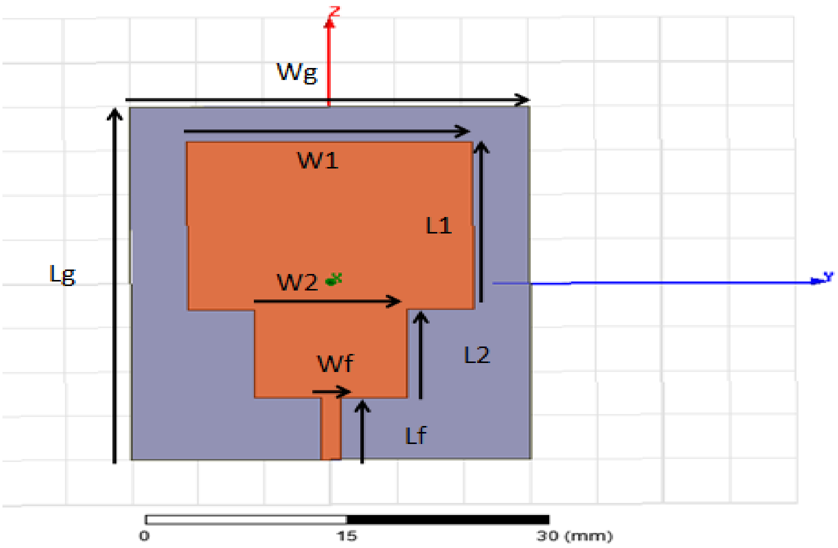
III.2 T-shaped Monopole Antenna:

III.2.1 T-shaped Patch Antenna without DGS:

The table III.1 outlines the geometry of T-shaped patch antenna without DGS and with thickness of substrate 1.6mm which is defined in the figure III.1.

Wg	Lg	W1	W2	L1	L2	Wf	Lf	h
30mm	40mm	21.5mm	11.5mm	19mm	10mm	1.5mm	7mm	1.6mm

Table III.1: Dimension of the T-shaped Patch Antenna without DGS



FigureIII.1: Design of T-shaped Patch Antenna without DGS

III.2.2 Effect of Dielectric constant ε_r of substrate:

The dielectric constant has an effect on the geometry of the antenna (Width and Length) as well as in the frequency which we can note in the formulae (seen chapter II). That's why we simulate the antenna with two materials (the FR4 material with dielectric constant 4.4 and the Rogers RO4350 material with a 3.66 dielectric constant).

a. FR4 substrate:

The figures III.2, III.3 ,III.4 show 3D Radiation Pattern ,Return Loss and the Total Gain of the antenna respectively when we choose a FR4 material.

a.1 3D Radiation Pattern:

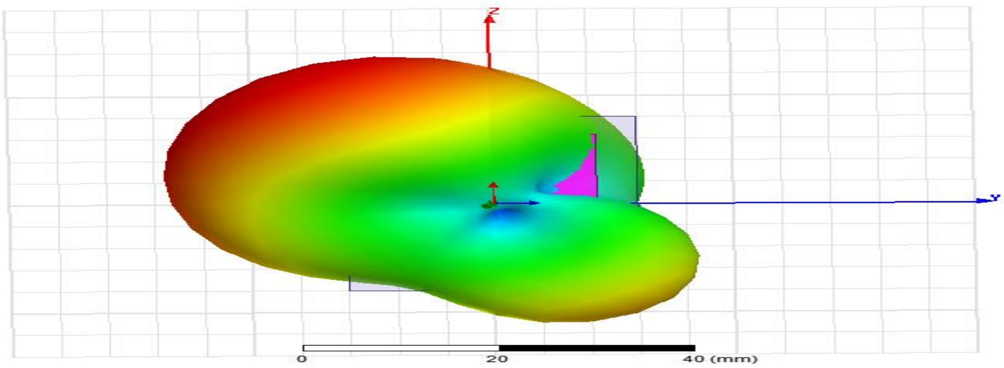


Figure III.2: 3D Radiation Pattern of the T-shaped Patch Antenna without DGS and with FR4 Substrate

As we see in the behavior figure III.2 the antenna typically doesn't radiate in all directions which it hasn't omnidirectional pattern and it can be a directive antenna.

a.2 Return Loss:

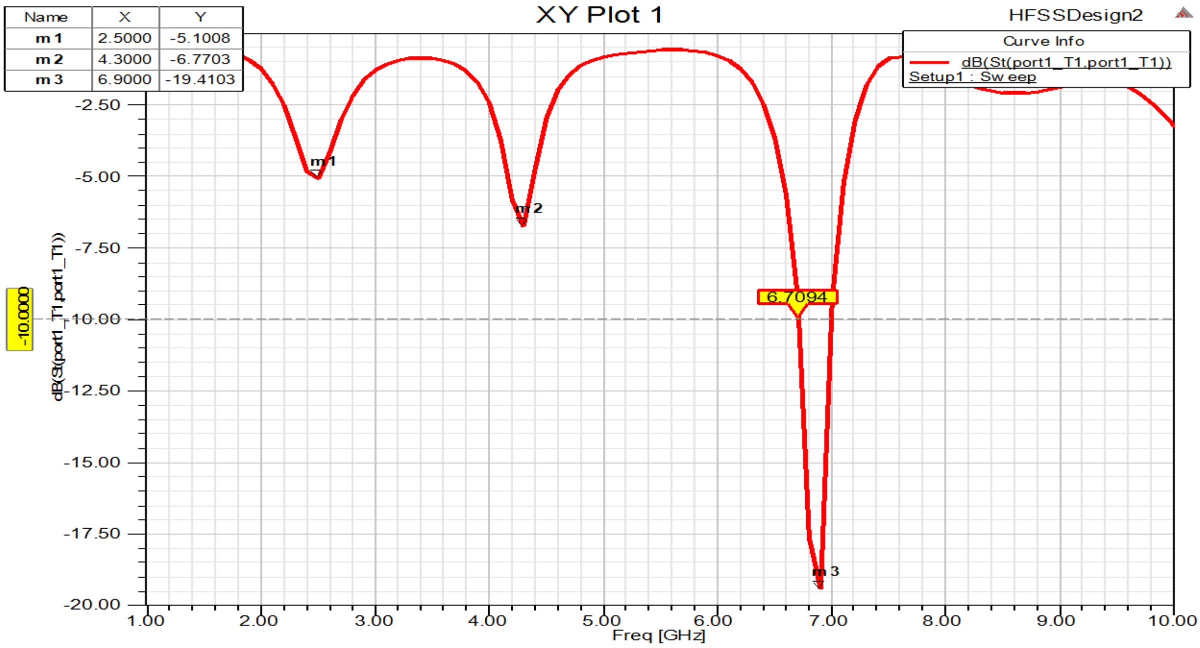


Figure III.3: Return loss of the T-shaped Patch Antenna without DGS and with FR4 Substrate

We notice as above in figure III.3 that the antenna shows resonance at frequency 6.9Ghz with a narrow band and a return loss -19.41 dB which belong in C-band and doesn't show the resonance at frequencies 2.5Ghz and 4.3Ghz.

a.3 Total Gain:

As shown in the figure III.4 the gain in the majority directions of this antenna is -0.4 dB which isn't good.

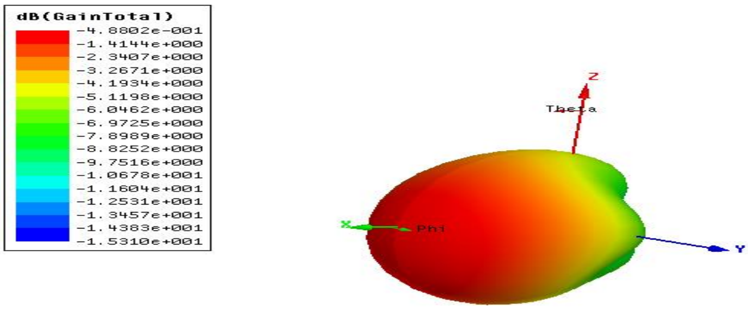


Figure III.4: The Total Gain of T-shaped Patch Antenna without DGS and with FR4 Substrate

b. Rogers substrate:

The figures III.5, III.6 ,III.7 show a 3D Radiation Pattern , Return Loss and the Total Gain of the antenna respectively when we use Rogers RO4350 material.

b.1 3D Radiation Pattern:

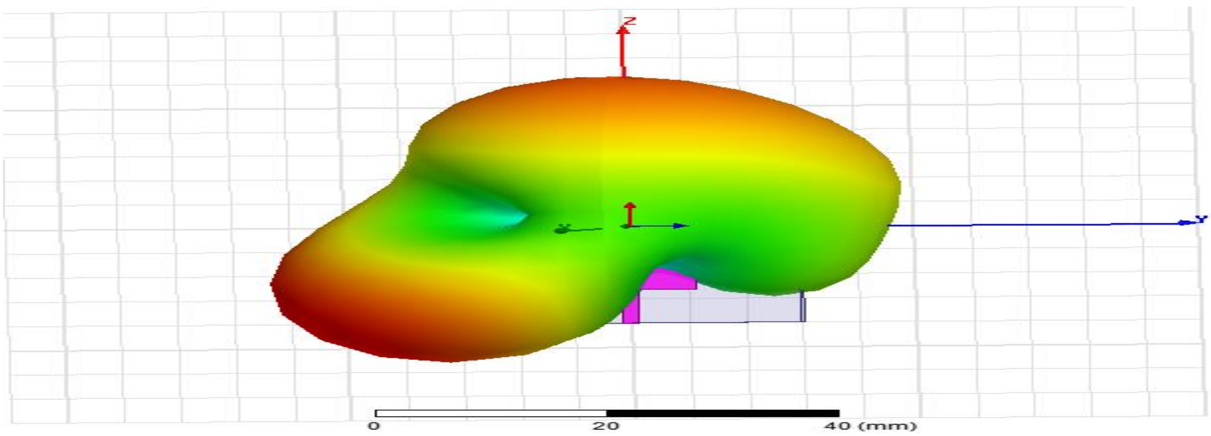


Figure III.5: 3D Radiation Pattern of T-shaped Patch Antenna without DGS and with Rogers Substrate

In the figure III.5 we see that the antenna radiate more than in one direction but it can't be an omnidirectional antenna.

b.2 Return Loss:

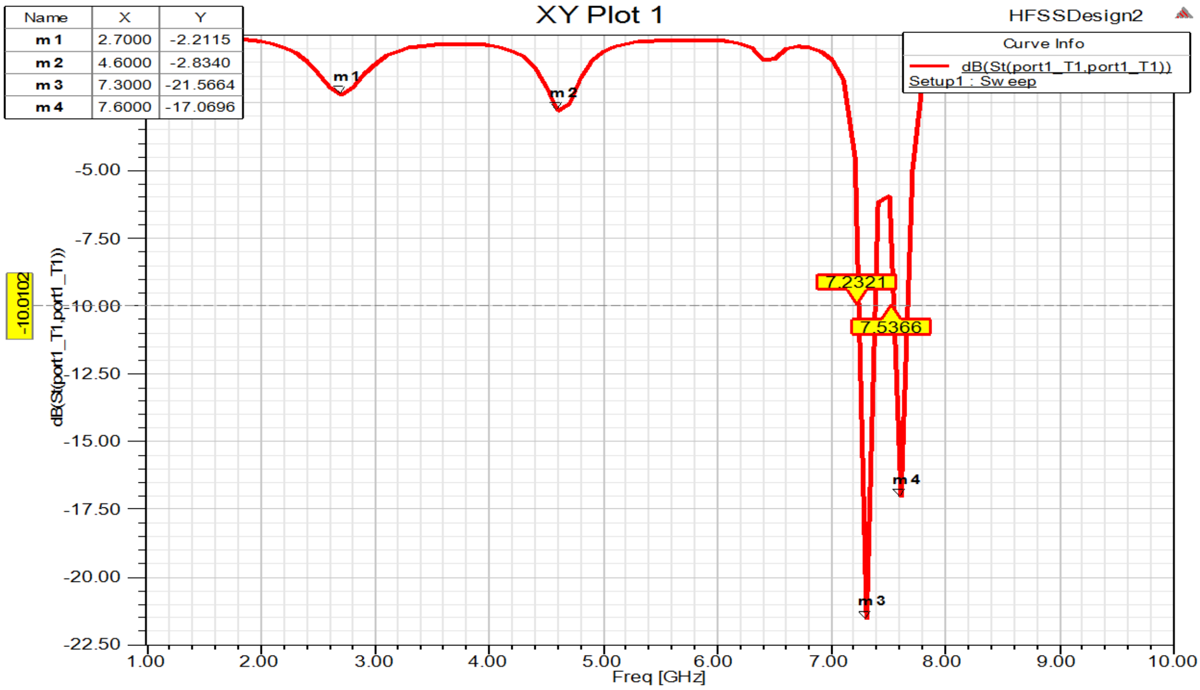


Figure III.6: Return loss of the T-shaped Patch Antenna without DGS and with Rogers Substrate

The antenna shows resonance at frequencies 7.3Ghz and 7.6Ghz with a return loss more than -17dB. In this case we notice an improvement in the return loss as shown in the figure III.6.

b.3 Total Gain:

The figure III.7 shows that the gain of this antenna is 3.91 dB in most directions which is a better result as compared with the results using the FR4 material (giving a better gain).

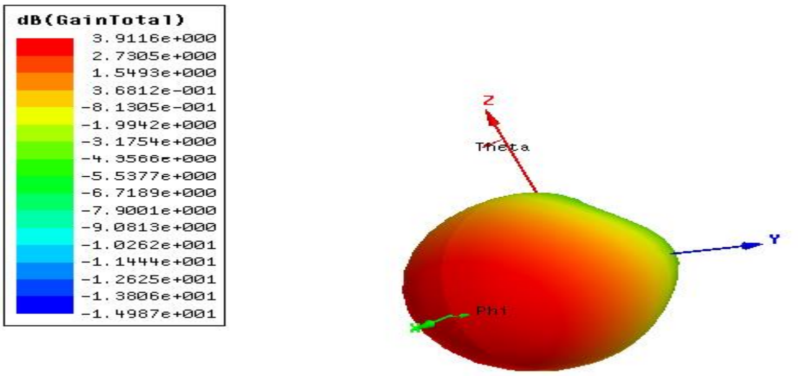


Figure III.7: The Total Gain of T-shaped Patch Antenna without DGS and with Rogers Substrate

III.2.3 T-shaped Patch Antenna with DGS (Defect Ground Structure):

The table III.2 gives geometry of T-shaped patch antenna with DGS structure which we got it by decreasing the size of the ground and that shown in the figure III.8.

Wg	Lg	W1	W2	L1	L2	Wf	Lf	h
30mm	5mm	21.5mm	11.5mm	19mm	10mm	1.5mm	7mm	1.6mm

Table III.2: Dimension of the T-shaped Patch Antenna with DGS

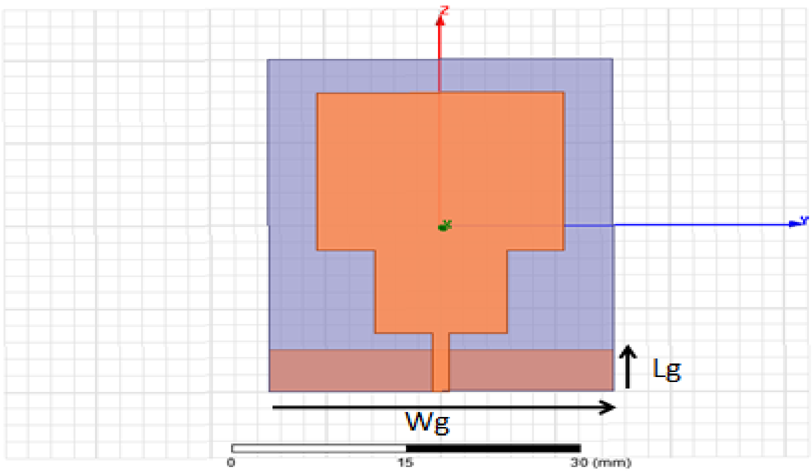


Figure III.8: Design of T-shaped Patch Antenna with DGS

The figures III.9, III.10 ,III.11,III.12 show 3D Radiation Pattern, Return Loss, Smith Chart and the Total Gain of the antenna respectively when we use Rogers RO4350 material which has been chosen since it gave better results as compared to the FR4 material.

a) 3D Radiation Pattern:

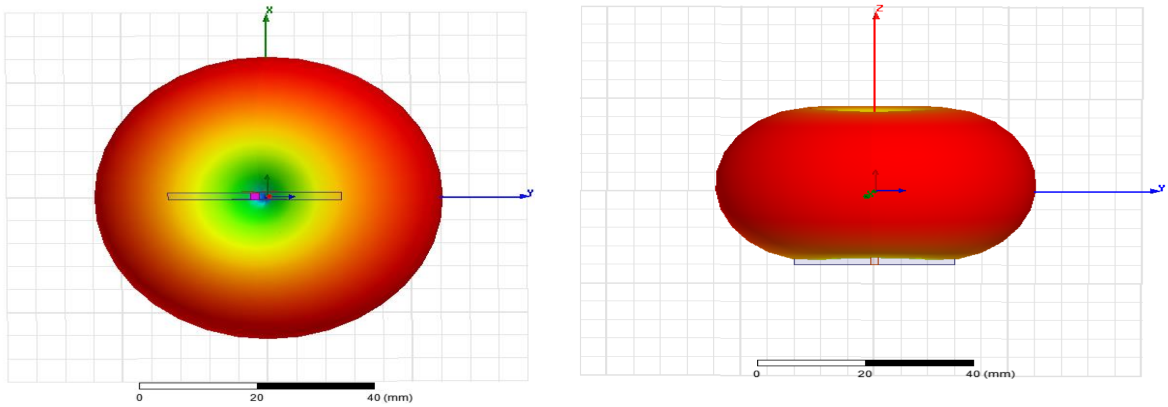


Figure III.9: 3D Radiation Pattern of T-shaped Patch Antenna with DGS

As shown in the figure III.9 above, the antenna typically radiate in all directions and it is an omnidirectional pattern which is designed to provide a 360 ° radiation pattern .It means that the DGS has improved the monopoly of the antenna for both materials FR4 and Rogers RO4350.

b) Return Loss:

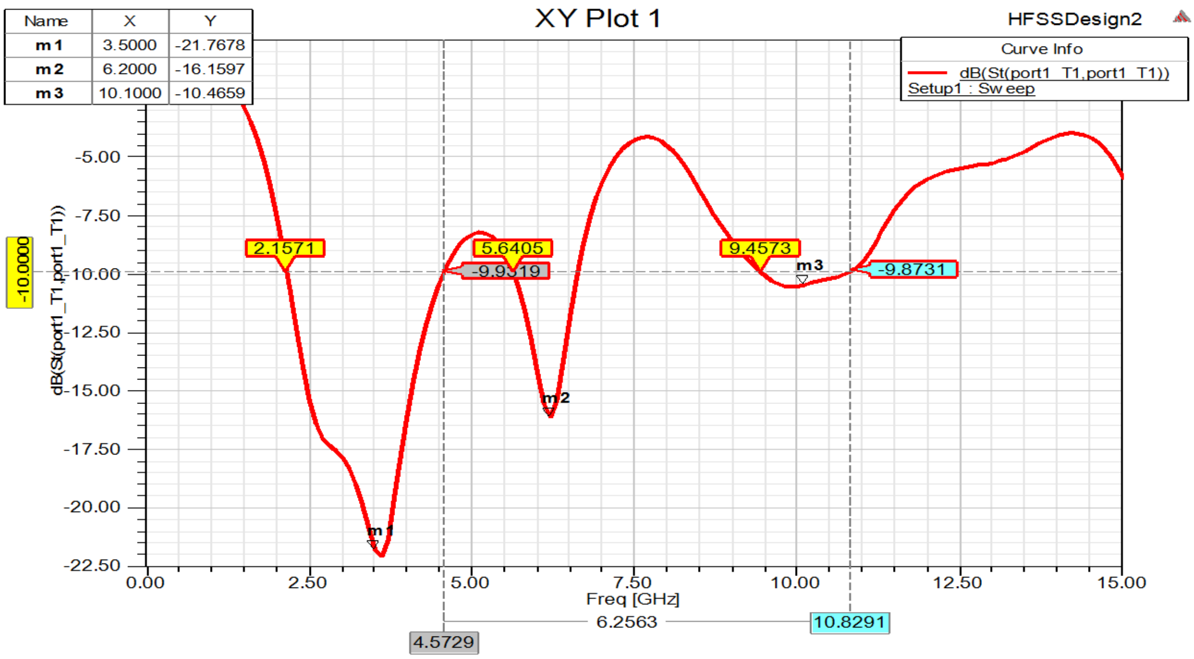


Figure III.10: Return Loss of T-shaped Patch Antenna with DGS

This shows that we obtain 3 bands:

- A large bandwidth of 67.2% between 2.15Ghz and 4.5Ghz belonging to the S-band with a return loss of -20dB.

- We can see that this antenna resonates at frequency of 6.2Ghz in the bandwidth of 15.4% belonging to the C-band with a return loss of -16 dB .
- Also this antenna shows resonance at frequency of 10.1Ghz in the bandwidth of 14.8% belonging to the X-band with a return loss of -10.2 dB .

c) Smith Chart:

The figure III.11 describes the variation of the impedance with the frequency. It shows that the resonance frequencies near to 1 are nicely matching (good adaptation with the antenna).

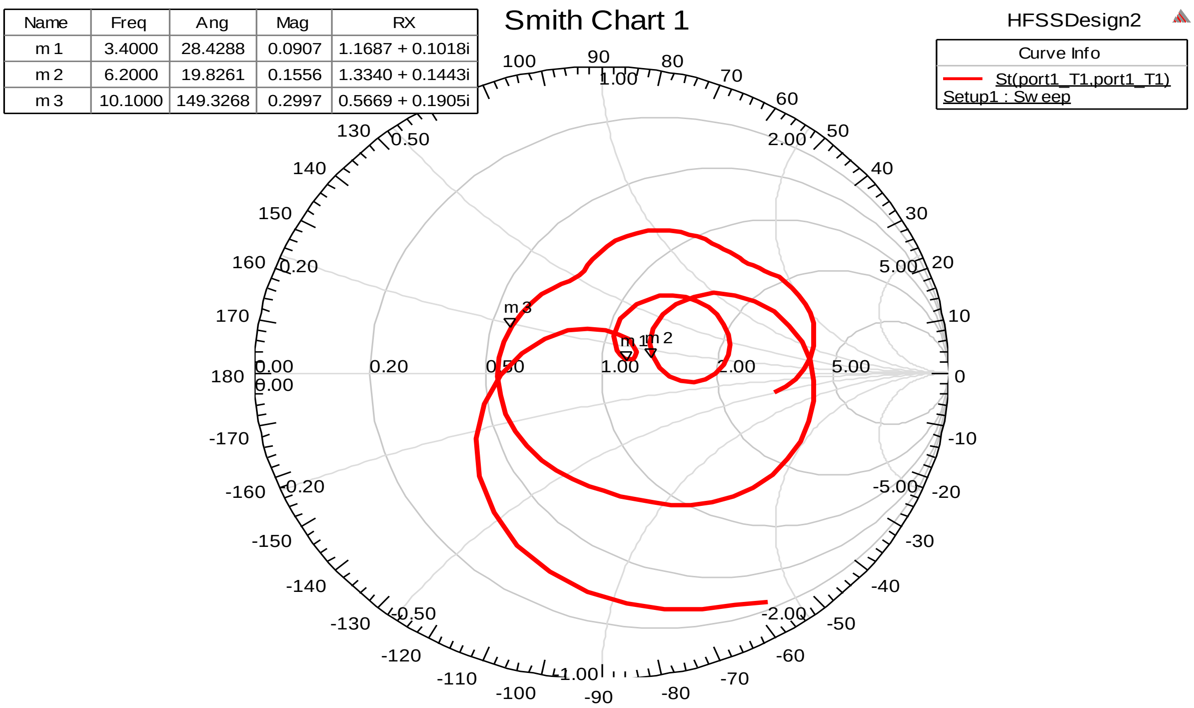


Figure III.11: Smith Chart of T-shaped Patch Antenna with DGS

d) Total Gain:

The figure III.12 shows that the gain of this antenna is 2.084 dB in all directions all over the circle 360° which is better than when we use FR4 material(2.01dB).

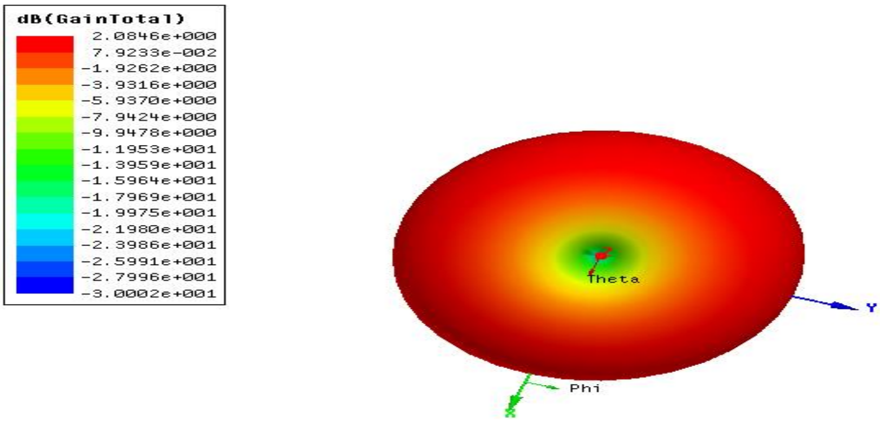


Figure III.12: The Total Gain of T-shaped Patch Antenna with DGS

III.3 Design One: Enhancing the bandwidth by using inverted U-slots in the patch of the monopole T-shaped patch antenna:

The table III.3 gives geometry of three inverted U-slots and its positions in the monopole T-shaped patch antenna and which is defined in the figure III.13.

W3	W4	W5	ln1	ln2	ln3	l3	l4	l5
18mm	12mm	6mm	7mm	5.5mm	5mm	4.5mm	10.5mm	16.75mm

Table III.3: Dimensions of 3 Inverted U-slots and its positions in the monopole T-shaped Patch Antenna

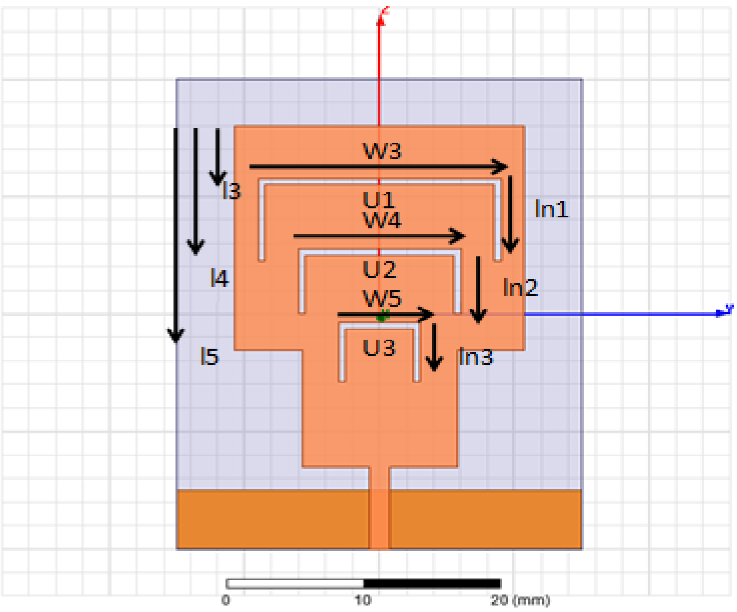


Figure III.13: Design of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

III.3.1 Using a Inverted U-slots in different positions 1,2,3:

The figures III.14, III.15 ,III.16,III.17 ,III.18,III.19 show Return Loss and the Total Gain of the antenna respectively for each Inverted U-slot with Rogers RO4350 material which has been chosen since it gave better results as compared to the FR4 material.

a. Use of one Inverted U-slot (U1):

a.1 Return Loss:

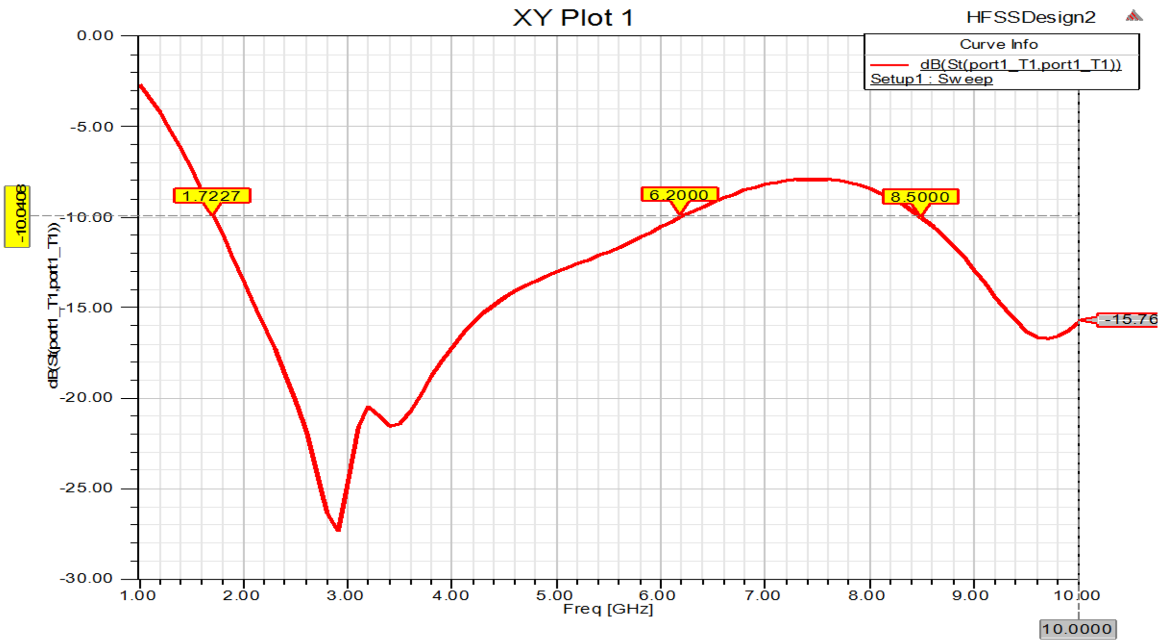


Figure III.14: Return loss of the Monopole T-shaped Patch Antenna with U1-slot

This shows that we obtain a very large bandwidth (Broadband) of 113 % between 1.727Ghz and 6.2Ghz belonging to the L-band (from 1.727Ghz to 2Ghz) ,S-band (from 2Ghz to 4Ghz) and C-band (from 4Ghz to 6.2Ghz) with a return loss of -27dB.

a.2 Total Gain:

The figure III.15 shows that the gain of this antenna is -3.11 dB in all directions all over the circle 360° .

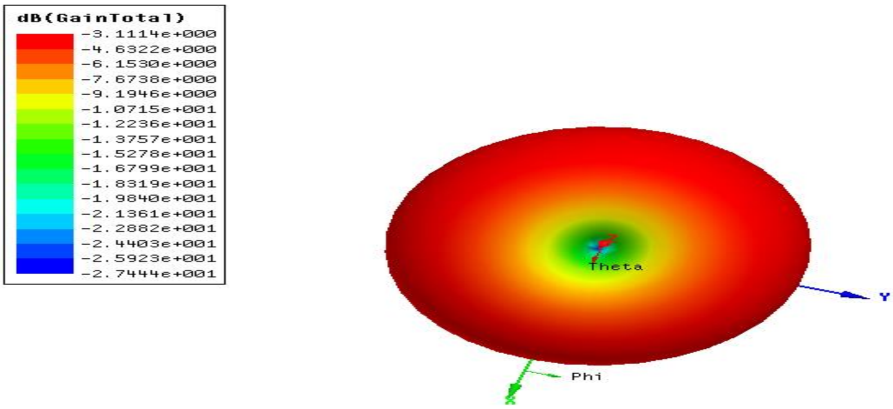


Figure III.15: The Total Gain of the Monopole T-shaped Patch Antenna with U1-slot

b. Use of one Inverted U-slot (U2):

b.1 Return Loss:

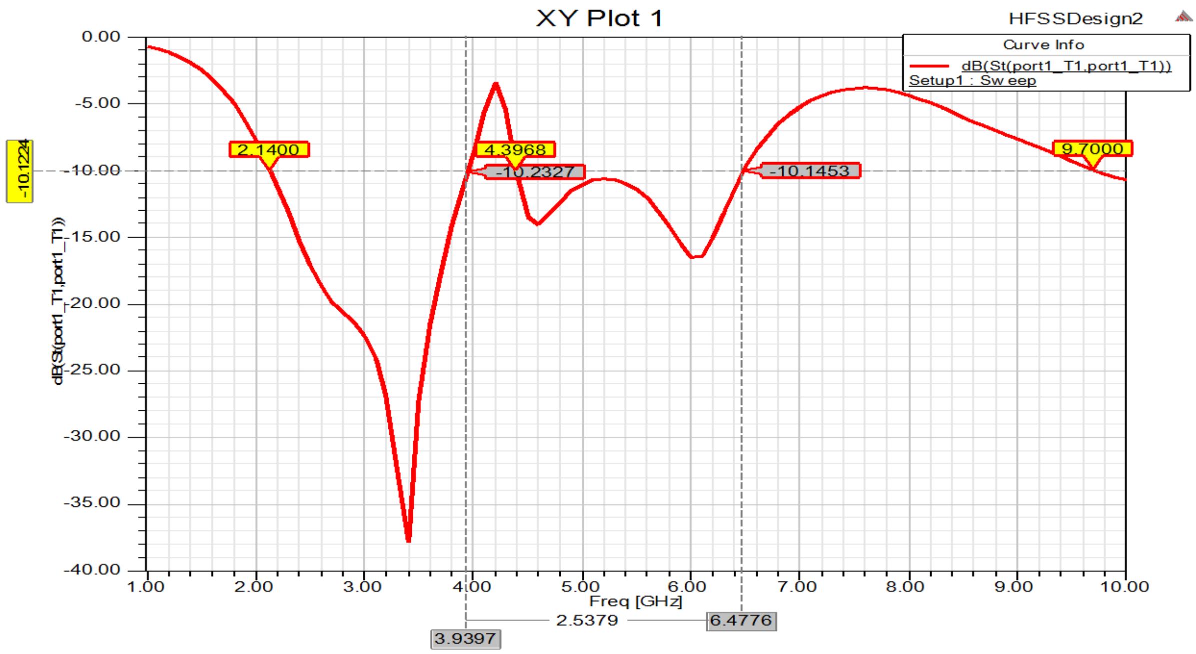


Figure III.16: Return loss of the Monopole T-shaped Patch Antenna with U2-slot

This shows that we obtain 2 bands:

- A very large bandwidth (Broadband) of 59 % between 2.14Ghz and 3.93Ghz belonging to the S-band with a return loss of -38dB.
- A large bandwidth of 38.23 % between 4.39Ghz and 6.47Ghz belonging to the C-band with a return loss of -16dB.

b.2 Total Gain:

The figure III.17 shows that the gain of this antenna is 2.222 dB in all directions all over the circle 360° and it is best than when we use FR4 material(2.05dB).

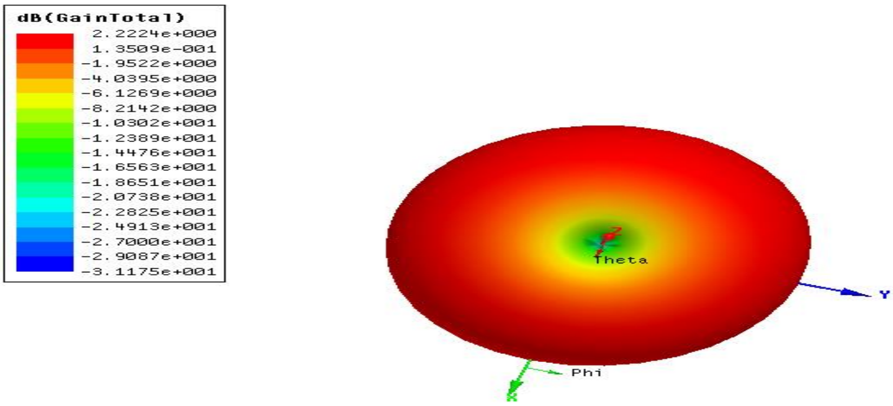


Figure III.17: The Total Gain of the Monopole T-shaped Patch Antenna with U2-slot

c. Use of one Inverted U-slot (U3):

c.1 Return Loss:

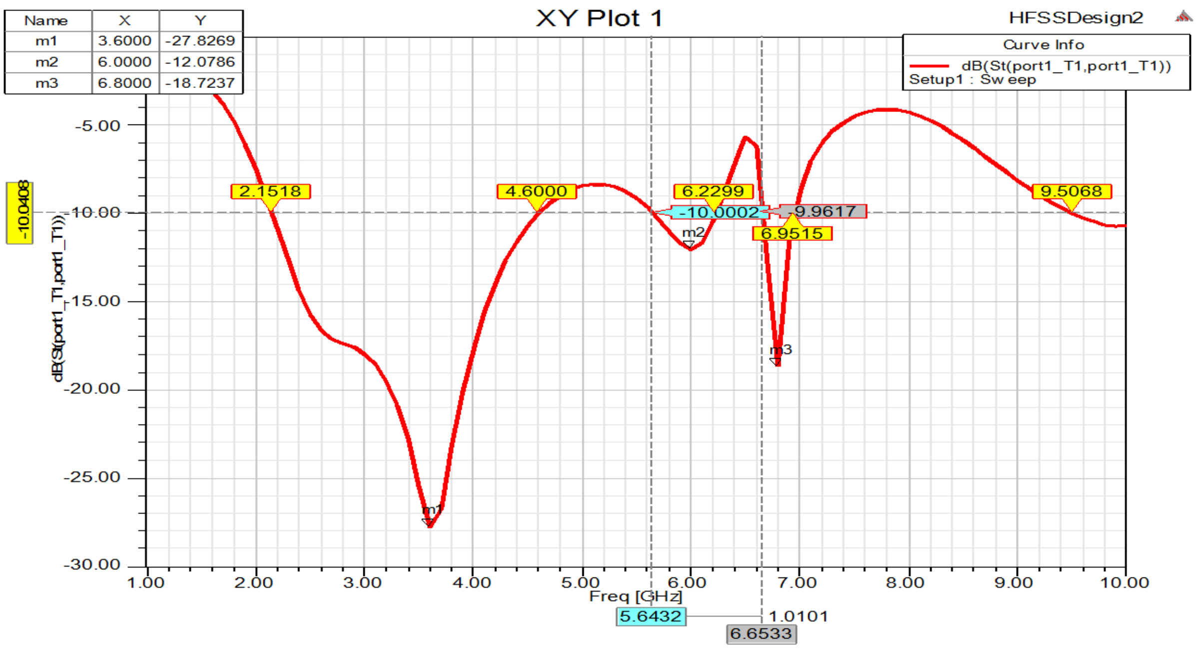


Figure III.18: Return loss of the Monopole T-shaped Patch Antenna with U3-slot

This shows that we obtain 3 bands:

- A large bandwidth of 72.9% between 2.15Ghz and 4.6Ghz belonging to the S-band with a return loss of -27.82dB.

- We can see that this antenna resonates at frequency of 6Ghz in the bandwidth of 9.6% belonging to the C-band with a return loss of -12 dB .
- Also this antenna shows resonance at frequency of 6.8Ghz in the bandwidth of 4.4% belonging to the C-band with a return loss of -18.72dB .

c.2 Total Gain:

The figure III.19 shows that the gain of this antenna is 2.16 dB in all directions all over the circle 360° and it is better than when we use FR4 material(2.06 dB).

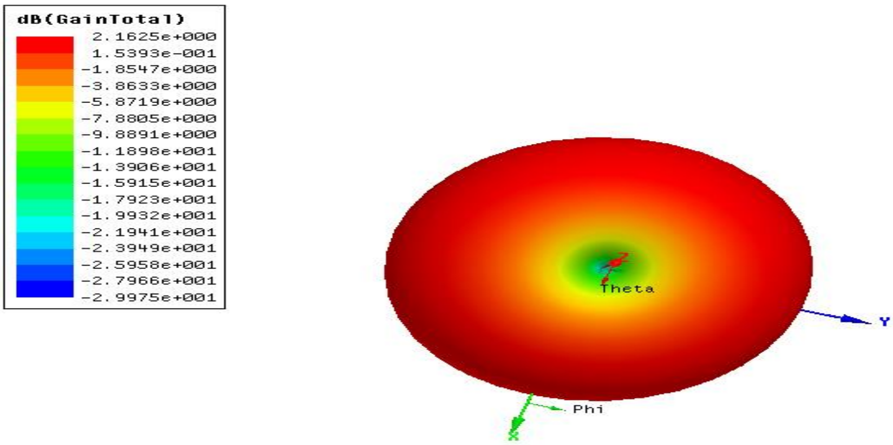


Figure III.19: The Total Gain of the Monopole T-shaped Patch Antenna with U3-slot

III.3.2 Using a 3 Inverted U-slots:

The figures III.20, III.21,III.22,III.23 ,III.24 show the Return Loss, VSWR ,Smith Chart, Total Directivity and the Total Gain of the antenna respectively when we use three inverted U-slots with Rogers RO4350 material which has been chosen since it gave better results as compared to the FR4 material.

a) **Return Loss:**

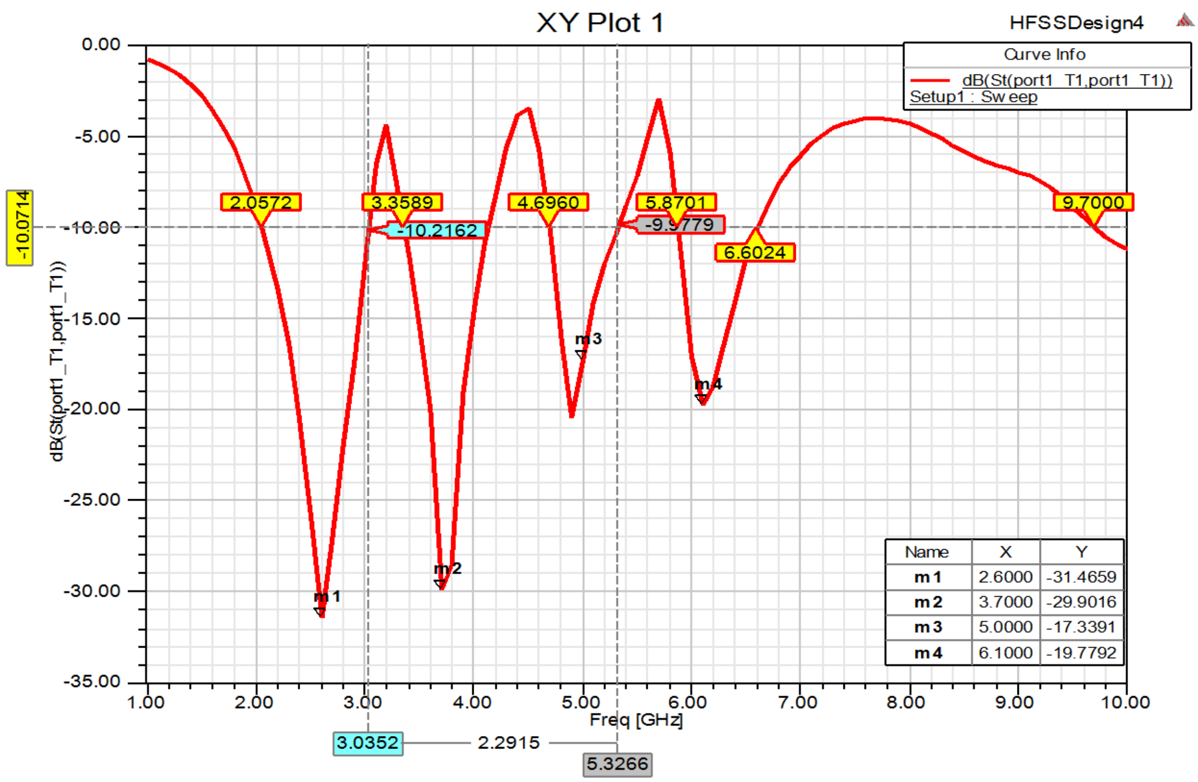


Figure III.20: Return Loss of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

This shows that we obtain a multiband antenna (4 bands):

- This antenna resonates at frequency of 2.6Ghz in the bandwidth of 38.2% belonging to the S-band with a return loss of -30 dB. Then we can use in WIMAX mobile (IEEE.802.16e) application (low band).
- We can see that this antenna resonates at frequency of 3.7Ghz in the bandwidth of 20.99% belonging to the S-band with a return loss of -29.9 dB which we can use in WIMAX mobile application (middle band).
- This antenna shows resonance at frequency of 5Ghz in the bandwidth of 12.61% belonging to the C-band with a return loss of -17.33dB which we can use in WLAN application as well as WIMAX mobile application (upper band).
- Also this antenna shows resonance at frequency of 6.2Ghz in the bandwidth of 11.81% belonging to the C-band with a return loss of -19dB which we can use in satellite application.

b) VSWR:

We see in the figure III.21 that we have a very good adaptation of the antenna because the resonance Frequencies 2.6Ghz , 3.7Ghz , 5Ghz and 6.3Ghz have a VSWR value near than 1.

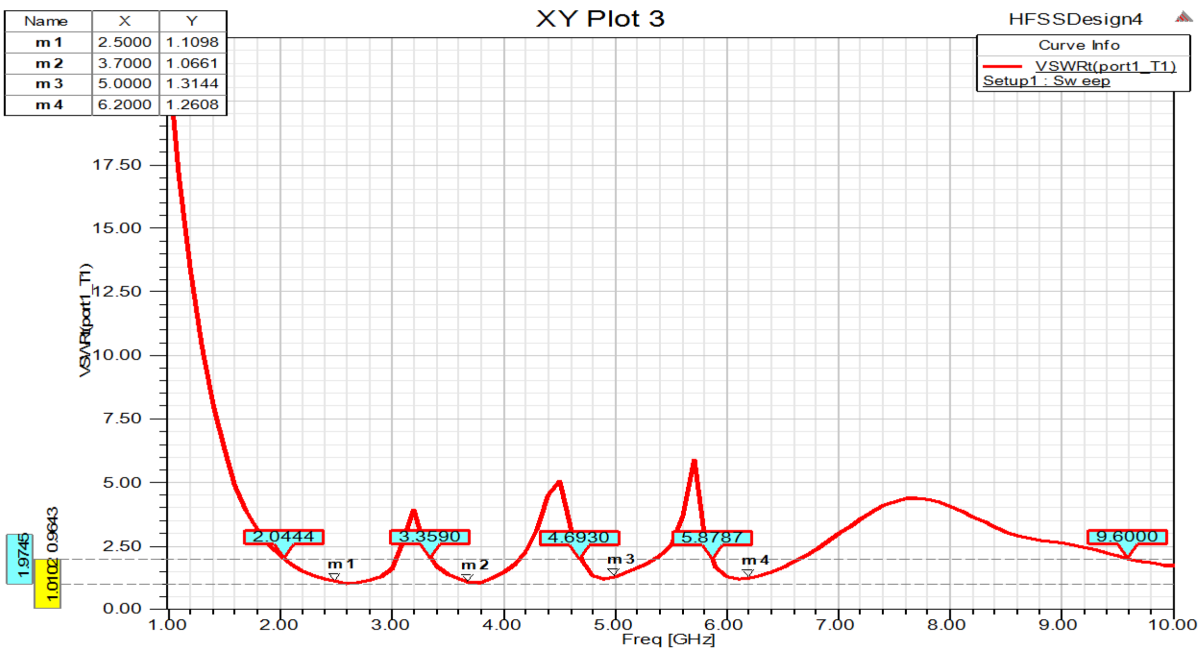


Figure III.21: VSWR of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

c) Smith Chart:

The figure III.22 describes the variation of the impedance matching with a frequency .It shows that the resonance frequencies near than 1 and that mean a good adaptation of the antenna.

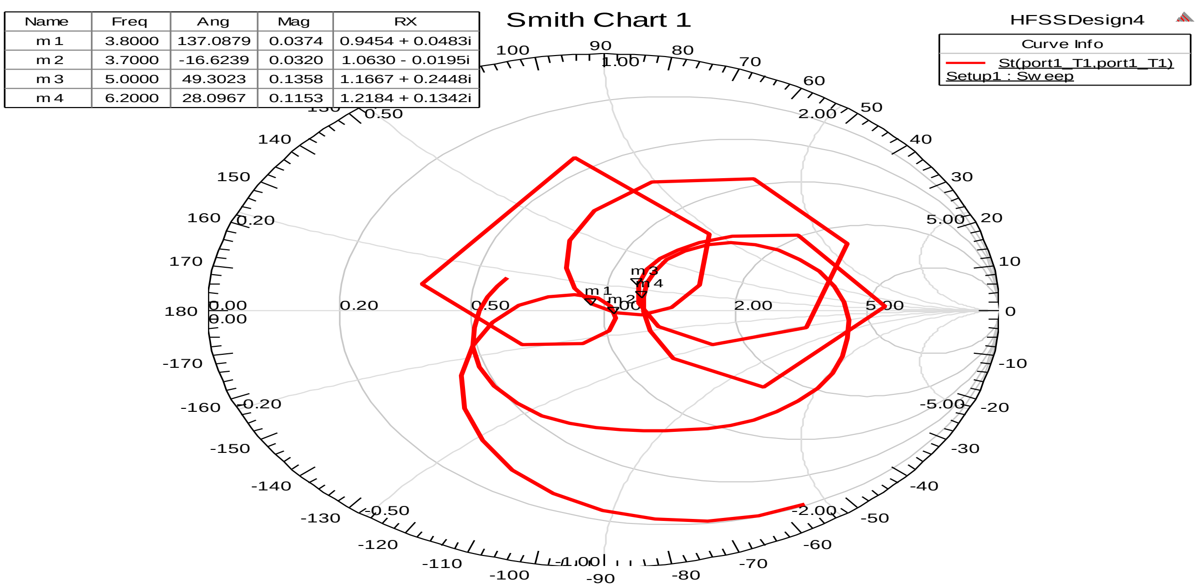


Figure III.22: Smith Chart of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

d) Total Directivity:

The figure III.23 shows that the directivity of this antenna is 1.41dB in all directions all over the circle 360°.

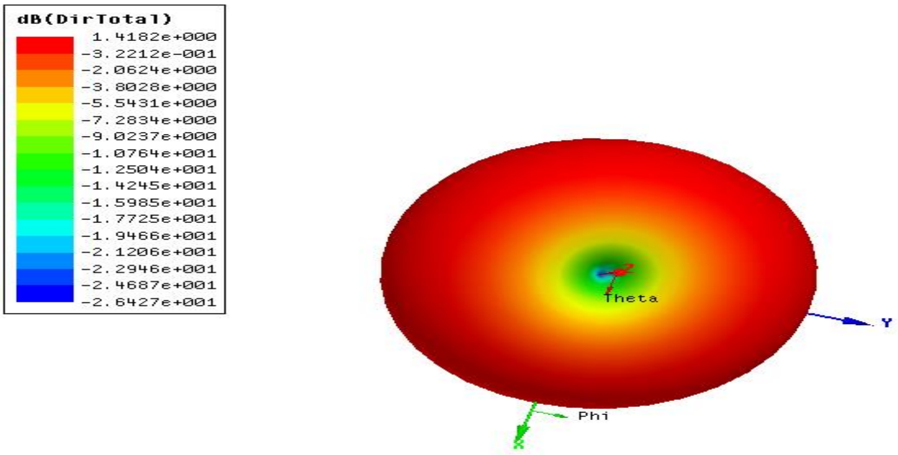


Figure III.23: The Total Directivity of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

e) Total Gain:

The figure III.24 shows that the gain of this antenna is 1.37 dB in all directions all over the circle 360°.We conclude with the formula I.14(seen chapter I) that the efficiency of the antenna is 0.96.

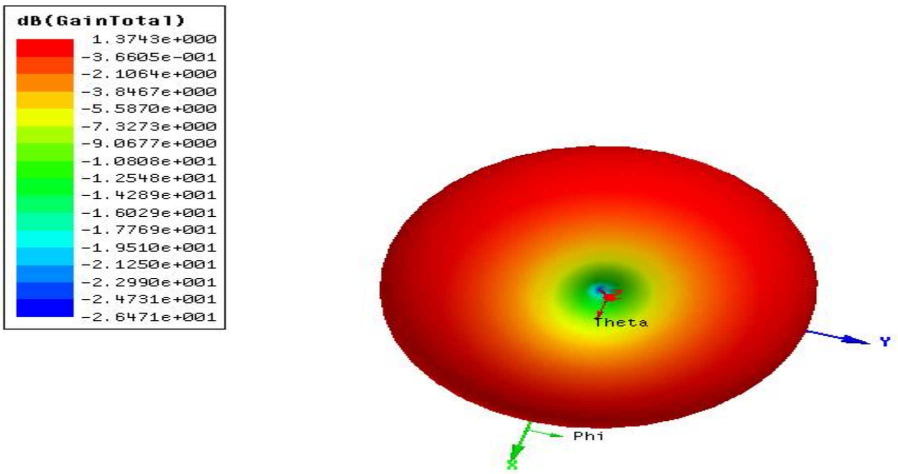


Figure III.24: The Total Gain of the Monopole T-shaped Patch Antenna with 3 Inverted U-slots

III.4 Design Two: Enhancing the gain by using CSRR's metamaterials in the patch of the monopole T-shaped patch antenna:

The table III.4 gives geometry of CSRR and its position in monopole T-shaped patch antenna which is defined in the figure III.26.

W6	L6	W6'	W6''	W6'''	Ln6	Ln6'	Ln6''	Ln6'''	*
18 mm	4.5 mm	17 mm	15 mm	13 mm	7 mm	6 mm	4 mm	2 mm	0.5mm

Table III.4: Dimension of CSRR's Metamaterials and its positions in the Monopole T-shaped Patch Antenna

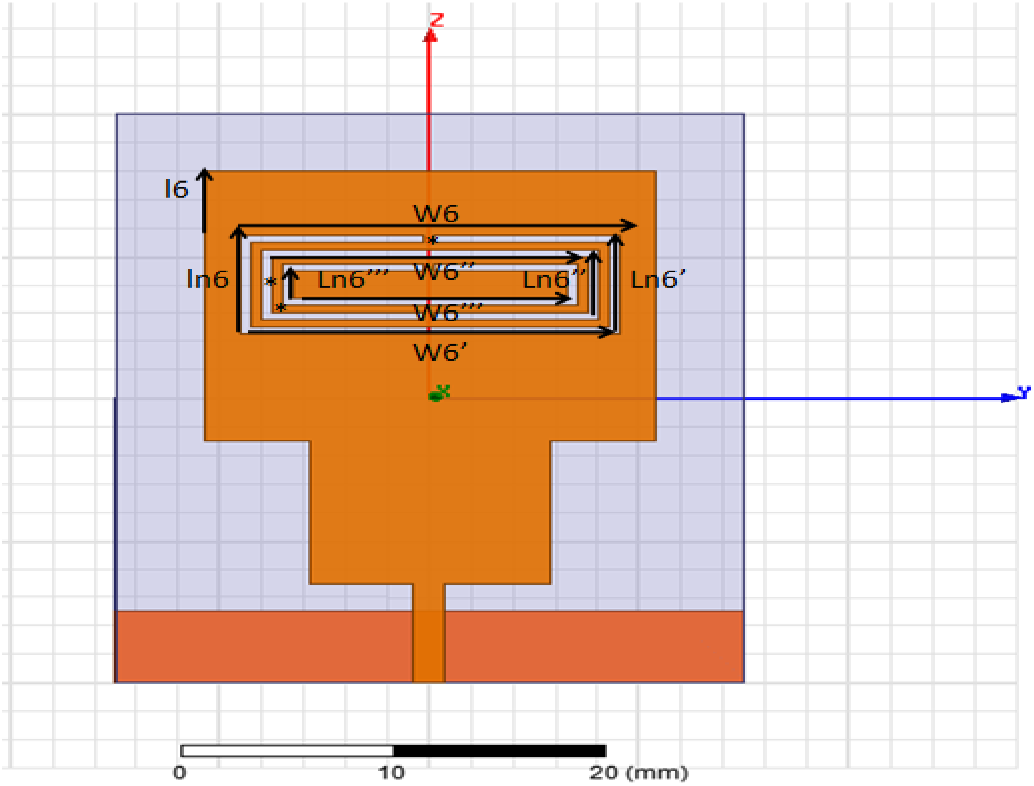


Figure III.25: Design of the Monopole T-shaped Patch Antenna with CSRR's Metamaterials

The figures III.26, III.27 ,III.28,III.29 show the Return Loss, VSWR ,Smith Chart , Total Directivity and the Total Gain of the antenna respectively when we use CSRR's metamaterials and with Rogers RO4350 material because it gives better results compared with using FR4 material.

a) Return Loss:

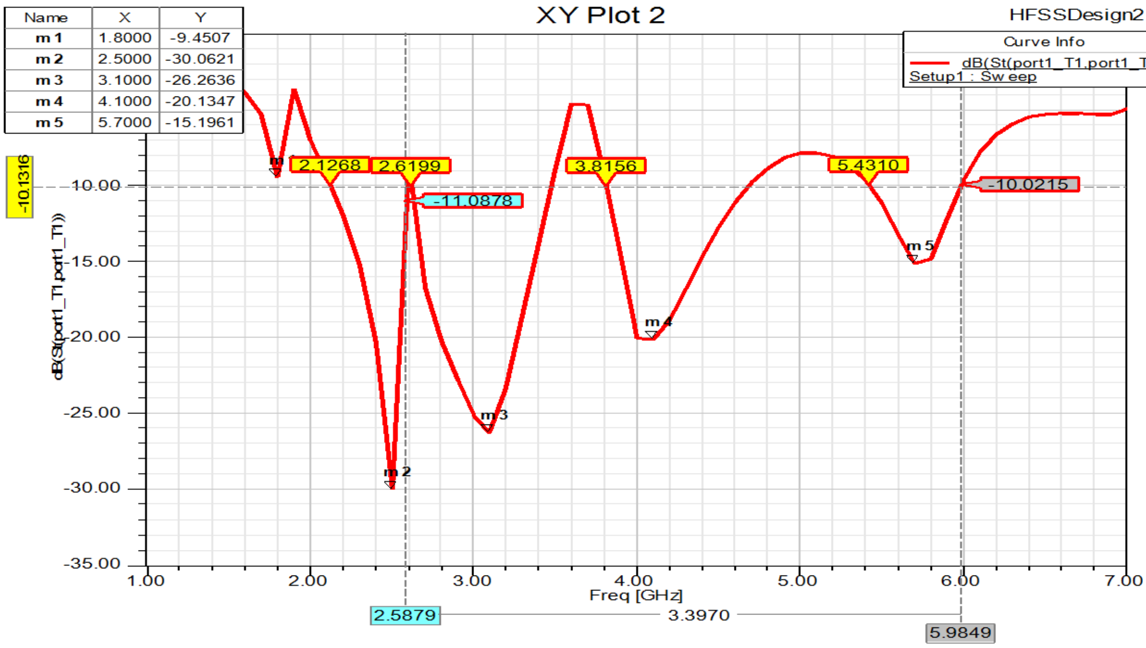


Figure III.26: Return Loss of the Monopole T-shaped Patch Antenna with CSRR's metamaterials

This shows that we obtain a multiband antenna (4 bands):

- This antenna resonates at frequency of 2.5Ghz in the bandwidth of 20.68 % belonging to the S-band with a return loss of -30 dB and we can use in WIMAX. mobile application (low band) and also in Bluetooth and WLAN applications.
- This antenna shows resonance at frequency of 3.1Ghz in the bandwidth of 27.87% belonging to the S-band with a return loss of -26.2 dB which we can use it in WIMAX application (middle band).
- We can see that this antenna resonates at frequency of 4.2Ghz in the bandwidth of 20.8% belonging to the C-band (middle band frequencies for 5G) with a return loss of -20 dB.
- Also this antenna shows resonance at frequency of 5.7Ghz in the bandwidth of 10.13% belonging to the C-band with a return loss of -15dB which we can use it in WIMAX mobile application (upper band).

b) VSWR:

We see in figure III.27 that we have a very good adaptation of the antenna because the resonance Frequencies 2.5Ghz , 3.1Ghz , 4.1Ghz and 5.7Ghz have a VSWR value near than 1.

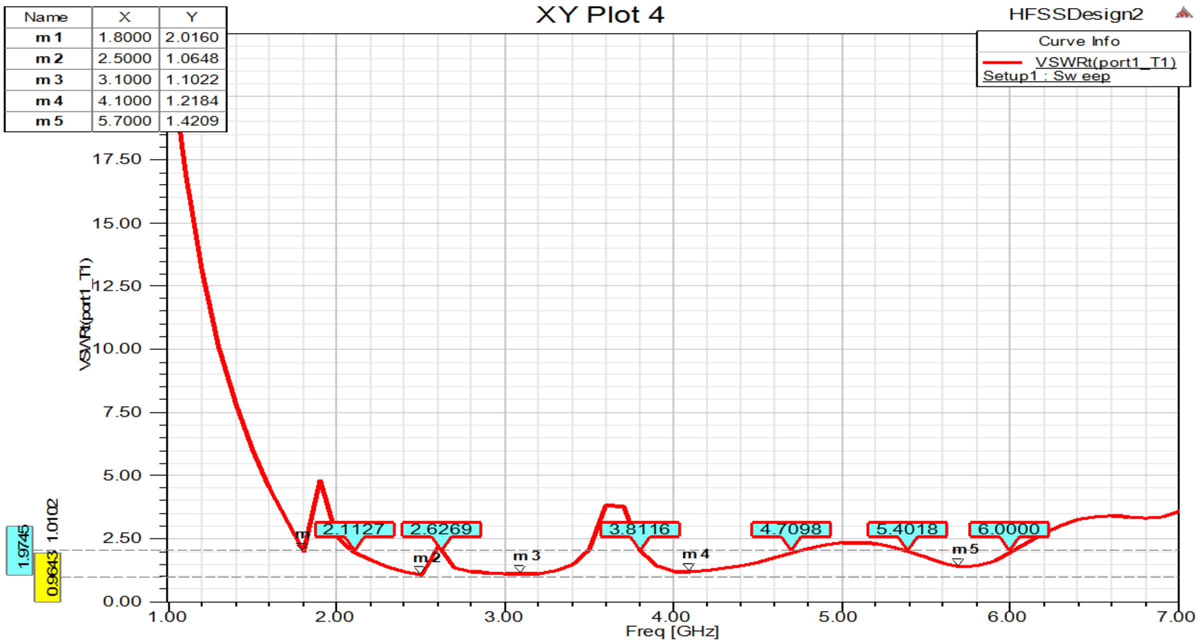


Figure III.27: VSWR of the MonopoleT-shaped Patch Antenna with CSRR's metamaterials

d) Total Directivity:

The figure III.28 shows that the Directivity of this antenna is 2.59 dB in all directions over the circle 360° which is better than when we use 3 Inverted U-slots.

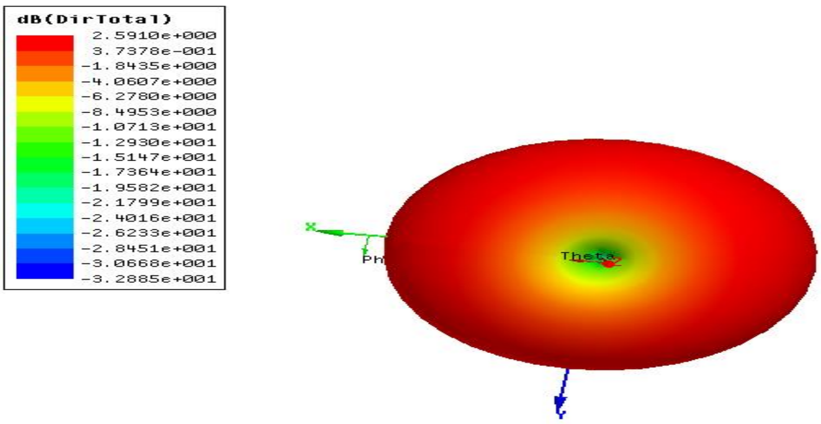


Figure III.28: The Total Directivity of the Monopole T-shaped Patch Antenna with CSRR's metamaterials

d) Total Gain:

The figure III.29 shows that the gain of this antenna is 2.46 dB in all directions over the circle 360° which is better than when we use 3 U-slots. We conclude with the formula I.14 that the efficiency of the antenna is 0.94.

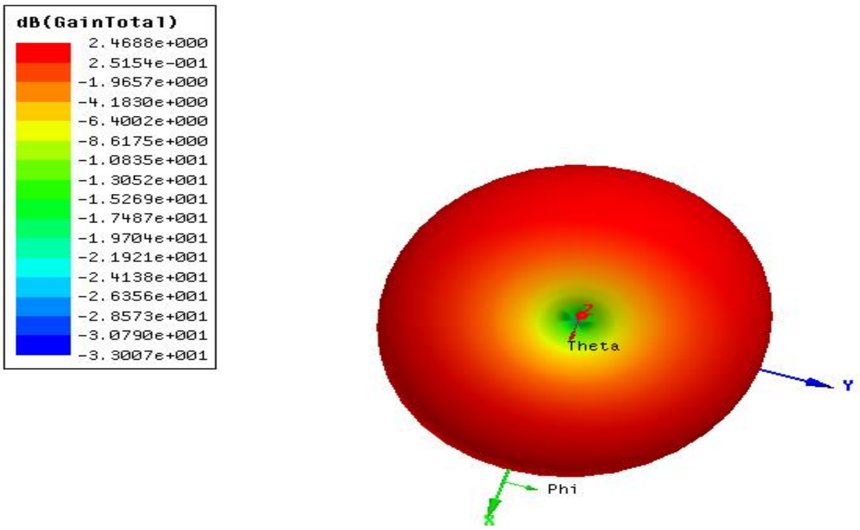


Figure III.29: The Total Gain of the Monopole T-shaped Patch Antenna with CSRR's metamaterials

III.5 Results of Broadband and Multiband Antenna:

The tables below explain results (Return Loss, % Bandwidth ,Wireless Networks and the Total Gain) of the different designs of monopole antennas when we use Rogers RO4350 material which the table III.5 explain the broadband monopole patch antennas and the table III.6 explain the multiband monopole patch antennas.

Design	Resonant frequencies	Return Loss	%Band-width	Wireless Network	Total Gain
T-shaped Patch antenna with DGS 40*30mm^2	From 2.15Ghz to 4.5Ghz At 6.2Ghz At 10.1Ghz	-20dB -16dB -10.2dB	67.2% 15.4% 14.8%	S-band C-band X-band	2.084dB
T-shaped Patch antenna with DGS and one inverted U-slot (U1) 40*30mm^2	From 1.72Ghz to 6.2Ghz	-27dB	113%	L-band ,S-band and C-band	-3.11dB
T-shaped Patch antenna with DGS and one inverted U-slot (U2) 40*30mm^2	From 2.14Ghz to 3.93Ghz From 4.93Ghz to 6.47Ghz	-38dB -16dB	59% 38.23%	S-band C-band	2.16dB

T-shaped Patch antenna with DGS and one inverted U-slot (U3) 40*30mm^2	From 2.15Ghz to 4.5Ghz At 6.2Ghz At 10.1Ghz	-27.8dB -12dB -18.7dB	72.9% 9.6% 4.4%	S-band C-band C-band	2.16dB

Table III.5: Resonant frequencies, Return Loss ,%BW ,Wireless Network and the Total Gain of the deferent designs of the Broadband Monopole Patch Antennas

Design	Resonant frequencies	Return Loss	%Band -width	Wireless Network	Total Gain
T-shaped Patch antenna with DGS and 3 Inverted U-slots 40*30mm^2	At 2.6Ghz At 3.7Ghz At 5Ghz At 6.2Ghz	-30dB -29.9dB -17.3dB -19dB	38.2% 20.99% 12.61% 11.81%	WiMAX(Low band) WiMAX(Middle band) WLAN(WiFi) or WiMAX(upper band) C-band	1.37dB
T-shaped Patch antenna with DGS and CSRR's Metamaterials 40*30mm^2	At 2.5Ghz At 3.1Ghz At 4.2Ghz At 5.7Ghz	-30dB -26dB -20dB -15dB	20.68% 27.87% 20.8% 10.13%	WiMAX(Low band)or Bluetooth or WLAN WiMAX(Middle band) C-band(middle band frequencies for 5G) WLAN(WiFi) or WiMAX(upper band)	2.46dB

Table III.6: Resonant frequencies, Return Loss ,%BW, Wireless Network and the Total Gain of the deferent designs of the Multiband monopole patch antennas

III.6 Conclusion:

The techniques (DGS,U-Inverted slots and CSRR metamaterial) help us to achieve our objective, a broadband monopole micro-strip patch antenna was achieved when we used one U-Inverted slot in the patch antenna with DGS structure (reducing the ground plane) which we obtained in each antenna L-band ,S-band ,C-band and X-band. Also we could validate a multiband monopole patch antenna when we used a 3U-Inverted Slots in the patch antenna with DGS that we got a WiMAX IEEE 802.16 e (Low band, Middle band and upper band) application and WLAN IEEE 802.11a (WiFi) also when we used The CSRR's metamaterial in the patch which resulted higher gain (more than 2dB) and enhanced the band of the WiMAX, WiFi, Bluetooth applications. All the proposed monopole designs with a transmission line fed can be used in cell phone (mobile).

CONCLUSION,

PERSPECTIVES AND FUTURE SCOPE

General Conclusion,
Perspectives and Future Scope

Rapid development has increased the need of the cost effective and several wireless technologies for the same devices. Therefore, we started our project by defining WPAN,WLAN and WMAN found in Bluetooth and WiFi in our phones, for large area coverage and the high security of the WiMAX mobile technology which is our goal.

In this project, we studied a monopole micro-strip T-shaped patch antenna with size 40*30mm^2 in which a different techniques has been introduced to obtain a broadband and multiband antennas that can be integrated in mobile phone. The antenna design is based on an artificial transmission line. The monopoly of the antennas has been obtained by a DGS structure which enhanced the bandwidth.

We opted in our study for broadband T-shaped patch monopole antenna designs by applying one inverted U-slot in the patch of the antenna giving several bands L-band, S-band, C-band and X-band and the largest band from 1.72Ghz to 6.2Ghz that we have got when we used one inverted U2-slot in the patch belonging to the L-band (from 1.727Ghz to 2Ghz) ,S-band (from 2Ghz to 4Ghz) and C-band (from 4Ghz to 6.2Ghz) with a return loss of -27dB.

We focused, in this thesis, on two multiband T-shaped patch monopole antenna designs by applying 3 inverted U-slots and CSRR's metamaterial techniques. The first design was achieved by using 3 inverted U-slots in the patch and we obtained as a result that WiMAX Mobile IEEE 802.16e (low band, middle, upper band), WiFi(IEEE 802.11a) with good gain 1.37dB and very good efficiency 0.96 in all directions over the circle 360°.The second design was represented in T-shaped patch monopole antenna with CSRR's metamaterial in the patch which gave a good gain(more than 2dB) and enhanced the band of the WiMAX, WiFi, Bluetooth applications.

The design using the simulator HFSS gave us excellent results showing good range of applications to obtain a very good performing antenna. The practical implementation of the antenna was planned to be fabricate and measured using PNA network analyzer "Agilent PNA" in the CDTA "Centre de Developpement des Technologies Avancées" in Algiers. Unfortunately all the arrangement couldn’t be produced due to Corona Covid government decision to forbid inter-cities travel by the time being. So we are deeply sorry for not being able to apply that to check and reinforce the working of our designs.

Perspectives and Future Scope:

Perspectives:

- The DGS technique is a good structure for obtain monopole antenna and enhance bandwidth.
- The Inverted U-slots technique has a great effect on the Bandwidth.
- The WiMAX technology is needed to the wideband antenna.
- The CSRR's metamaterials have a great effect to enhance the gain of the antenna.

Future Scope:

- Use other type of DGS technique like U-DGS, circular DGS or applied slots to the ground to increase the bandwidth or to obtain UWB (Ultra Wide Band).
- Add a diode to the CSRR's metamaterials technique to make the antenna reconfigurable and to obtain a cognitive radio which is very demanded in the last decade.
- Fabricate the proposed antennas for use in cell phones.

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