KASDI MERBAH UNIVERSITY OF OUARGLA

Faculty of New Technologies of Information and Communication
Department of Electronics and Telecommunications

Academic Master Thesis

Domain: Sciences and Technologies
Field: Telecommunication
Option: Telecommunication systems

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Title:

Bandwidth Improvement Of Microstrip Patch Antenna Using DGS Technique

Approved by supervising committee:

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DEDICATION

This thesis is dedicated To:

The sake of Allah, Our Creator and Our Master

Our great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life.

Our great parents, who never stop giving of themselves in countless ways "god bless them"

Our beloved brothers and sisters.

All Our family.

All the teachers of the Electronics and telecommunications Department of the University of Ouargla.

All Our friends and colleagues.

Messatfa Tarek, Annou Abderrahim.

ACKNOWLEDGMENT

In the Name of Allah, the Most Merciful, the Most Compassionate all praise be to Allah, the Lord of the worlds; and prayers and peace be upon Mohamed His servant and messenger.

Before all and foremost, We must acknowledge Our limitless thanks to Allah, the Ever-Magnificent; the Ever-Thankful, for His help We are totally sure that this work would have never become truth, without His guidance.

First, we would like to thank our supervisor Mr. BELHEDRI Abdelkrim for his supervision, availability, fruitful remarks and precious guidance during our study and realization of this project.

In addition, we would like to express our gratitude to Mr. MEKIMAH Boualem who is always shown to listen and very available throughout the realization of this thesis.

We extend our thanks to the jury members who we have honored by evaluating, reviewing and enriching our modest work.

We also would like to express our wholehearted thanks to our family for their generous support they provided us throughout us entire life and particularly through the process of pursuing the master degree. Because of their unconditional love and prayers, we have the chance to complete this thesis.

Finally thank you to all those who have contributed to the realization of this work.

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Abstract

In the recent years, The Wireless Technology is one of the main areas of research in the world of communication systems and the development in communication systems requires the development of low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a wide range of frequencies. The performance and advantages of microstrip patch antennas make them the perfect choice for communication systems. This was the main reason why we select this project. In this work, a circular microstrip patch antenna is designed and simulated using the Computer Simulation Technology (CST). The aim of our work is to improve and increase the bandwidth of an antenna by using Defected Ground Structure (DGS) technique in order to use this antenna in Ultra and Super wideband (UWB/SWB) applications.

Key words: DGS, UWB, SWB, CST, microstrip patch antenna, bandwidth

ملخص

في السنوات الأخيرة، تعد التكنولوجيا اللاسلكية واحدة من المجالات الرئيسية للبحث في عالم أنظمة الاتصالات، ويتطلب تطوير أنظمة الاتصالات تطوير هوائيات منخفضة التكلفة، وأقل وزناً وحجما وقادرة على الحفاظ على الأداء العالي لها عبر نطاق واسع للترددات، ومن أجل المزايا التي تتمتع بها هوائيات ذات الرقعة الصغيرة (ميكروستريب باتش) جعلها الخيار الأمثل لأنظمة الاتصالات.

وهذا كان السبب الرئيسي لاختيارنا لهذا المشروع. في هذا السياق، تم تصميم ومحاكاة هوائي ذي رقعة دائري صغير باستخدام برنامج المحاكاة (CST) بهدف تحسين وزيادة النطاق الترددي لهذا الهوائي عن طريق استخدام تقنية الهيكل الأرضي المنشق المعروف ب (DGS) وهذا لأجل استعماله في تطبيقات ذات النطاق الترددي الفائق والعريض جدا (UWB/SWB).

الكلمات المفتاحية: النطاق الترددي العريض والفائق، DGS، الهوائي ذات رقعة صغيرة، CST، النطاق الترددي،

Résumé

Durant les dernières années, La technologie sans fil est l'une des principaux domaines de recherche dans le monde des systèmes de télécommunications. Le développement de ces derniers nécessite le développement d'antennes à faible coût, de poids minimal et de faible taille capables de maintenir de hautes performances sur une large gamme de fréquences. Les performances et les avantages des antennes microbandes en ont fait le choix parfait pour les systèmes de télécommunication. C'est la raison principale pour nous d'avoir choisi ce projet. Dans ce travail, une antenne patch circulaire est conçue et simulée par le simulateur (CST). Le but de notre travail est d'améliorer et d'augmenter la bande passante de cette antenne en utilisant la technique de structure à plan de masse irrégulier (Defected Ground Structure, DGS) pour pouvoir utiliser cette antenne dans les applications à Ultra et Supra large bande UWB / SWB.

Mots clés : DGS, ULB, SLB, CST, antenne patch microruban, bande passante

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List of Abbreviations

A)

- **ABW**: Absolute Band-Width
- **ADCs**: Analog-To-Digital Converters.

B)

- **BW**: Band-Width.

C)

- **CPW**: Coplanar Waveguide.
- **CST**: Computer Simulation Technology.

D)

- **DGS**: Defected Ground structures.
- **DVD**: Digital Video Disc.

F)

- **FBW**: Fractional Bandwidth.
- **FCC**: The Federal Communication Commission.
- **FDTD**: Finite Difference Time Domain.
- **FEM**: Finite Element Method.
- **FIT**: Finite Integral Technique.

G)

- **GPS**: Global Positioning System.

H)

- **HFSS** : High frequency structural simulator

I)

- **I/O**: Input/Output.
- **IE3D**: Integral Equation Three-Dimensional.
- **IEEE**: Institute of Electrical and Electronics Engineers.

L)

- **LHC**: Left-Hand-Circular.
- **LPF**: Low Pass Filter.

M)

- **MAI**: Multiple-Access Interference.
- **MMIC**: Microwave Monolithic Integrated Circuit.
- **MNM**: Multiport Network Model.
- **MoM**: Method of Moments.
- **Mp3**: Mpeg Audio Layer 3mpeg: Moving Picture Experts Group.
- **MPAs**: Microstrip patch antennas.
- **MSA**: Microstrip antenna

O)

- **OEIC**: OptoElectronic Integrated Circuit.

P)

- **PCs**: Personal Computers.
- **PCB**: Printed-Circuit Board.
- **PPM**: Pulse-Position Modulation.

R)

- **RF**: Radio Frequency.
- **RHC**: Right-Hand-Circular.

- **RL**: Return Loss
- **RLC**: Resistor, Inductor, Capacitor.

S)

- **S-parameters**: Scattering parameters.
- **SDT**: Spectral Domain Technique.
- **SWB**: Super Wide Band.

T)

- **TEM**: Transverse Electric-Magnetic.
- **TM**: transmission mode.

U)

- **USB**: Universal Serial Bus.
- **UWB**: Ultra-Wide Band.

V)

- **VSWR**: *Voltage Standing Wave Ratio*.

W)

- **WLAN**: Wireless local area network.
- **WPAN**: Wireless Personal Area Network.
- **Wi-Fi**: Wireless Fidelity.
- **Wimax**: Worldwide Interoperability for Microwave Access.

List of Symbols

- **U**: radiation intensity.
- **E** : Electric field.
- **H** : Magnetic field.
- **Prad**: total radiated power.
- **D**: directivity.
- η: efficiency.
- **G**: gain.
- η_0: impedance of free space.
- k_0: the wave number in the dielectric.
- ε_r: Relative dielectric constant of the material.
- Z_{in}: the antenna impedance at the terminals.
- R_{in}: the antenna resistance at the terminals.
- X_{in}: the antenna reactance at the terminals.
- ***Rr***: radiation resistance.
- R_L: loss resistance.
- **dB**: decibel.
- S_{11}: Forward Reflection Coefficient
- Γ : reflection coefficient.
- ***Q***: Quality
- ***Qt***: total Q factor.
- δ : loss tangent.
- σ_c: conductivity of the metal.
- G_r: the radiation conductance.
- Z_0: the characteristic impedance.
- λo : the free-space wavelength.

List of Symbols

- ε_{reff}: effective dielectric constant.
- ε_r: dielectric constant of substrate.
- L_{eff}: effective length of the patch.
- P_r: received power (watt).
- P_t: transmitted power (watt).
- G_t: transmission gain of emission antenna.
- Gr: receiving gain of receiving antenna.
- c: Velocity of light in free space.
- **d**: distance between transmission and receiving antennas (meters).
- **f** : the transmission frequency (Hz).
- f_H : highest frequency.
- f_L :lowest frequency
- fc : center frequency
- **W**: watt

INTRODUCTION

Introduction

The explosion in information technology and wireless communications has created many opportunities for enhancing the performance of existing signal transmission and processing systems. This has provided a strong motivation for developing novel devices and systems. An indispensable element of any wireless communication system is the antenna. An antenna is a device used for radiating or receiving radio waves. The new generation of wireless systems demands effective and reliable antennas, these antennas include parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas [1].

Each type of antenna has its own advantages and disadvantages but without a proper design, the signal generated by the radio frequency (RF) system will not be effectively transmitted and poor signal detection will be experienced at the receiver.

The sizes and weights of various wireless electronic systems (for example, mobile handsets) have rapidly reduced due to the development of modern integrated circuit technology. In many wireless communication systems, there is a requirement for low profile antennas. [1].

Microstrip patch antennas (MPAs) are examples of low profile antennas. MPAs have many attractive features such as low profile, lightweight, ease of manufacture, conformability to curved surfaces, low production cost, and compatibility with integrated circuit technology. These attractive features have recently increased MPAs popularity and applications and stimulated greater research effort to understand and improve their performance [2].

Over all these advantages of micro-strip patch antenna, some limitations are also mentioned like their efficiency and power is low, polarization purity is poor, scan performance is also poor, fake feed radiation and very narrow frequency bandwidth is also the limitation of micro-strip patch antenna.

Most of the proposed designs for patch antennas suffer from narrow bandwidths, and a number of techniques have been proposed and investigated to render them suitable for UWB communication applications by enhancing their bandwidth. Ultra-wideband (UWB) antennas are one of the most important elements for UWB systems. With the release of the 3.1 - 10.6 GHz band, applications for short-range and high-bandwidth handheld devices are primary research areas in UWB systems [3] [4].

The one of these techniques is defected ground structure or DGS, where the ground plane metal of a microstrip circuit is intentionally modified to enhance performances. This technique's name is simply means that a "defect" has been placed in the ground plane, what is generally regarded as an approximation of 'an infinite, current collector perfectly-conducting. When considering patch antenna design for ultra-wideband applications, defected ground structures present a novel technique for modifying the characteristics of the microwave device [5].

DGS has been used in the field of microstrip antennas for enhancing the bandwidth and gain of microstrip antenna and to suppress the higher mode harmonics, mutual coupling between adjacent element, and cross-polarization for improving the radiation characteristics of the microstrip antenna[5].

In this work, we propose the microstrip patch antenna that has a narrow bandwidth and large dimensions. Then, we apply the technique of defected ground structures (DGS) to improve its bandwidth and reduce its dimensions and its works well in UWB applications, and also in SWB applications.

This project contains three chapters organized as follow:

Chapter I: The first chapter a brief overview of the antenna concept and its characteristics and in particular for the microstrip patch antennas and its structural components, its advantages and disadvantages, its applications, the feeding technics, and different methods of analysis.

Chapter II: Overview about UWB technology, its definition, advantages, disadvantages, and its applications in wireless communication systems, Microstrip UWB Antennas. Then the most important techniques to improve the antenna bandwidth (Coplanar Waveguide "CPW", Defected Ground structures "DGS")

Chapter III: Simulation and discussion of the proposed antenna with DGS (Defected Ground structures) and the comparison between the proposed antenna without DGS and after using DGS technique and also the comparison between this work with and other proposed work

Finally, we conclude this thesis with a conclusion and the appendix was added to provide an overview of the simulation software CSTMWS (Computer Simulation Technology Microwave Studio) we used in this work.

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Chapter I

Basic Concepts of Antennas

I.1 Introduction

The antennas play an important role in any wireless system and with the advances in telecommunication; the requirement for a compact antenna has increased significantly. In mobile communication, the requirement for smaller antennas is quite large, so significant developments are carried out to design compact, minimal weight, low profile antennas for both academic and industrial communities of telecommunication. The technologist focused into the design of microstrip patch antennas. Many varieties in designing are possible with microstrip antenna.

An antenna is a device that is used to convert electromagnetic waves into electrical signals in reception and vice versa in emission. Antennas are essential part in communication systems, therefore understanding their basics is important [1].

In this chapter, we will present a brief overview of the antenna concept and its characteristics and in particular for the microstrip patch antennas and its structural components, its advantages and disadvantages, its applications, the feeding technics, and different methods of analysis.

I.2 Antenna Basics

I.2.1 Definition of antenna

An antenna is an electrical conductor or system of conductors. According to the IEEE standard definitions of terms for antennas, an antenna is defined as “a means for radiating or receiving radio waves” [2]. In other words, a transmitting antenna is a device that gets the signals from a transmission line, converts it into electromagnetic waves and then broadcasts it into free space as shown in Figure I. 1.while operating in receiving mode, the antenna collects the incident electromagnetic waves and converts it back into signals.

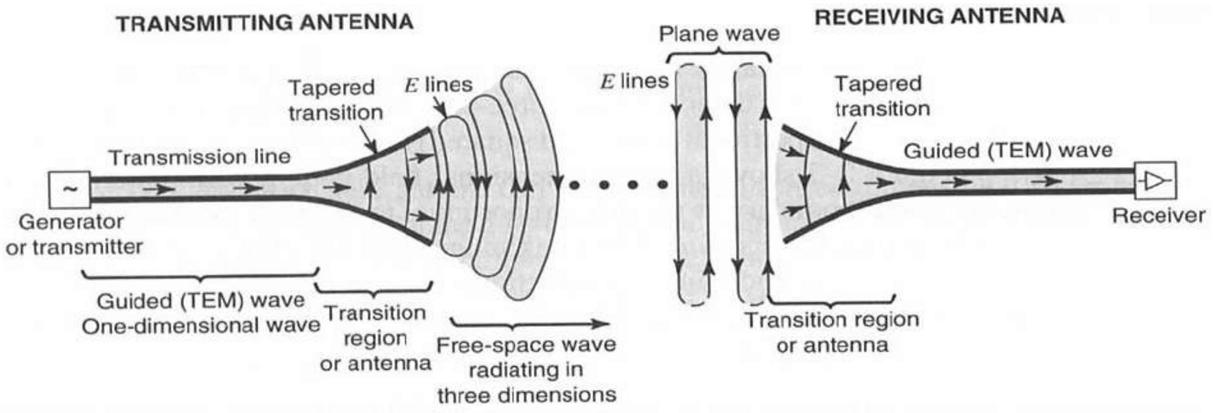


Figure I. 1 : Antenna as a Transition Device

I.2.2 Transmitting antenna

The role of the transmitting antenna is to transform the guided electromagnetic power from a generator into a radiated power. In this sense, it is a transducer.

I.2.3 Receiving antenna

Conversely, a receiving antenna can pick up the radiated power. In this sense, the antenna appears as a sensor and a radiated power transformer in guided electro-magnetic power. It plays the same role as a telescope that captures light from stars and transforms it.

I.2.4 Reciprocity

In most cases, an antenna can be used for reception or transmission with the same radiating properties. It is said that its operation is reciprocal.

I.3 Fundamental Antenna Parameters

The antennas, in general, are characterised by parameters like gain, input impedance, directivity, radiation pattern, effective area and polarization properties. some basic parameters affect the antenna’s performance .Some of the antenna parameters are described below [3].

I.3.1 Gain

Gain is a parameter that measures the directionality of a given antenna. An antenna with low gain emits radiation about same power in all directions, whereas a high gain antenna preferentially radiates in particular directions. Especially the gain, directive gain or power gain of an antenna is defined as the ratio of intensity of the signal radiated by the antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic lossless antenna. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π Steradians [3]:

$$\boldsymbol{Gain} = \frac{\boldsymbol{4\pi\, radiation\ intensity}}{\boldsymbol{total\ input\ (transmitted) power}} \tag{I.1}$$

Antenna Gain (G) can be related to directivity (D) and antenna efficiency (η) by [3] :

$$\boldsymbol{G = \eta * D} \tag{I.2}$$

I.3.2 Directivity

The directivity of the antenna has been defined as “the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over all directions”. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. In other words, the directivity of a nonisotropic source is equal to the ratio of its radiation intensity in given direction, over that an isotropic source [3]:

$$\boldsymbol{D} = \frac{\boldsymbol{4\pi U}}{\boldsymbol{Prad}} \tag{I.3}$$

Where : U is the radiation intensity in (W/unit solid angle) and Prad is total radiated power in (W), D is the directivity of antenna If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as U_{max} [2]:

$$\boldsymbol{D} = \frac{\boldsymbol{4\pi Umax}}{\boldsymbol{Prad}} \tag{I.4}$$

I.3.3 Input Impedance

The input impedance of an antenna is defined by [2] as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. Hence, the impedance of the antenna can be written as:

$$\boldsymbol{Z_{in} = R_{in} + jX_{in}} \tag{I.5}$$

Where Z_{in} is the antenna impedance at the terminals, R_{in} is the antenna resistance at the terminals and X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance Rr and the loss resistance R_L. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

I.3.4 Radiation Pattern

The radiation pattern (or antenna pattern) is the representation of the radiation properties of the antenna as a function of space coordinates. In most cases, it is determined in the far-field region where the spatial (angular) distribution of the radiated power does not depend on the distance. The radiation property of most concern is the two- or three-dimensional (2D or 3D) spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius.

For a linearly polarised antenna, its performance is often described in terms of its principle E-plane and H -plane patterns. The E-plane is defined as the plane containing the electric-field vector and the direction of maximum radiation whilst the H -plane is defined as the plane containing the magnetic-field vector and the direction of maximum radiation [3].

Three common radiation patterns are used to describe an antenna's radiation property:

- **Isotropic** (uniform radiation in all directions, it is not possible to realize this practically but a useful reference for quantifying how directive real antennas are.)
- **Directional** (Radiates significantly more power in one direction than others)
- **Omni-directional (**radiation response is constant in one of the principal planes of the antenna)

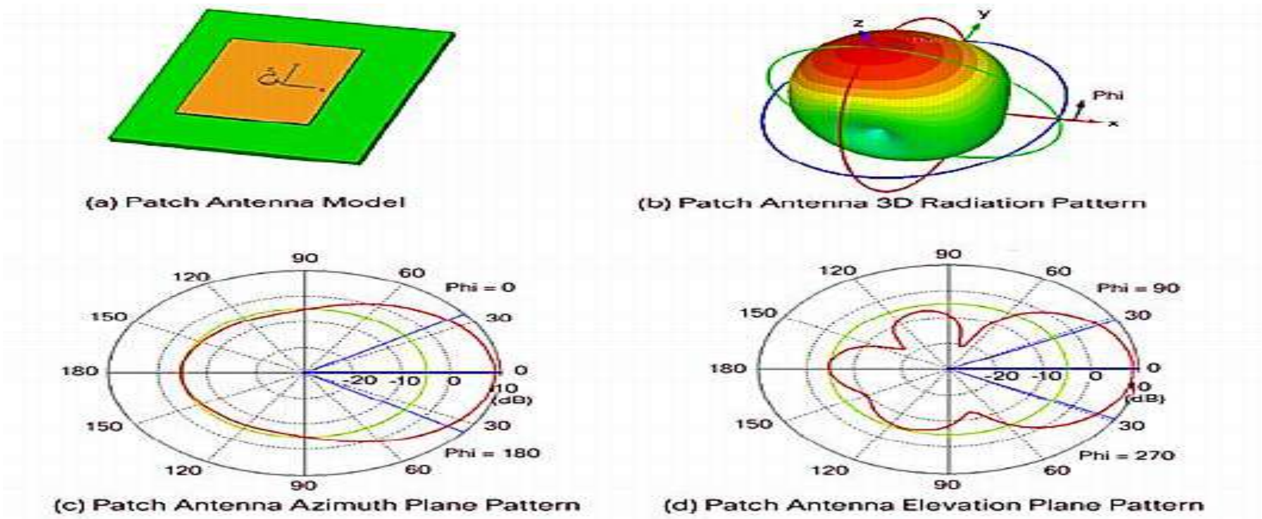


Figure I. 2 : 3D and polar Radiation Pattern of patch Antenna

I.3.5 Return Loss (S11) and Voltage Standing Wave Ratio (VSWR)

Return loss is a measure of the effectiveness of power delivery from a transmission line to a load, which is in our case the antenna [4]. The reflection coefficient at the antenna input is the ratio of the reflected voltage to the incident voltage and is same as the S11 when the antenna is connected at the port 1 of the network analyzer. It is the measure of the impedance mismatch between the antenna and the source line. The degree of mismatch is usually described in terms of Return loss or VSWR. The return loss (RL) is the ratio of the reflected voltage to the incident voltage, expressed in dB as [5] :

$$RL = -\,20\log\left(|\Gamma|\right) = -20\log\left(|S11|\right) = -|S11|\ (dB) \tag{I.6}$$

For perfect matching between the transmitter and the antenna, the reflection coefficient $\Gamma = 0$ and hence RL= ∞ which means no power would be reflected back, whereas $\Gamma = 1$ has a RL= 0 dB, which implies that all incident power is reflected back.

The voltage standing wave ratio (VSWR) is the ratio of the voltage maximum to the minimum of the standing wave existing on the antenna input terminals. VSWR equals to two gives a return loss of approximately equals to 10 dB and it is set as the reasonable limits for a matched antenna.

A VSWR of 1:1 is ideal. A VSWR of 1.5:1 is considered marginally acceptable in low power applications. Minimizing impedance differences at each interface will reduce VSWR and maximize power transfer through each part of the system. The VSWR can be expressed as [5]:

$$\boldsymbol{VSWR} = \frac{\mathbf{1} + |\boldsymbol{\Gamma}|}{\mathbf{1} - |\boldsymbol{\Gamma}|} \tag{I.7}$$

I.3.6 Q factor

The **Q** of an antenna is a measure of the bandwidth of an antenna relative to the center frequency of the bandwidth. If the antenna operates over a band between *f1* and *f2* with center frequency *fc* then the Q is given by [5]:

$$\mathbf{Q} = \frac{\boldsymbol{fc}}{\boldsymbol{f}_2 - \boldsymbol{f}_1} \ \boldsymbol{with} \ \boldsymbol{fc} = \frac{\boldsymbol{f}_1 + \boldsymbol{f}_2}{\mathbf{2}} \tag{I.8}$$

Antennas with a high Q are narrowband; antennas with a low Q are wideband. The higher the value of Q, the more sensitive the input impedance is to small changes in frequency.

I.3.7 Frequency Bandwidth

Bandwidth (BW) is another fundamental antenna parameter. Bandwidth describes the range of frequencies over which the antenna can properly radiate or receive energy. Often, the desired bandwidth is one of the determining parameters used to decide upon an antenna. For instance, many antenna types have very narrow bandwidths and cannot be used for wideband operation. The bandwidth is often specified in terms of its Fractional Bandwidth (FBW) The Fractional bandwidth (FBW) is a factor used to classify signals as narrowband, wideband, or ultra-wideband and is defined by the ratio of bandwidth at -10 dB points to center frequency.

If $\boldsymbol{f_H}$ is highest frequency and $\boldsymbol{f_L}$ is lowest frequency of the antenna bandwidth. The bandwidth BW is given by [1]:

$$\boldsymbol{BW} = \boldsymbol{f}_{\mathrm{H}} - \boldsymbol{f}_{\mathrm{L}} \tag{I.9}$$

The FBW is designated as the percentage of the frequency difference over the center frequency, is given by [1]:

$$\%\,\boldsymbol{FBW} = \mathbf{2}\,\frac{\boldsymbol{f_H} - \boldsymbol{f_L}}{\boldsymbol{f_H} + \boldsymbol{f_L}} * \mathbf{100} \text{ or } \%\,\boldsymbol{FBW} = \mathbf{2}\,\frac{\boldsymbol{BW}}{\boldsymbol{f_H} + \boldsymbol{f_L}} * \mathbf{100} \tag{I.10}$$

Here is the classification of signals based on their fractional bandwidth:

FBW < 1% Narrowband

1% < FBW< 20% Wideband

FBW > 20% Ultra-wideband

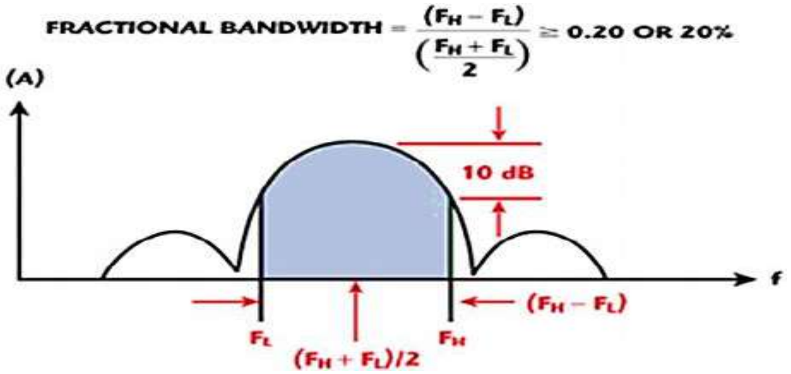


Figure I. 3 : Fractional spectrum bandwidth

I.3.8 Antenna Efficiency

The efficiency of an antenna is a ratio 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, or reflected away due to impedance mismatch. The transmitting and receiving antenna efficiency is the same, and since it is easier to understand efficiency in terms of power radiated vs. power supplied. The antenna efficiency (or radiation efficiency) can be written as the ratio of the radiated power to the input power of the antenna:

$$\eta = \frac{\text{power radited}}{\text{power input}} \tag{I.11}$$

Antenna efficiency (η) can be related to directivity (D) and antenna gain (G) by [3] :

$$\eta = G/D \tag{I.12}$$

I.4 Microstrip Patch Antenna

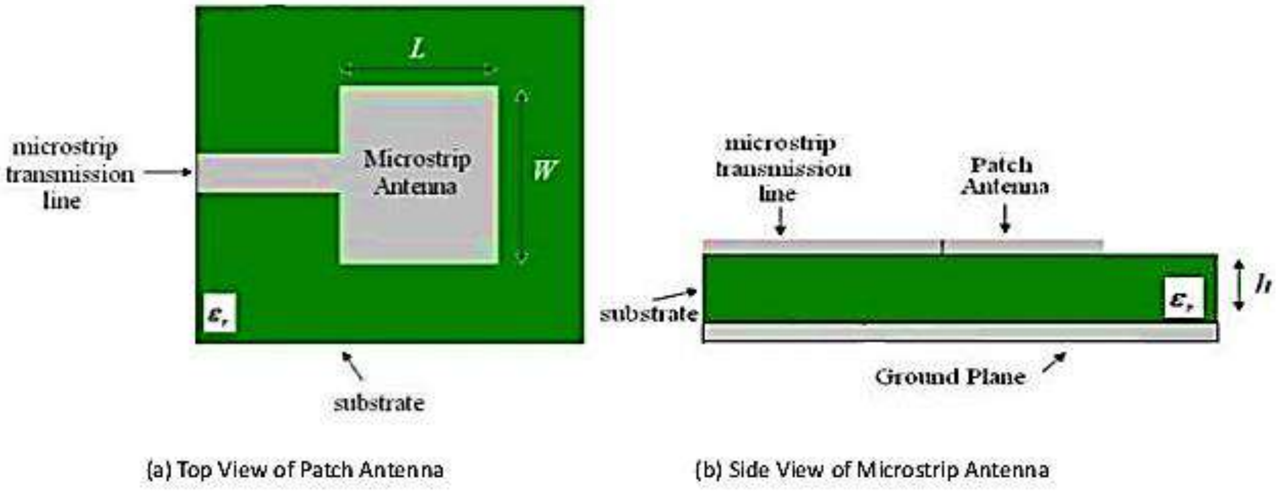
I.4.1 Introduction

Antenna design is an active field in communication for future development. Many types of antenna have been designed to suit with most devices. One of the types of antenna is the microstrip patch antenna (MPA). The idea of microstrip antenna was first presented in 1950s but it only got serious attention in the 1970s [6].

Microstrip antennas, in recent years, have been one of the most innovative topics in antenna theory and design. The basic idea of microstrip antenna came from utilizing printed circuit technology not only for the circuit component and transmission lines but also for the radiating elements of an electronic system. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated.

I.4.2 Definition

A microstrip patch antenna has a radiating patch on one side of a dielectric substrate having very small thickness and has an infinite ground plane on the other side as shown in Figure I. 4



(a) Top View of Patch Antenna

(b) Side View of Microstrip Antenna

Figure I. 4 : Structure of a microstrip patch antenna

The microstrip antenna shown in Figure I. 4, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length *L*, width *W*, and sitting on top of a substrate (some dielectric circuit board) of thickness *h* with permittivity ***εr.***

For simplified analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other regular shape as shown in Figure I. 5. Rectangular patches are the most utilized patch geometry.

To design a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\ \lambda o$, where λo is the free-space wavelength. Thickness of patch is selected such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$, and fringing fields between the patch edge and the ground plane is main parameter for radiation in microstrip patch antennas. A thick dielectric substrate is required for good antenna performance. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$ [7].

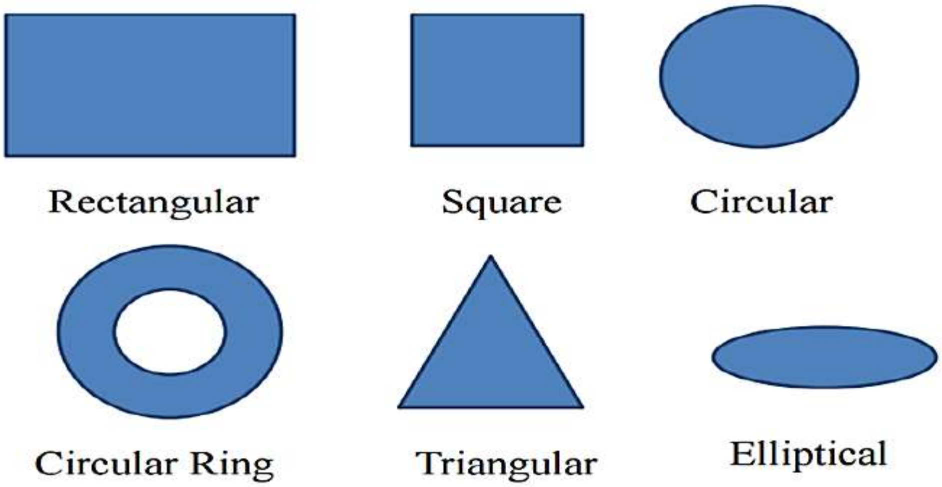


Figure I. 5 : Common shape of microstrip patch elements [7]

Substrates with lower dielectric constant are preferred for antenna design for better performance. The possible shapes for conducting patch are shown in Figure I. 5 , but rectangular and circular configurations are most commonly used configurations.

I.5 Advantages and Disadvantages of Patch Antennas

Microstrip patch antennas found attention of scientific community due to its inherent well-known advantages over other conventional antenna structures. Some of the advantages of patch antennas as discussed in [8] [9] [10] [11] are :

- Light weight and low volume and small surface.

- Low planar surface ,possible integration with circuit elements.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Generate with printed circuit technology.
- Can be designed for dual and multiband frequencies.
- Mechanically robust when mounted on rigid surfaces.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas as discussed in [7] [8] [9] [10], such as:

- Narrow bandwidth.
- Low efficiency Due to losses in the dielectric substrate.
- Low Gain.
- Extraneous radiation from feeds and junctions.
- Low power handling capacity.
- Surface wave excitation.
- Require quality substrate and good temperature tolerance.

I.6 Applications of Microstrip Patch Antenna

The usage of the MPAs is spreading widely in both commercial and non-commercial aspects due to the low cost of the substrate material and ease of fabrication, with the most applications being on mobile communication systems. MPAs are mostly applicable where small, lightweight, low profile, and low-cost conformal structures are required. As discussed in [5] [10] [12] [9], some of the applications include;

- Mobile and Satellite communications.
- Aircraft antennas.
- Missiles and telemetry.
- Missiles Guidance Systems.
- Environmental instrumentation and remote sensing.
- Biomedical Instruments.
- Radar systems.

- Satellite navigation receiver.
- Global positioning system.

I.7 Radiation mechanism of microstrip antenna

Radiation from microstrip antenna can be understood by considering the simple case of a rectangular microstrip patch spaced a small fraction of a wavelength above the ground plane as shown in the Figure I. 6 (Top view). Assuming no variation of the electric field along the width and the thickness of the microstrip structure, the electric field configuration of the radiator can be represented as shown in the Figure I. 6 (Side view). The field varies along the patch length, which is about half a wavelength. Radiation may be ascribed mostly to the fringing fields at the open circuited edge of the patch. The field at the end can be resolved into the normal and tangential component with respect to the ground plane. The normal components are out of phase because the patch line is λ/2 long. Therefore the far field produced by them cancel in the broadside direction. The tangential components, which are parallel to the ground plane, are in phase and the resulting fields combine to give maximum radiated field normal to the surface of the structure. Therefore the patch may be represented by two slots λ/2 apart excited in phase and radiating in half space above the ground plane [13].

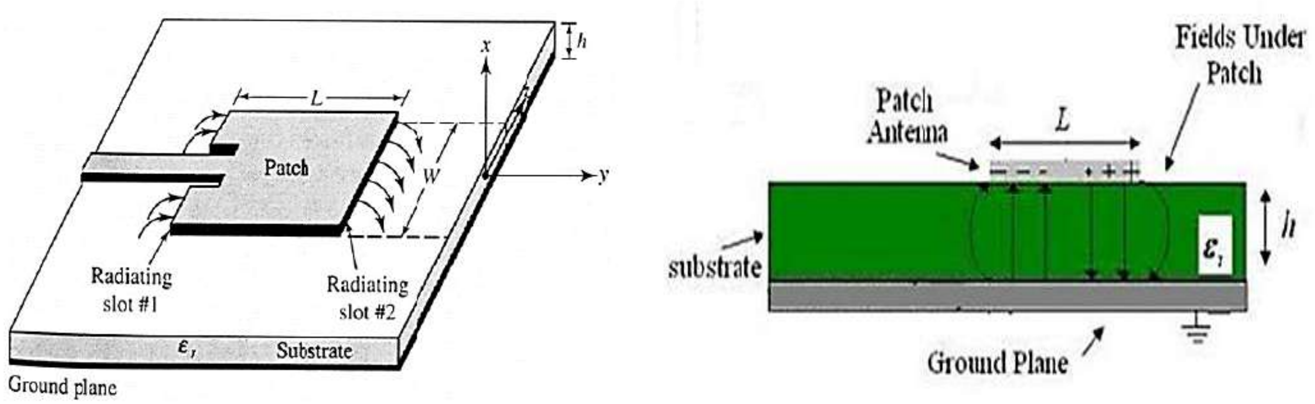


Figure I. 6: Radiation mechanism of microstrip patch antenna [12]

I.8 Feeding Techniques

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

I.8.1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure I. 7. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

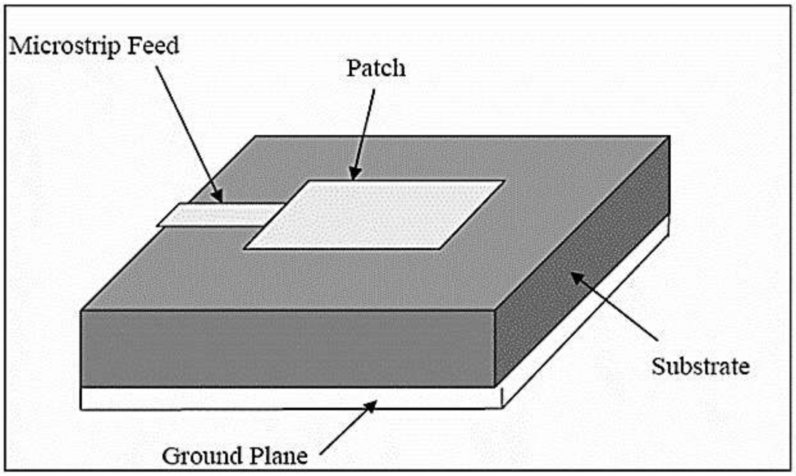


Figure I. 7: Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence, this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation [14].

I.8.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure I. 8, 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. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques discussed below, solve these problems[15].

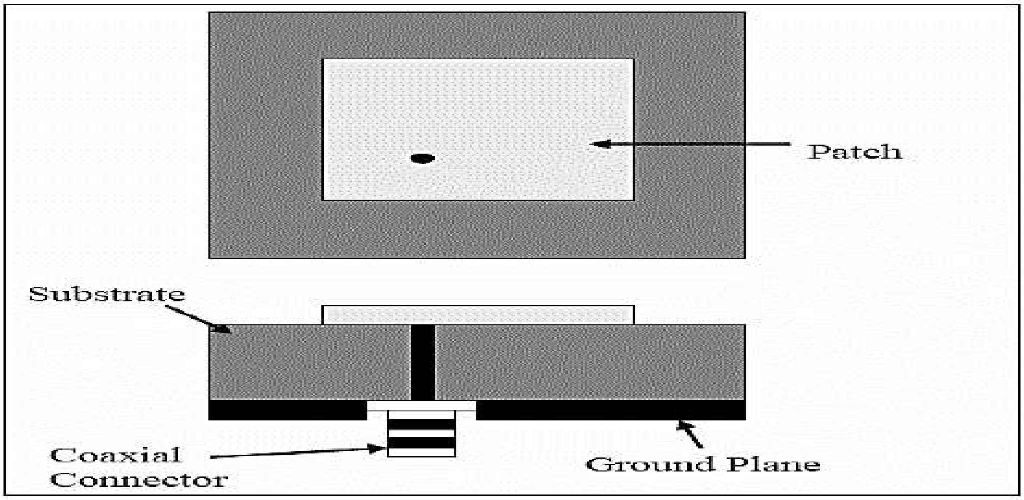


Figure I. 8 : Coaxial Feed

I.8.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure I. 9. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized [16].

Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

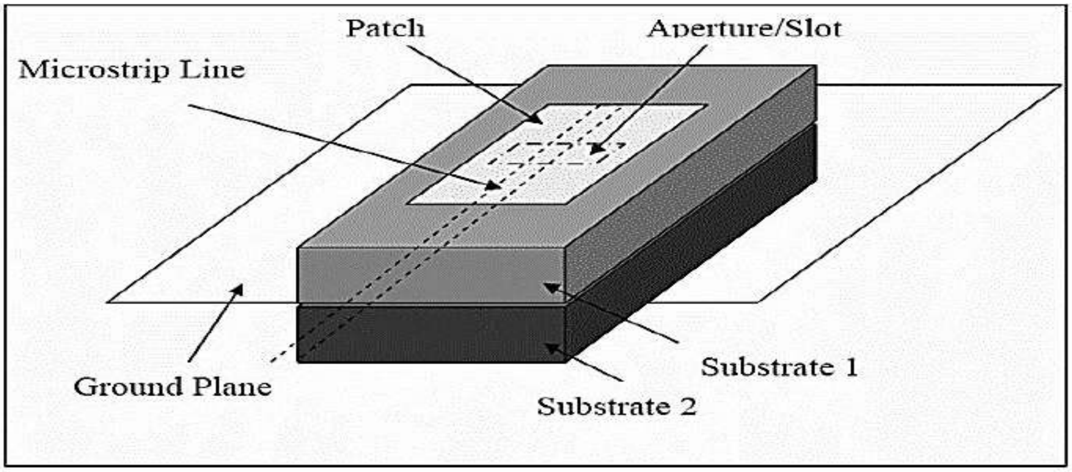


Figure I. 9 : Aperture Feed

I.8.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure I. 10, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers, which need proper alignment. Also, there is an increase in the overall thickness of the antenna [17].

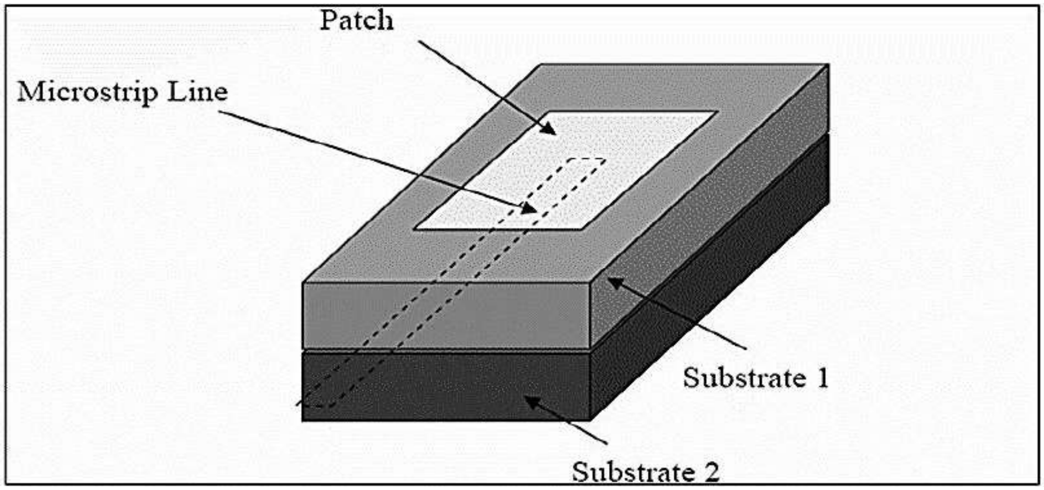


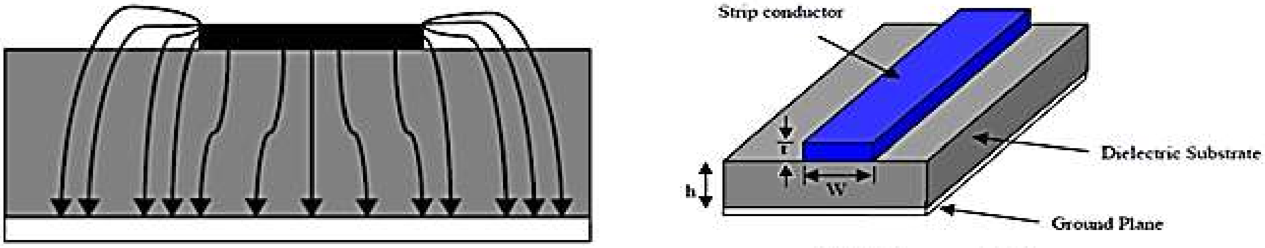
Figure I. 10 : Proximity Coupled Feed

I.9 Methods of analysis

The most popular methods for the analysis of microstrip patch antennas are the transmission line model, the cavity model and full wave. The transmission line model is the simplest of all and it gives good physical insight but it is less accurate and it lacks the versatility and difficult to model coupling. 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. However, they usually give less insight as compared to the two models mentioned above and are far more complex in nature [18].

I.9.1 Transmission Line Model

This model represents the microstrip antenna by two radiating slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non-homogeneous line of two dielectrics, typically substrate and air as shown in Figure I. 11 (b).



(a) Electric field lines **(b) Microstrip line**

Figure I. 11 : Microstrip line and its field lines

As seen from the Figure I. 11 (a), most of the electric field lines lies reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric-magnetic (TEM) mode of transmission, since phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode [18]. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spreads in the air [19].

The expression for ε_{reff} is given by [19]:

$$\boldsymbol{\varepsilon_{reff}} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\,(1+\frac{12h}{W})^{-0.5} \qquad \text{(I.13)}$$

Where ε_{reff} is effective dielectric constant, ε_r is dielectric constant of substrate, h is the height of dielectric substrate and W is width of the patch of antenna.

In the Figure I. 12 (a) shown below, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

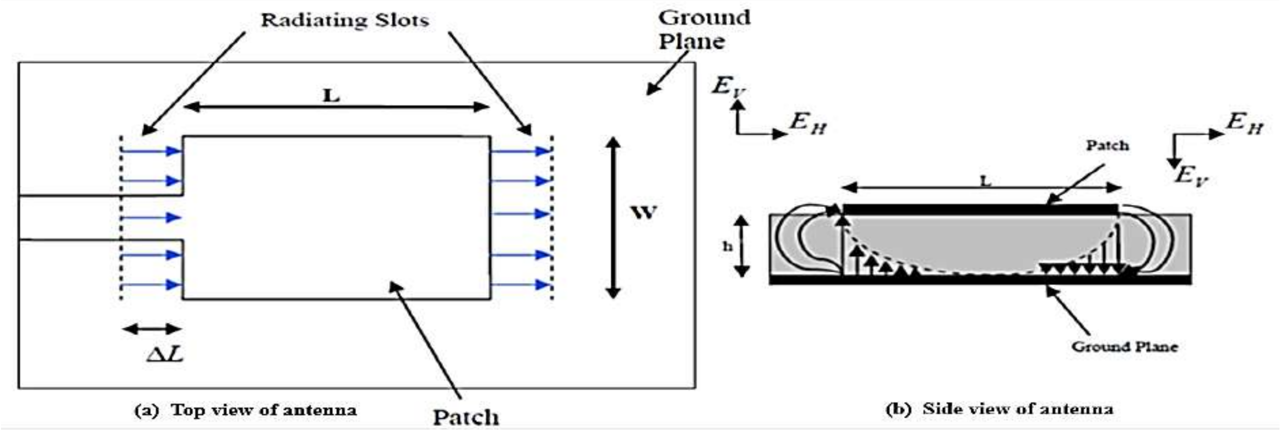


Figure I. 12 : Transmission line model for patch antenna

It is seen from Figure I. 12 (b) that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase and hence they cancel each other in the broadside direction. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad [20] as:

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{reff}+0.3)(w/h+0.264)}{(\varepsilon_{reff}-0.258)(w/h+0.813)}\right] \qquad \text{(I.14)}$$

The effective length of the patch L_{eff} now becomes:

$$L_{eff} = L + 2\Delta L \qquad \text{(I.15)}$$

For a given resonant frequency f_0, the effective length is [21] :

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \qquad \text{(I.16)}$$

Where ***c*** is the speed of light. For a rectangular Microstrip patch antenna, the resonance frequency for any TM mode is given by James and Hall [22] as:

$$f_0 = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}}\left[\left(\frac{m}{W}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{0.5} \tag{I.17}$$

Where m and n are modes along L and W respectively.
For efficient radiation, the width W is [23]:

$$W = \frac{c}{2f_0}\left(\frac{\varepsilon_r + 1}{2}\right)^{0.5} \tag{I.18}$$

I.9.2 Cavity Model

Cavity model gives the more accurate results than the transmission line model. In the cavity model, a patch antenna is represented as a dielectric loaded cavity. The cavity is formed via a substrate that is truncated on the top and bottom by two perfectly conducting electric boundaries, the patch and ground plane. The sidewalls are perfectly conducting magnetic boundaries that are determined by the dimension of the patch. Therefore, the electric field lines contained within the substrate (between the patch and the ground plane) are propagating perpendicular to the conducting walls, as required by Maxwells equations. In the case of patch antenna, when the microstrip patch is energized, a charge distribution is established on the upper and lower surfaces of the patch, as well as on the surface of the ground plane. The movement of these charges creates electric current densities on the top and bottom surfaces of the patch [24].

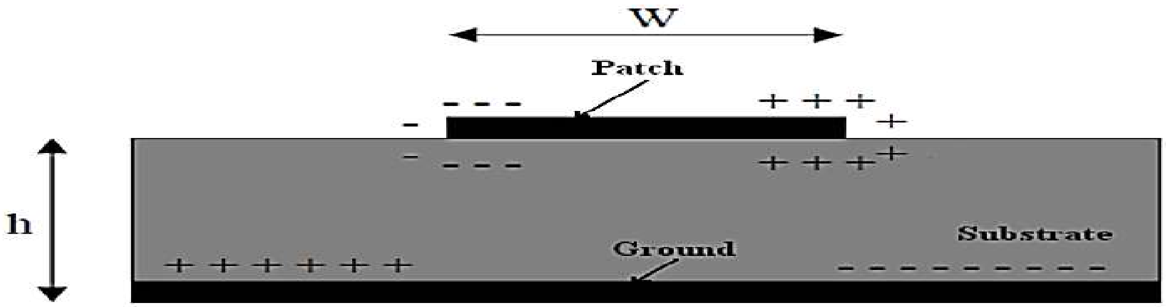


Figure I. 13 : Charge distribution and current density creation on the microstrip patch

I.9.3 Multiport Network Model

In the cavity model, the solution for the far field is difficult to evaluate. To overcome this problem MNM is used for analyzing the MSA. In this model, the multiple numbers of ports are used around the periphery of the patch to analyze MSA. The EM fields are modelled separately for both under and outside the patch. As the patch is supposed as two-dimensional planar networks, the Green's Function is used to obtain the multiport impedance matrix of the patch. Then the segmentation method is used to find the overall impedance matrix. From voltage distribution around the periphery, we can obtain the radiated fields from the patch [20]. The above three analytical methods are very simple but these methods are accurate only for the regular patch geometries instead of arbitrary patch geometries. The numerical methods are used for the complex geometries based on electric current distribution. These analytical methods are given as: {Method of moments (MoM), Finite element method (FEM), Spectral domain technique (SDT), and Finite difference time domain (FDTD)}.

I.9.4 Method of Moments

The MoM is the technique to solve volume integral equations in the frequency domain. In this method, the surface current and the volume polarization current are used to model the fields in microstrip patch and dielectric slab respectively. The fringing fields outside the physical boundary of the two-dimensional patch takes into account for obtaining solution that is more exact. For analyzing various MSA configurations MoM based IE3D software is commercially used [25].

I.9.5 Finite Element Method

FEM is a method in which we use variation form to solve the frequency domain boundary valued electromagnetic problems. For a highly accurate discretization of the solution domain FEM can be used with two or three-dimensional conical elements of different shapes. Unlike the MoM, this method is suitable for the volumetric configurations. Based on the structures to be analyzed, the region is first divided into number of finite volume elements. These finite elements can be well defined geometrical shapes like triangular, rectangular elements for planar configuration and tetrahedral and curved geometry for three dimensional configurations [26]. HFSS (High frequency structural simulator) is using FEM modeling for analyzing. [27].

I.9.6 Spectral Domain Technique

In this SDT technique, along the two orthogonal directions of the patch the two-dimensional Fourier transform is used along with boundary conditions. By using this technique the various parameters of the antenna can be evaluated [28]. The electric current distribution on the patch and the magnetic current distribution surrounding the substrate surface are evaluated by solving the matrix equation.

I.9.7 Finite Difference Time Domain Method

The FDTD technique is well suited for MSAs, it offers many advantages as an electromagnetic simulations, modeling and analysis tools. It can capable for arbitrary three-dimensional model geometry and predict the response of MSA over broad range of frequency [31]. For practical consideration of the FDTD the initial choice is the cell size. At highest frequency, the cell size must be small for the accurate results. FDTD is most suitable technique at the analysis of inhomogeneous and nonlinear media. However due to the discretization of entire solution domain its demand for system memory are high. The spatial discretizations along Cartesian coordinates are same. The E-cell edges are aligned with the boundary of the patch and H-fields are located at the center of each E-cell [29].

The above numerical techniques, which are based on the electric current distribution on the patch conductor and the ground plane, give results for any arbitrarily shaped antenna with good accuracy, but they are time consuming. These methods can be used to plot current distributions on patches but otherwise provide little of the physical insight required for antenna design.

CST uses FIT (Finite Integral Technique, a relative of FDTD) for its transient solver, FEM for its Frequency domain solver, MoM for its Integral equation solver [30] . FIT and FDTD are very similar. Whereas MOM code really solves the integral equations, FIT is actually a Finite difference method based on a small-scale interpretation of Maxwells equations (as opposed to a large-scale Integral equation approach). So if you go to the details of the solver, you will find the solutions of integral of E and H fields, is same as FDTD. Therefore CST microwave studio is using FDTD modeling for analyzing [27].

I.10 Conclusion

In this chapter, we briefly presented the concept of the antenna and its characteristics, and in particular, the concept of Microstrip Patch Antennas .We describe its shape and components and their radiation mechanism, advantages and disadvantages and its applications. After that we explained the different Feeding techniques and the most methods used for the analysis of microstrip patch antennas. We mentioned that the numerical techniques gives results for an arbitrarily shape antenna with better accuracy, but these techniques are time consuming.

In the next chapter we will explain some techniques to improve antenna bandwidth including technique DGS, that we will use in this work.

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ssssssssss Chapter II

Bandwidth Enhancement Techniques

II.1 Introduction

The rapid development of components and systems for future ultra-wideband (UWB) technology has significantly increased measurement efforts within the electromagnetic compatibility community. Therefore, frequency- and time-domain testing capability for UWB compliance is at the forefront of research and development in this area [1]. Many future systems will utilize handheld devices for such short-range and high bandwidth applications.

Ultra-wideband (UWB) antennas are one of the most important elements for UWB systems. With the release of the 3.1 - 10.6 GHz band, applications for short-range and high-bandwidth handheld devices are primary research areas in UWB systems [2]. Therefore, the realization of UWB antennas in printed-circuit technologies within relatively small substrate areas is of primary importance.

In this chapter we will provide a brief overview about ultra-wideband (UWB) technology, which is agreed in February 2002 by the Federal Communications Commission (FCC), for communication applications in the 3.1–10.6 GHz frequency band. The advantages, disadvantages and applications of UWB technology. After that we pointed to Microstrip UWB Antennas and the most important techniques to improve the antenna bandwidth (Coplanar Waveguide “CPW”, Defected Ground structures “DGS”)

II.2 General Overview of Ultra-Wideband Technology:

Consider the term "ultra wideband" (UWB) as a relatively new term to describe a technology, which had been known since the early 1960’s. The old definition was referring to "carrier-free", “baseband”, or "impulse" technology. The fundamental concept is to develop, transmit and receive an extremely short duration burst of radio frequency (RF) energy, like a short pulse [2]. The pulse typically has a duration of a few tens of picoseconds to a few nano-seconds.These pulses represent one to only a few cycles of an RF carrier wave; therefore, as for resultant waveforms, extremely broadband signals can be achieved [2].

The amount of power transmitted is a few milliwatts, which, when coupled with the spectral spread, produces very low spectral power densities. The Federal Communication Commission (FCC) specifies that between 3.1 and 10.6 GHz, the emission limits should be less than -41.3 dBm/MHz, or 75 nW/MHz. The total power between these limits is a mere 0.5 mW [2].

The FCC defines UWB technique is a radio transmission technology which occupies a relatively wide bandwidth, which exceed 500MHz as a minimum or it has at least 20% of the center frequency [3].

II.2.1 Advantages of UWB technology

UWB has a number of encouraging advantages that are the reasons why it presents a more eloquent solution to wireless broadband than other technologies. The unique characteristics are listed below [4] [5]:

- Since UWB has an ultra wide frequency bandwidth, it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances of 1 to 10 meters.
- UWB waveforms have large bandwidths due to their short time pulse duration, UWB pulses can provide extremely high data rate performance.
- UWB system based on impulse radio features low cost and low complexity which arise from the essentially baseband nature of the signal transmission.
- UWB systems operate at extremely low power transmission levels. By dividing the power of the signal across a huge frequency spectrum, the effect upon any frequency is below the acceptable noise floor, as illustrated in Figure II. 1.
- UWB provides high secure and high reliable communication solutions. Due to the low energy density, the UWB signal is noise-like, which makes unintended detection quite difficult.

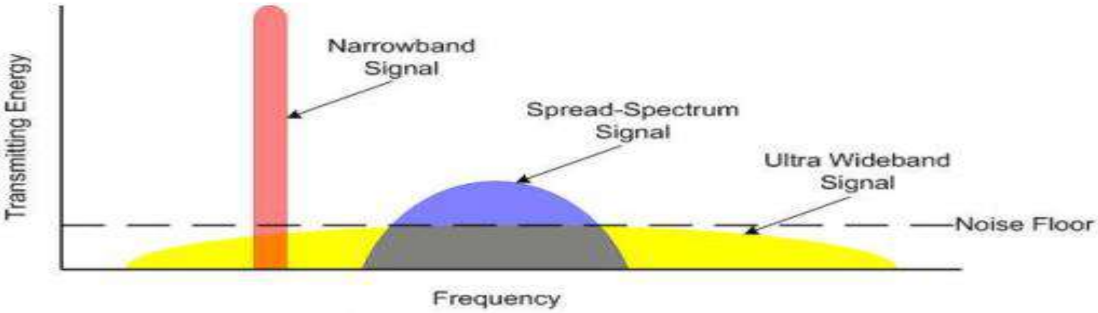

Figure II. 1 : Ultra wideband communications spread transmitting energy across a wide spectrum of frequency [1]

II.2.2 Disadvantages of UWB technology

UWB technology for communications is not all about advantages there are many disadvantages. These limitations, could be the results of some properties of an UWB signal like: low output power, short duration, …etc, or it is caused by the transmission medium: according to the widely used Friis transmission formula [6][7]:

$$P_r = P_t\, G_t\, G_r \left(\frac{c}{4\pi d f}\right)^2 \qquad \text{(II.1)}$$

Where: P_r: received power (watt), P_t: transmitted power (watt), G_t: transmission gain of emission antenna, Gr: receiving gain of receiving antenna , c: Velocity of light in free space , d: distance between transmission and receiving antennas (meters), f : the transmission frequency (Hz).

The weak and low-powered UWB pulses, throughout the transmission channel, can be subject of many phenomena, like: pulse-shape distortion and multi-access interferences. Because, according to the equation (II.3), received power *Pr* drastically changes with the wide range of frequencies covered by the UWB spectrum. These phenomena makes channel estimation like a very complicated operation and a high frequency synchronization is needed [7].

Figure II. 2 represents an UWB multiple-access channel. The addition of multiple-access interference (MAI) to the unavoidable channel noise and narrowband interference can significantly degrade the low-powered UWB pulses and make the detection process very difficult [6] [7].

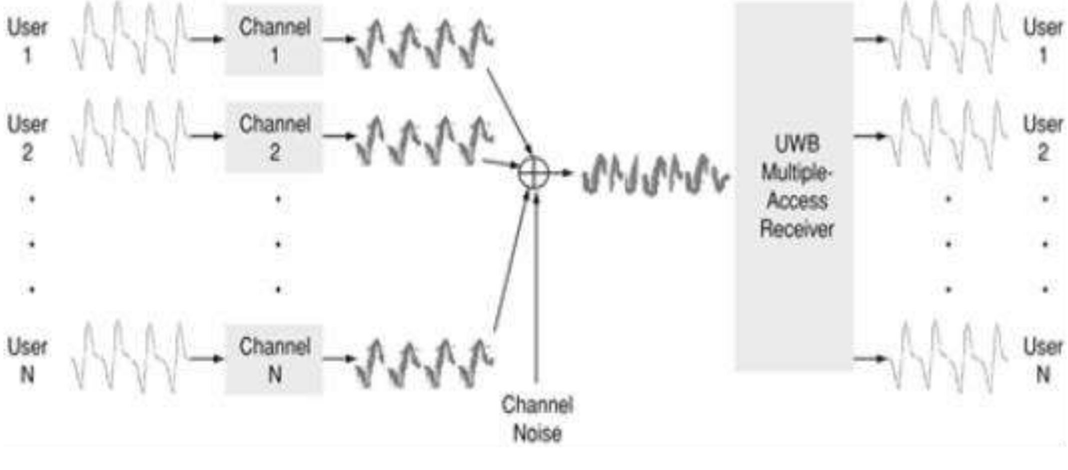

Figure II. 2: An UWB multiple-access channel [6]

II.2.3 UWB Applications

UWB offers some unique and distinctive properties that make it attractive for various applications [4][8]:

- UWB has the potential for very high data rates using very low power at very limited range, which will lead to the applications well suited for WPAN. The peripheral connectivity through cable less connections to applications like storage, I/O devices and wireless USB will improve the ease and value of using Personal Computers (PCs) and laptops. High data rate transmissions between computers and consumer electronics like digital cameras, video cameras, MP3 players, televisions, personal video recorders, automobiles and DVD players will provide new experience in home and personal entertainment.
- Sensors of all types also offer an opportunity for UWB to flourish. The key requirements for sensor networks include low cost, low power which can be well met by using UWB technology.
- Positioning and tracking is another unique property of UWB. Because of the high data rate characteristic in short range, UWB provides an excellent solution for indoor location with a much higher degree of accuracy than a GPS.
- UWB can also be applied to radar and imaging applications. It has been used in military applications to locate enemy objects behind walls and around corners in the battlefield. UWB radar could detect a person’s breath beneath rubble, or medical diagnostics where X-ray systems may be less desirable.

II.3 UWB Antenna

The UWB antenna is one of the most essential components for an UWB system. Many applications such as local network, imaging radar, and communication employ UWB technology. Therefore, developments of UWB antennas become important and complex for system and antenna designers. In conventional UWB systems, the antenna radiates in the preferred direction with high gain performance and operates over a broad impedance-matched bandwidth.

However, when applying UWB systems to portable devices, conventional UWB antennas are not suitable. This is mainly due to their bulky size and directional properties. Monopole and dipole antennas are good options for portable UWB devices. They have great features such as broadband impedance matching, small size and omni-directional radiation. However, from a system design point of view, fabrication may not be easy because those antennas require a perpendicular ground plane. Therefore, planar or printed-circuit board (PCB) antennas are much more suitable in terms of manufacturing complexities. Also, when designing UWB antennas, designers must make new considerations based on new UWB standards [2].

For that, different types of planar UWB antennas have been developed. UWB PCB antennas are usually compact in design and small in size. Also, planar antennas can be easily designed to have broad bandwidth and omni-directional radiation. Relatively small planar antennas will tend to generate low-dispersive waveforms. Most of the planar antennas developed so far are in microstrip or coplanar waveguide (CPW) technology [2].

II.3.1 Requirements for UWB Antenna

As is the case in conventional wireless communication systems, an antenna also plays a crucial role in UWB systems. However, there are more challenges in designing a UWB antenna than a narrow band one [9]:

First, what distinguishes a UWB antenna from other antennas is its ultra-wide frequency bandwidth. According to the FCC’s definition, a suitable UWB antenna should be able to yield an absolute bandwidth no less than 500MHz or a fractional bandwidth of at least 0.2 [4].

Secondly, the performance of a UWB antenna is required to be consistent over the entire operational band. Ideally, antenna radiation patterns, gains and impedance matching should be stable across the entire band. Sometimes, it is also demanded that the UWB antenna provides the band-rejected characteristic to coexist with other narrowband devices and services occupying the same operational band [10][11].

Thirdly, directional or Omni-directional radiation properties are needed depending on the practical application. Omni-directional patterns are normally desirable in mobile and hand-held systems. For radar systems and other directional systems where high gain is desired, directional radiation characteristics are preferred.

Fourthly, a suitable antenna needs to be small enough to be compatible to the UWB unit especially in mobile and portable devices. It is also highly desirable that the antenna feature low profile and compatibility for integration with printed circuit board (PCB)[4].

Lastly, a good design of UWB antenna should be optimal for the performance of overall system. For example, the antenna should be designed such that the overall device (antenna and RF front end) complies with the mandatory power emission mask given by the FCC or other regulatory bodies.

II.3.2 Microstrip UWB Antenna

Over the last few years the micro-strip patch antenna is a topic of intense investigation because this technology has many advantages and better future aspects. Some popular advantages of these types of antennas are light weight, smaller size and its lesser volume. These antennas can be easily molded to any desired structure and easily linked to any host surface because of their conformal structures of low profile planar configuration. Production of these antennas also so simple and easy, and the major advantage of MPA is low cost. The fabrication process of micro-strip patch antenna is suitable with MMIC (microwave monolithic integrated circuit) and OEIC (optoelectronic integrated circuit) technologies [12]. Over all these advantages of micro-strip patch antenna, some limitations are also mentioned like their efficiency and power is low, polarization purity is poor, scan performance is also poor, fake feed radiation and very narrow frequency bandwidth is also the limitation of micro-strip patch antenna [13].

Most of the proposed designs for patch antennas suffer from narrow bandwidths, and a number of techniques have been proposed and investigated to render them suitable for UWB communication applications by enhancing their bandwidth

II.4 Bandwidth Enhancement Techniques

We point out that some of the proposed UWB antennas cannot cover the entire impedance bandwidth designated by the FCC, which ranges from 3.1 GHz to 10.6 GHz. In order to enhance the impedance bandwidth of these antennas, several bandwidth enhancement techniques have been proposed.

These include introducing stair-case tapers on the radiating patch, or inserting slots either on the radiating patch or in the ground plane of these UWB antennas [3] , as shown in the examples presented in shown in Figure II. 3. By using these bandwidth enhancement techniques, the impedance bandwidth of the related antennas can be significantly improved.

Figure II. 3 : Bandwidth enhancement for UWB antenna designs [3]

Some alternate designs of microstrip-fed wide slot antennas can also achieve the wide impedance bandwidth designated by the FCC. However, these designs do not match the advantages of the CPW-fed techniques. And, consequently, a variety of wide slot antennas fed by CPW, which have radiating patches of different shapes, have been proposed and investigated for UWB communication applications [3].

II.4.1 Coplanar Waveguide (CPW)

Most of the PCB antennas are microstrip-type antenna. They will need a ground plane on the opposite side of the substrate for electromagnetic waves to travel along the feed line. However, by applying CPW feed technology, only one side of the substrate needs to be processed.

Both radiating elements and ground planes are on the same side of the substrate. Therefore, most of the electromagnetic wave travels in the slots on the surface of the substrate, and less energy is lost in the substrate. Thus, this provides a possibility for a wider impedance matching bandwidth. Also, the CPW feeding technique requires an easier fabrication process.

In addition, corresponding bandwidth enhancement methods have also been integrated into these CPW-fed wide slot UWB antennas to broaden their bandwidths [14] [15]. These configurations of CPW-fed UWB antennas are shown in Figure II. 4 and Figure II. 5.

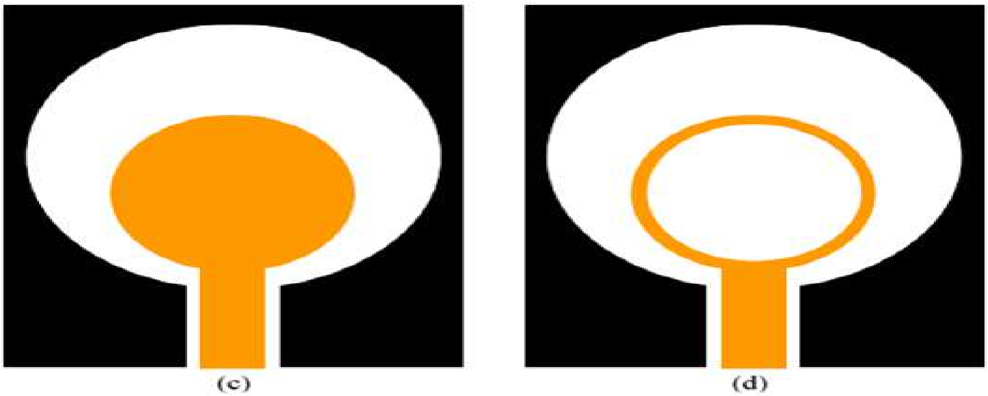

Figure II. 4 : CPW-fed wide slot UWB antennas. (yellow part is the feed line and radiating patch, while the black part is the ground plane) [3]

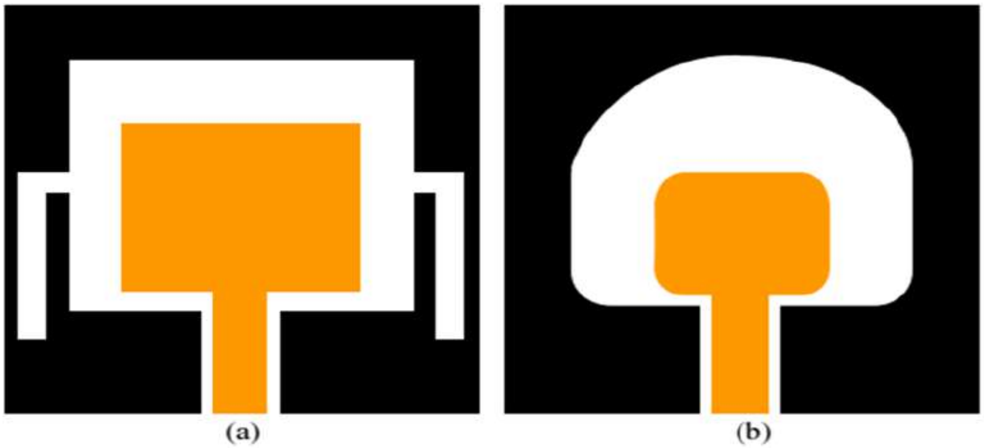

Figure II. 5: Bandwidth enhancement of CPW-fed wide slot UWB antennas (yellow part is the feed line and radiating patch, while the black part is the ground plane) [3].

II.4.2 Defected Ground structures (DGS)

Over the past few years, there has been a different new concept applied in order to distribute microwave circuits. The one of these techniques is defected ground structure or DGS, where the ground plane metal of a micro strips circuit is intentionally modified to enhance performances. This technique's name is simply means that a "defect" has been placed in the ground plane, what is generally regarded as an approximation of 'an infinite, current collector perfectly-conducting. Indeed, a ground plane at microwave frequencies is far removed from the idealized behavior of perfect ground. Although the additional perturbations of DGS alter the uniformity of the ground plane, they do not render it defective [16].

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance [17].

II.4.2.1 Different forms of DGS

Many various shape of DGS such as a concentric ring circle, spiral, dumbbells, elliptical and U- and V- slots. Each DGS form can be represented as a circuit consisting of inductance and capacitance, which can lead to a certain frequency band gap determined by the shape, dimension and position of the defect [18].

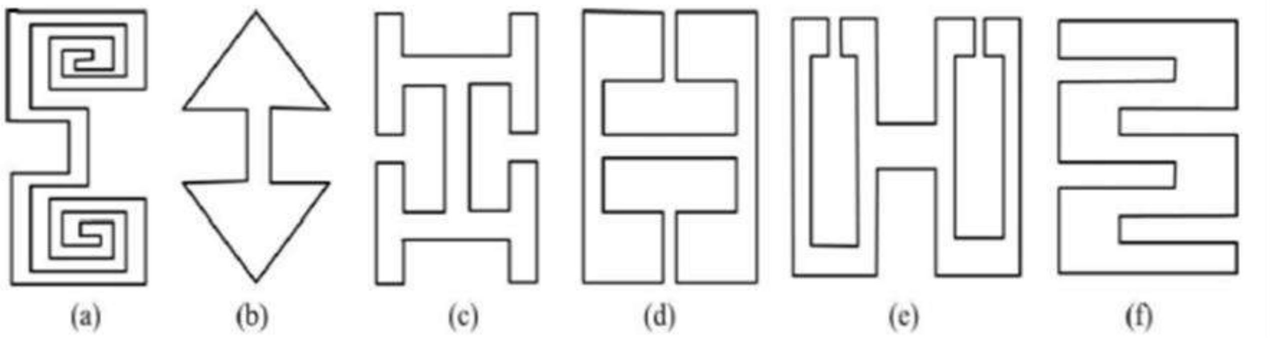

Figure II. 6 : Different types of DGS: (a) spiral head (b) arrow-head slot (c) "H" shape slot (d) square open-loop with a slot in middle section (e) open loop dumbbell (f) inter-digital DGS [18]

II.4.2.2 Advantages of DGS

The most important characteristics of DGS are [7]:

- Disturbs shielding fields on the ground plane.
- Increases effective permittivity.
- Capacitance and inductance of transmission line.
- One-pole LPF characteristics.

II.4.2.3 Disadvantages of DGS

The main disadvantage of the defected ground technique is that it radiates [16]. Although much of the incident energy at the resonant frequency is reflected back down the transmission line, there will be significant radiation.

Radiation within enclosed microwave circuits can be difficult to include in simulation. Boundary conditions are usually set to be absorbing (no reflections), which simplifies calculations, but excludes the structures around the circuit being examined. In some cases, the size of the enclosure will make the problem too large to achieve a solution in a reasonable time, and the details of the physical structure may take a very long to determine and enter into the software [16].

A lesser disadvantage is that DGS structures increase the area of the circuit. However, the additional area will usually be less than that of alternative solutions for achieving similarly improved performance [16].

II.4.2.1 Equivalent circuit of DGS

Today, a DGS can be designed by three types of equivalent circuits [7]:

a) LC and RLC equivalent circuits

b) π shaped equivalent circuit

c) Quasi-static equivalent circuit

II.5 Microstrip Antenna with Defected Ground structure for UWB Applications

As the important part of the UWB systems, the antenna has received increased attention due to its impedance bandwidth, simple structure and onmi-directional radiation pattern. Microstrip antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side of the substrate.

Defected Ground Structure is one of the methods which is used for this purpose. The defect in a ground is one of the unique techniques to reduce the antenna size. So to design the antenna with the defected ground structure, the antenna size is reduced for a particular frequency as compared to the antenna size without the defect in the ground. DGS is realized by introducing a shape defected on a ground plane thus will disturb the shielded current distribution depending on the shape and dimension of the defect [19].

When considering patch antenna design for ultra-wideband applications, defected ground structures present a novel technique for modifying the characteristics of the microwave device [20].

DGS has been used in the field of microstrip antennas for enhancing the bandwidth and gain of microstrip antenna and to suppress the higher mode harmonics, mutual coupling between adjacent element, and cross-polarization for improving the radiation characteristics of the microstrip antenna.

The notches in the ground plane control the impedance bandwidth and return loss levels by modifying the capacitance between the patch and the ground plane. Additionally, the size and placement of these notches are the most critical parameter since they determine the upper and lower UWB frequencies. This is because they help reduce the lower frequency and improve the upper frequency, hence contributing to bandwidth enhancement [21].

In this project, we will use the technique of defected ground structures to enhance the bandwidth of a microstrip patch antenna. That is what we will see in the next chapter.

II.6 Conclusion

In this chapter, we discussed an overview of UWB technology, its advantages, disadvantages and its applications. Then we explained the requirements for UWB Antenna. After that we mentioned the most important techniques used to enhance the bandwidth of antennas, including the technique of Coplanar Waveguide (CPW) Also, the technique of Defected Ground Structure "DGS" which we have referred to its advantages ,disadvantages, Different forms of DGS and its equivalent circuit . In the last, we explained the importance of using DGS technique with microstrip antenna to improve its bandwidth and to use Microstrip Antennas in the UWB applications, and that will be applied in the next chapter.

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ssssssssssss Chapter III

Results and Discussions

III.1 Introduction

In this chapter, a circular microstrip patch antenna with a wide bandwidth is proposed by using defected ground structure (DGS). This antenna is designed and simulated by using the simulator CST MICROWAVE STUDIO (CST MWS 2017).

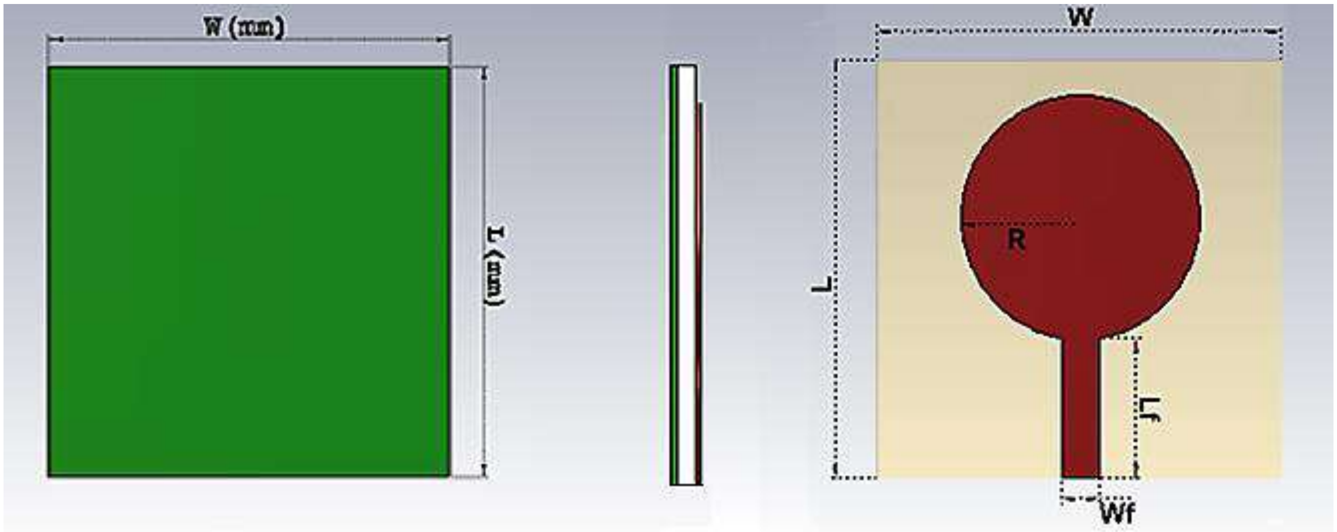
The aim of this chapter is to design an antenna with large bandwidth that has a high gain, small size and a good efficiency.

The design plan was done in two Steps. In first step, a conventional antenna (circular patch antenna with ground plane below the substrate) was designed. Then in second step, defected ground structure (DGS) is used by inserting several slots on the ground plane to improve the bandwidth of this antenna.

III.2 Simulation results

III.2.1 Design Antenna Geometry

Figure III.1 below shows the structure of the simulated conventional patch antenna.



(a) Back view **(b)side view** **(c)front view**

Figure III. 1 : conventional circular microstrip patch antenna.

The antenna shown in Figure III.1 is fabricated with a Rogers RO4003C substrate of size W=35 mm by L=35 mm and a thickness of 1.524 mm. The relative dielectric constant of the substrate is ε_r= 3.38. On the top side of the substrate, there is a circular patch with Radius of R=10.5 mm, and fed by a 50 Ohms microstrip feed line with dimensions Wf =3.48 mm by Lf =7.15 mm. On the bottom side of the substrate, there is a ground plane with the same sizes of substrate.

The conventional circular microstrip patch antenna is designed using the above parameters, and simulated with CST STUDIO SUIT software. The simulated graphical results such as return loss, Voltage Standing Wave Ratio (VSWR), gain and directivity for the designed model are given as follow.

III.2.1.1 Coefficient of reflection (S_{11})

Figure III. 2 shows the simulated return losses (The Reflection Coefficient S_{11}) of the conventional antenna.

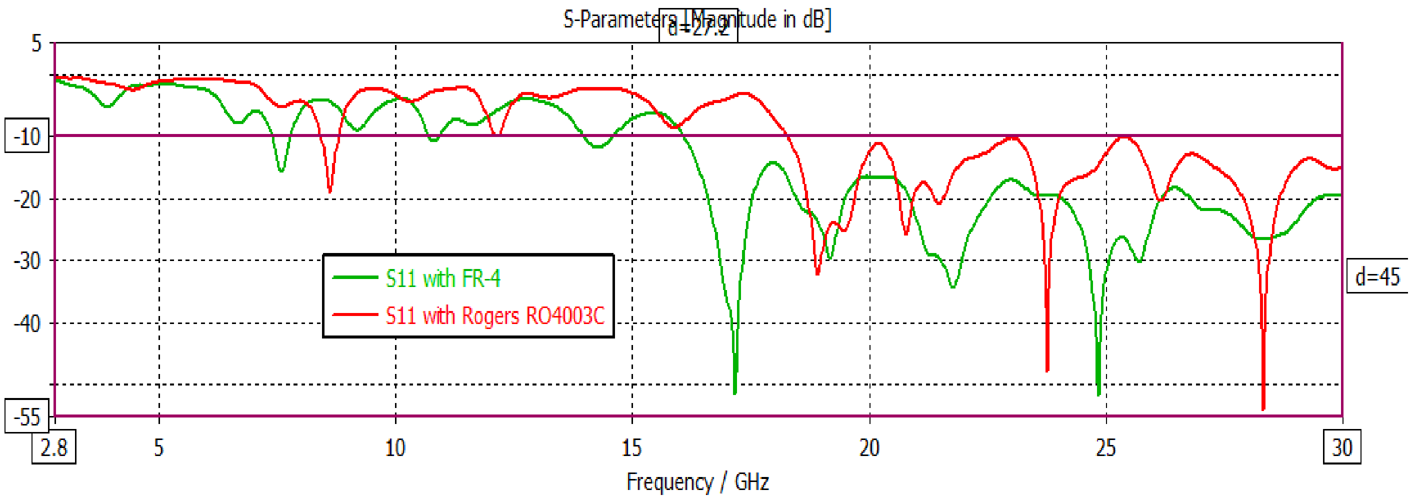


Figure III. 2 : reflection coefficient (S11, dB) versus frequency (GHz) for conventional antenna

The red graph obtained using the Rogers RO4003C substrate, From the graph above, we can observe that the most of the return losses greater than -10 dB in the UWB frequencies, so it is not suitable for UWB applications.

To enhance the bandwidth of the conventional antenna we changed its substrate material to FR-4 with a relative dielectric constant ε_r= 4.3, we also had to change the feed line width to Wf = 3.05mm

As shown with the green graph, we note an improvement in the bandwidth of the conventional antenna when we use the FR-4 substrate, comparing to the Rogers RO4003C substrate. So we will choose the FR-4 substrate for this work and we will apply the DGS technique to enhance the antenna bandwidth.

III.2.1.2 Voltage Standing Wave Ratio (VSWR)

Figure III. 3 show the curves of the standing wave ratio as a function of frequency.

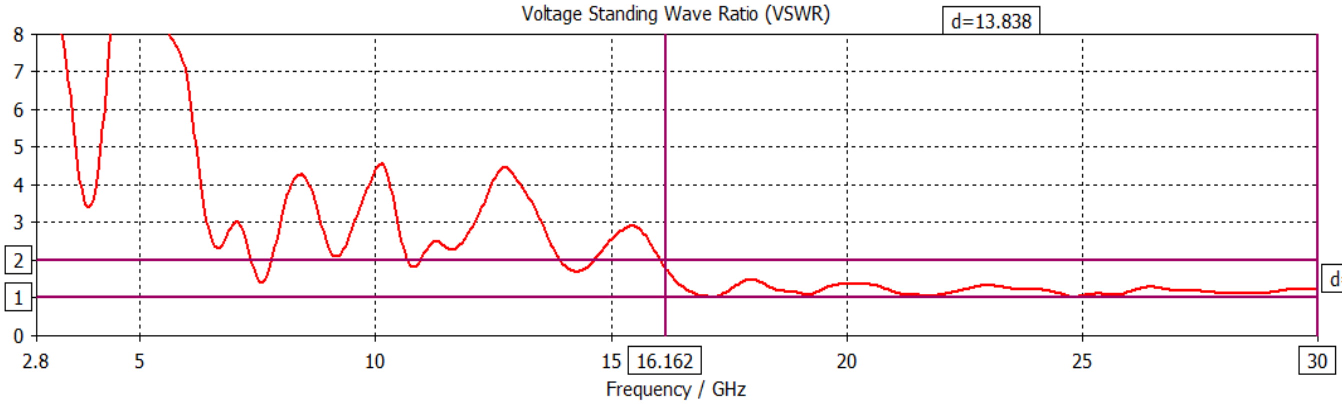


Figure III. 3 : The frequency (GHz) versus VSWR figure for conventional antenna

VSWR values are not acceptable and not adapted in the UWB frequencies, because they are over 2 in this band. But VSWR is acceptable for SWB frequencies (VSWR<2), also for efficient performance, the range of VSWR must fall under the values from 1 to 2.

III.2.1.3 Gain and Directivity

Figure III. 4 shows the simulated variation of gain and directivity versus frequency of the conventional antenna.

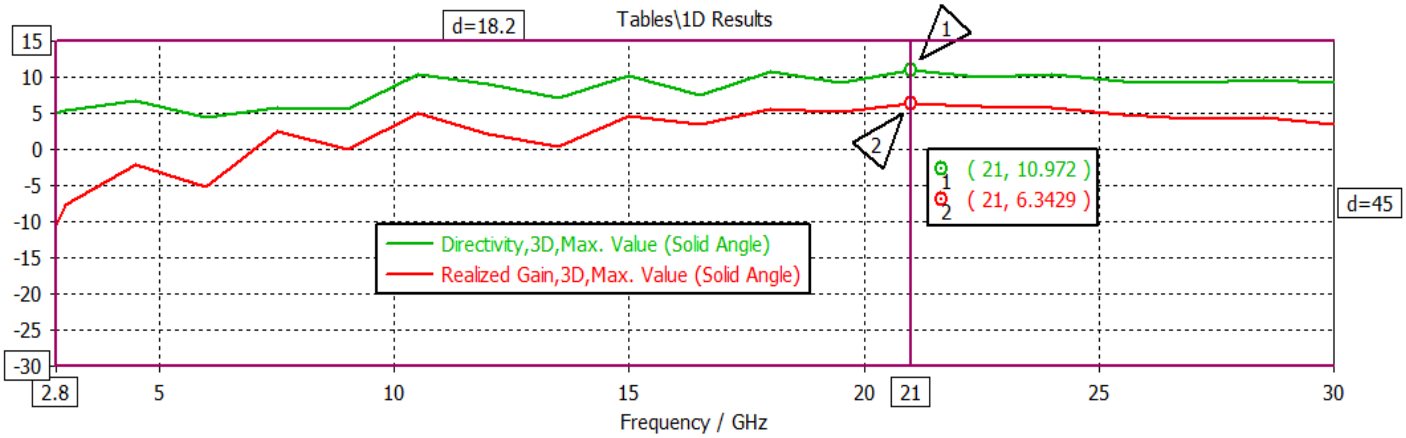


Figure III. 4 : Gain (dB) and Directivity (dB) versus frequency (GHz) for conventional antenna

The gain varies between -10.61 and 6.34 dB for frequency range from 2.8 to 30 GHz, with a maximum gain of 6.34 dB at f =21 GHz, while directivity varies between 4.35 and 10.97 dB at the same frequency range of gain; with maximum value of directivity 10.97 dB at f=21 GHz.

III.2.1.4 Efficiency

The Antenna Efficiency is calculated by the equation bellow:

$$\eta\ (\%) = 10^{\left(\frac{(G-D)}{10}\right)} * 100 \tag{III.1}$$

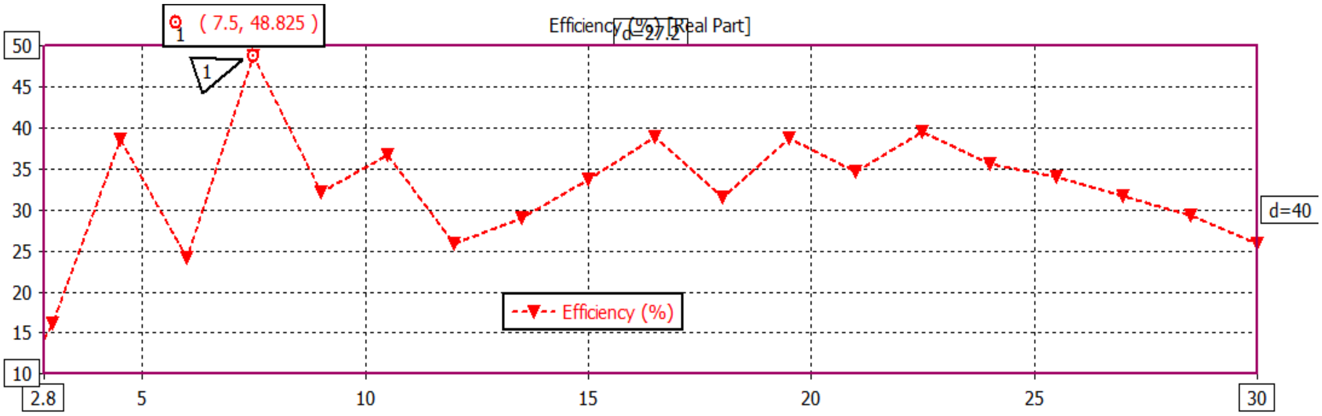


Figure III. 5 : Efficiency (%) versus frequency (GHz) figure for conventional antenna

Where: G is Gain (dB), D is Directivity (dB), $\eta\ is\ Efficieny$ (%)

Figure III. 5 shows the variation of efficiency (%) versus the frequency of the conventional antenna. The antenna efficiency varies between 14.24% and 48.82% for the frequencies 2.8 to 30 GHz, with a maximum of efficiency 48.82% at f =7.5 GHz, which is low efficiency.

Through the obtained simulation results we conclude that:

- The bandwidth is very narrow in UWB frequency range.
- The gain is very bad in bandwidth for low frequencies.
- The efficiency is weak.

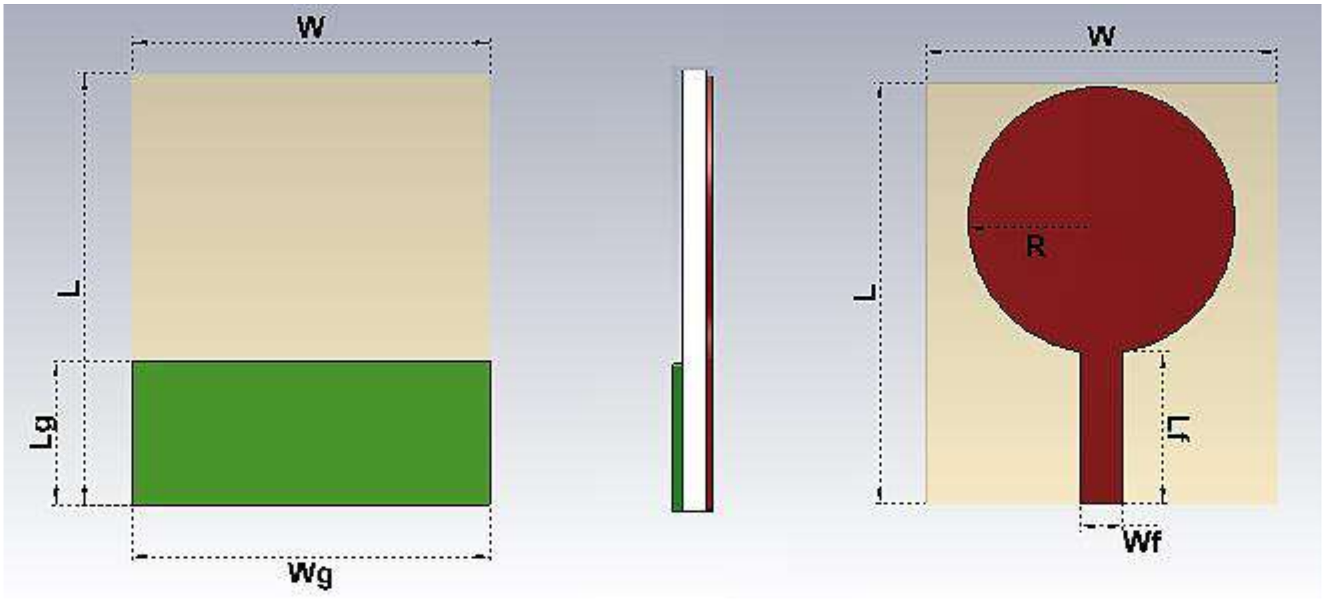
So in the next point, we will try to eliminate these disadvantages, and improve the characteristics of this antenna especially the bandwidth.

III.2.2 Antenna with Defected Ground Structure (DGS)

As mentioned in the second chapter, there is two methods to improve the bandwidth of a microstrip patch antenna: the DGS and the CPW technique, our aim is to employ DGS technique, the procedure for applying DGS on the proposed antenna has gone through 3 steps. In the first step, we reduced the dimensions of the substrate, the ground plan and the circular patch .In the second step, a semi-circular shape was removed from the upper middle part of the ground plane. In the last step, two quarters of a circle were removed from the two upper edges of the ground plane.

III.2.2.1 First Step

The first step before applying DGS is to design an antenna with partial ground. The antenna is fabricated with FR-4 substrate, this monopole antenna demotions were significantly reduced comparing to the conventional antenna, the new size is 25x30 mm^2 with thickness of 1.6 mm. The relative dielectric constant of the substrate is ε_r= 4.3, on the top side of the substrate, there is a circular patch with Radius of R= 9.5 mm and a microstrip 50 Ohms feed line with dimensions Wf=3.05 mm by Lf=10.82 mm. On the bottom side of the substrate, a partial ground plane is printed with size of 10*25 mm^2



(a) bottom view **(b) Side view** **(c) top view**

Figure III. 6 : Design of the monopole antenna

III.2.2.1.1 Coefficient of reflection (S11)

Figure III. 7 shows the simulated return losses (S parameter) of the monopole antenna.

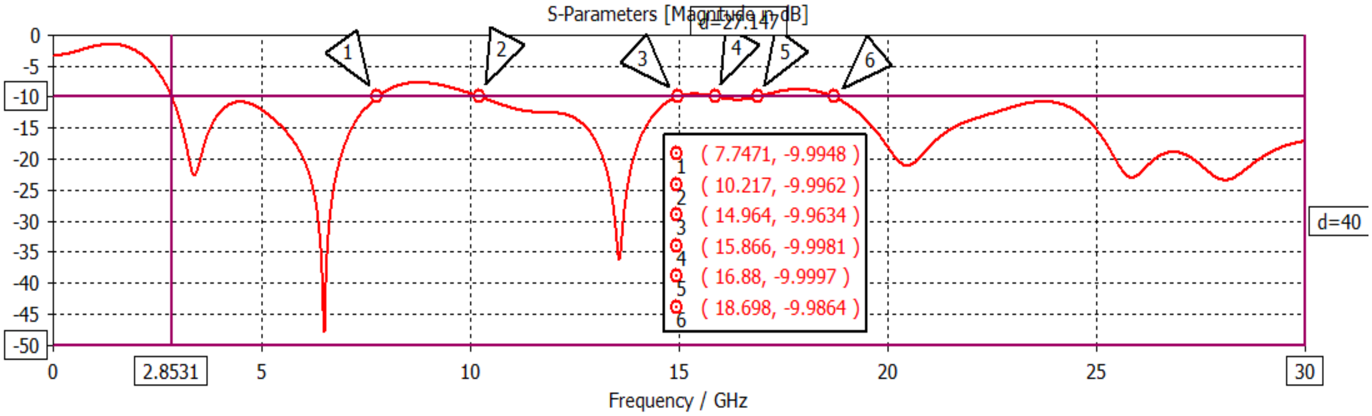
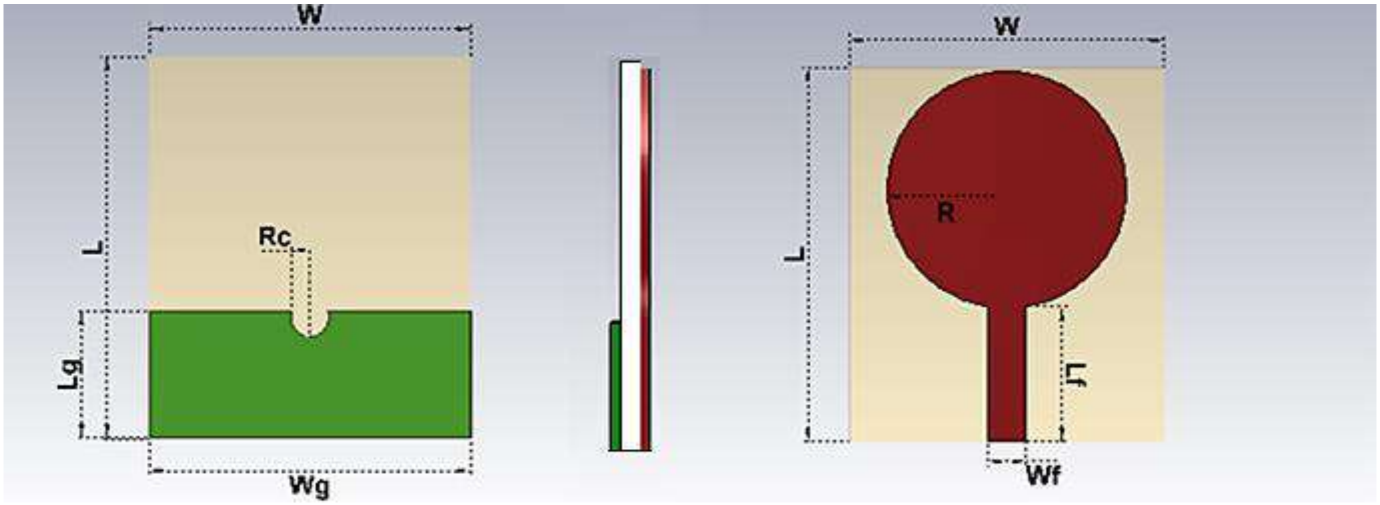


Figure III. 7: reflection coefficient (S11, dB) versus frequency (GHz) of monopole antenna

We observe an improvement in the bandwidth from 2.85 GHz to 30 GHz .But there is some exceptions in certain frequency ranges with reflection coefficient over -10, To resolve this mismatching, and reduce the return loss in these frequency bands, some changes will be added on the ground plane as will be explained through the next steps.

III.2.2.2 Second Step

In the second step, a semi-circular shape with a radius Rc has been etched from the upper middle of the ground plane, as shown below**.**



(a)Bottom view **(b) Side view** **(c) Top view**

Figure III. 8 : geometry of the monopole antenna with semicircular DGS

III.2.2.2.1 Coefficient of reflection (S_{11})

Figure III. 9 shows the effect of the variation in radius Rc on the return losses thus on the bandwidth of antenna with semicircular slot on middle upper of the ground.

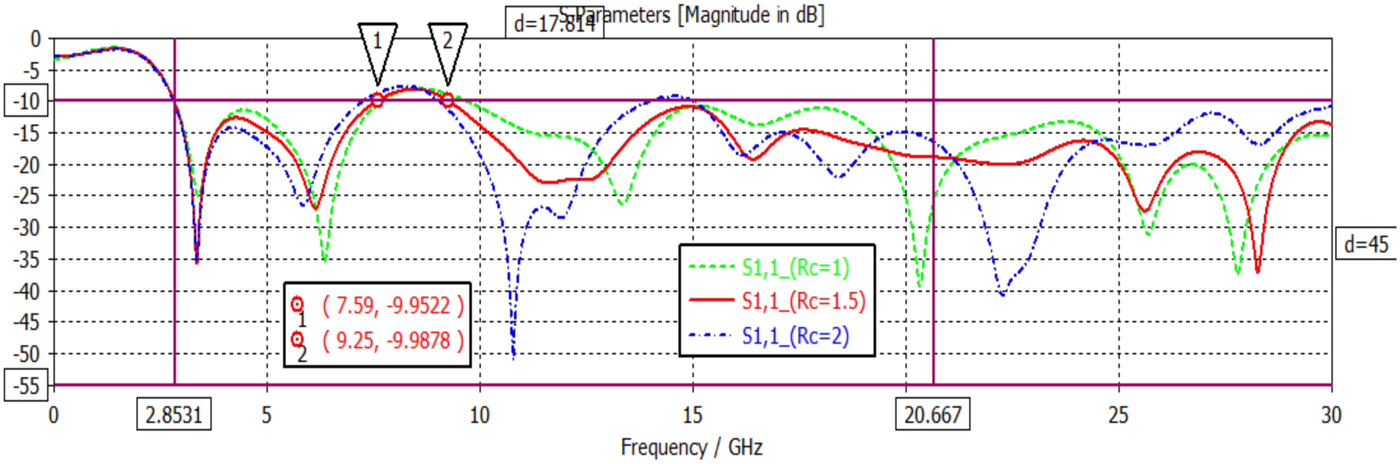


Figure III. 9 : the effect of the radius Re variation on the both return losses and bandwidth of the monopole antenna with semicircular DGS

Three values of radius Rc (1mm, 1.5mm, and 2mm) and we chose the value Rc=1.5mm because it gives the lowest reflection coefficient . We observe after etching a semi-circular shape from the ground plane, that the frequency bands marked (3 to 4 and 5 to 6) in the previous step was reduced. But there is still a frequency range with return losses greater than -10 dB that we have to reduce, as shown by markers (1 to 2) in Figure III. 9.

III.2.2.3 Third Step

In the last step, two quarters of a circle, with a radius Re has been etched from the upper edges of the ground plane, as shown in Figure III.

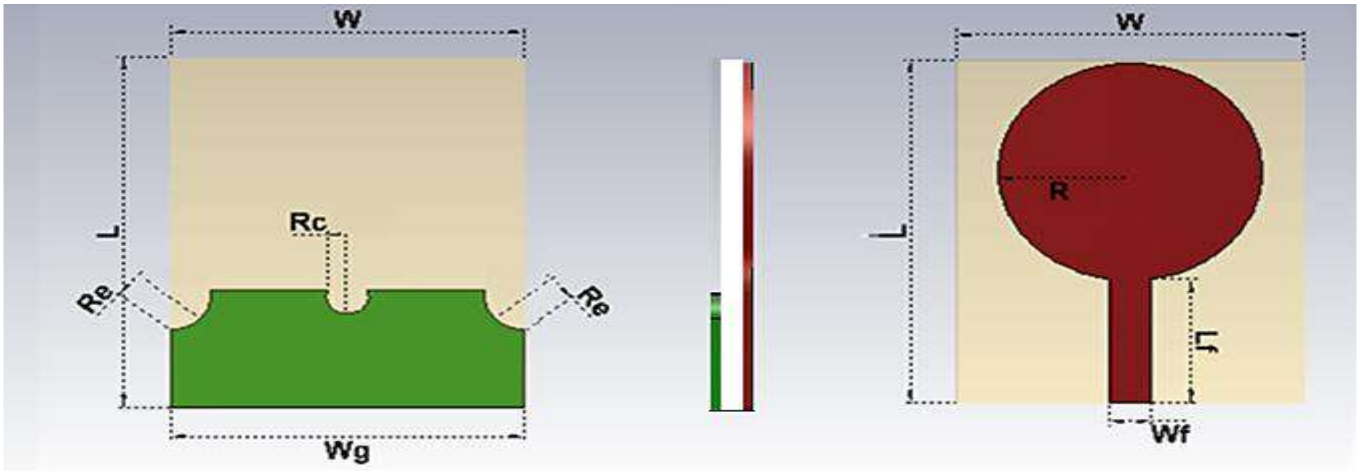


Figure III. 10 : Design of the final proposed antenna with DGS in last step.

III.2.2.3.1 Coefficient of reflection (S_{11})

The simulated return losses (S parameter) in Figure III. 11, shows the effect of variation in the radius Re on the bandwidth of the proposed antenna.

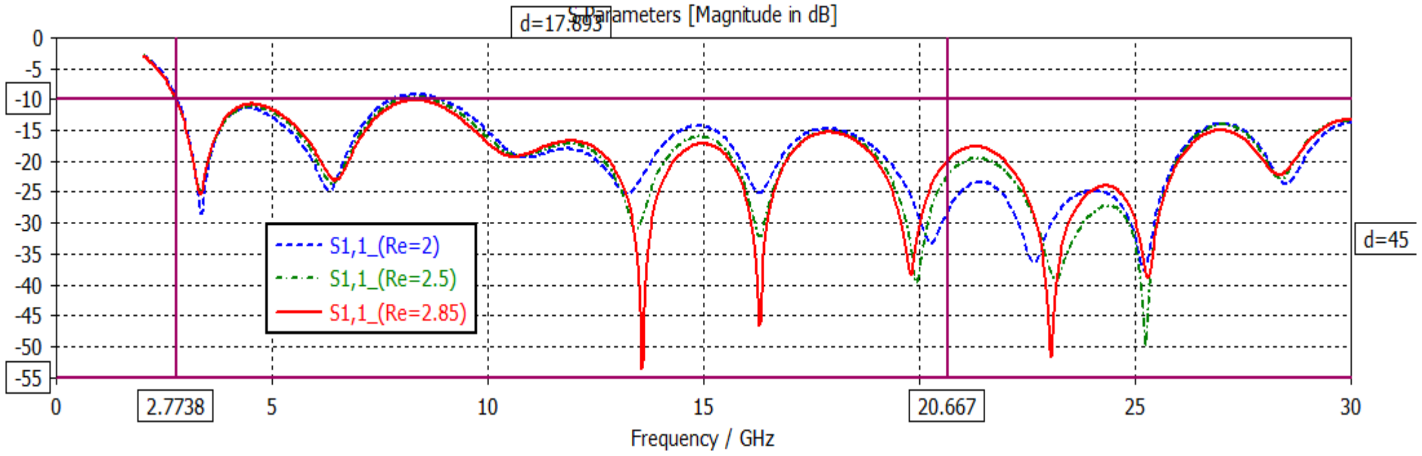


Figure III. 11 : the effect of radius Re variation on both the return losses and bandwidth of final proposed antenna

After simulating three values (2mm, 2.5mm, and 2.85mm) of radius Re we chose the value (2.85mm), as it gives the best return losses which is lower than -10 dB in the entire frequency range. Also we can notice that after the last changes in the ground plane, we got a bandwidth that covers the entire frequency range from f_L=2.77 GHz to f_H=30 GHz.

The antenna bandwidth where the return loss is lower than -10dB occupies the band of frequency from 3.1GHz to 10.6GHz, so it works well in UWB applications, and also in SWB applications.

In order to have a return loss far from -10 db (lower than -10 db), we have modified the antenna by etching the top of the radiating patch as indicated in Figure III. 12

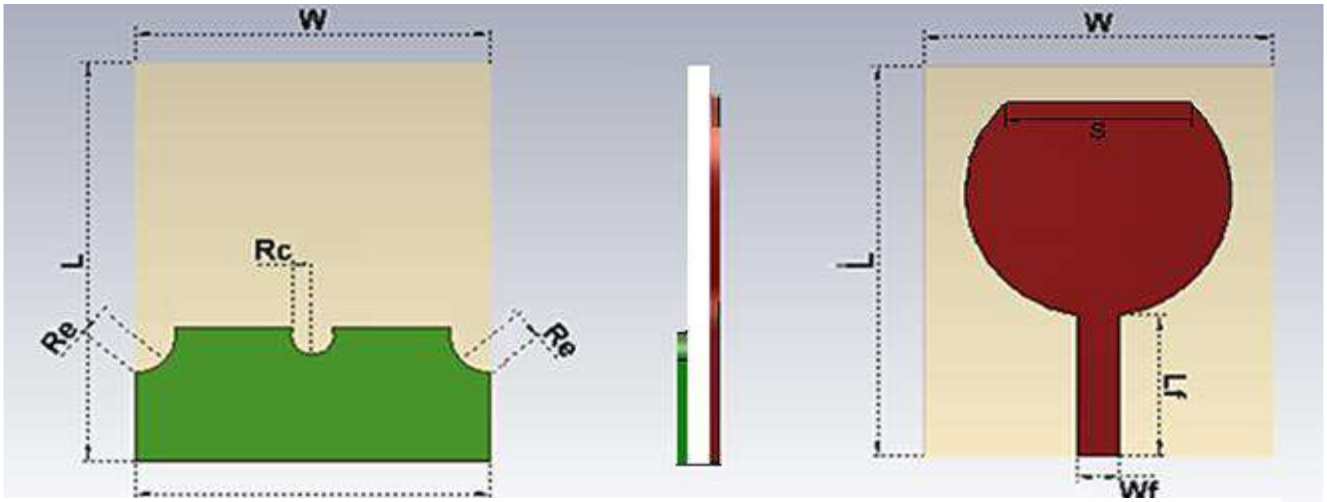


Figure III. 12 : The Final design of the final proposed antenna plus modified the patch

The simulated return loss of the antenna with and without modification in the patch are shown in figure bellow.

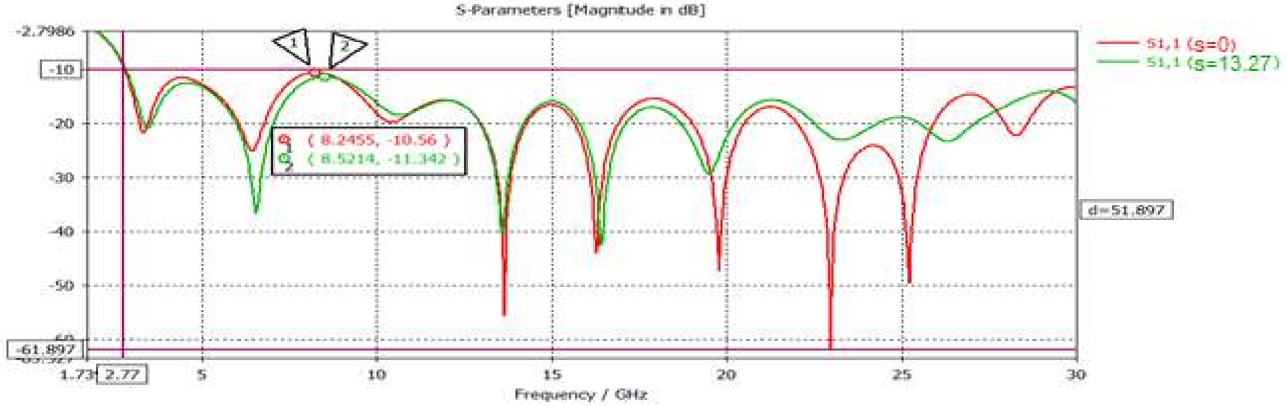


Figure III. 13 : simulated return loss of the final proposed antenna plus modified the patch

Figure III. 13 shows that etching the top of the conducting patch has slightly lowered the return loss, but in other side has shifted the reflection coefficient to the right which is not helping for increasing the antenna bandwidth. Since our thesis project is limited in the improvement of the bandwidth of a microstrip antenna using the DGS structure, we will maintain the conducting patch on its circular form and only apply modification to the ground plane.

So for the next simulation results we will use the best chosen values (Rc=1.5mm for a semicircular slot and Re=2.85mm for the two quarters of a circle slot) and maintain the same parameters of the antenna in third step.

III.2.2.3.2 Voltage Standing Wave Ratio (VSWR)

Figure III. 14 shows the simulated Voltage Standing Wave Ratio (VSWR) of the proposed antenna with DGS.

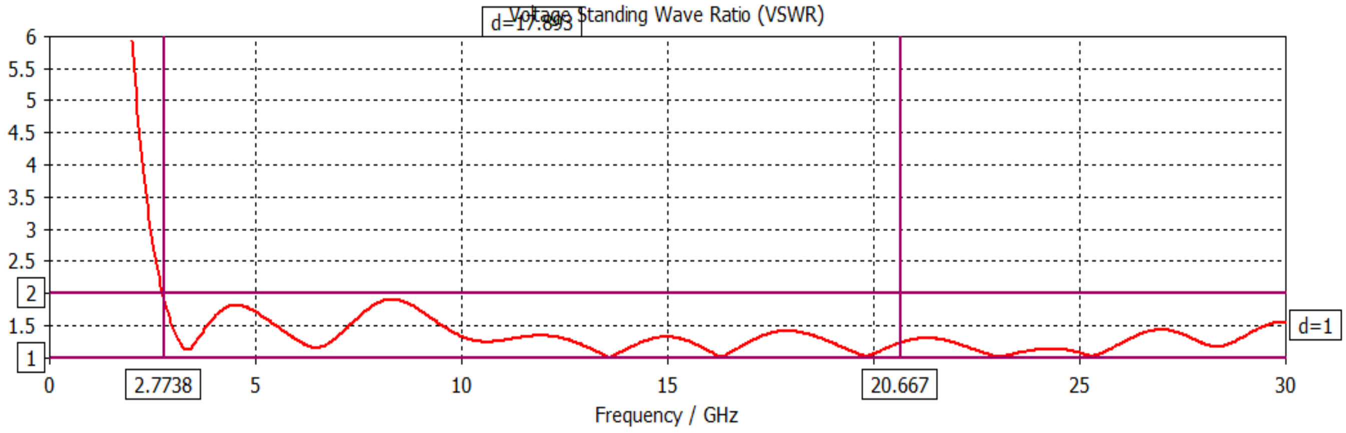


Figure III. 14 : The frequency (GHz) versus VSWR of the proposed antenna with DGS

The results are acceptable and more adapted in the band of 2.77GHz to 30 GHz .Because the VSWR is less than 2 on this band. There is improvement in VSWR compared to previous VSWR of antenna without DGS.

III.2.2.3.3 Gain and Directivity

Figure III. 15 shows the simulated variation of gain and directivity of the proposed antenna with DGS versus the frequency,

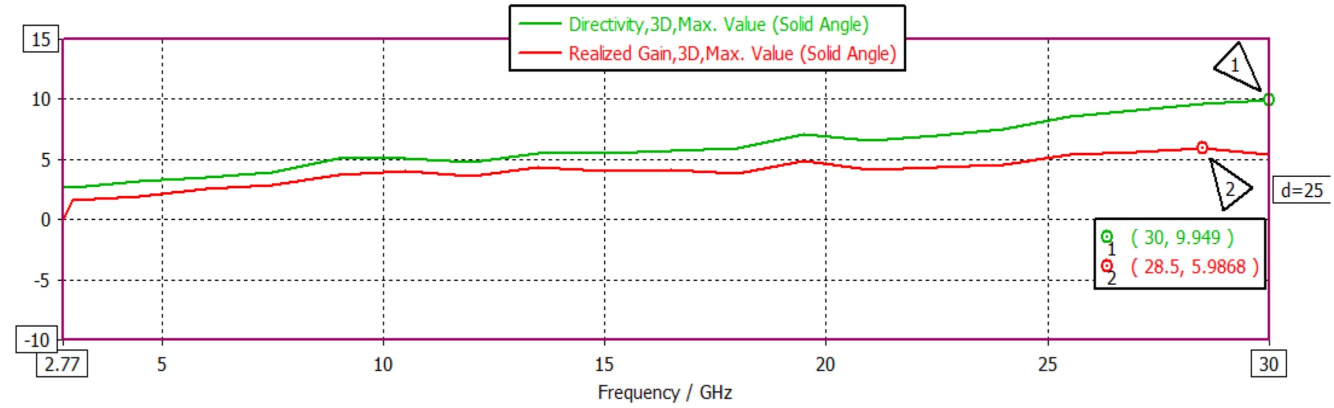


Figure III. 15 : Gain (dB) and Directivity (dB) versus frequency (GHz) of proposed antenna with DGS

The gain and directivity are proportional with frequency, except directivity values are increasing rapidly than gain values, which will decrease the efficiency versus frequency.

At 28.5 GHz, the both maximum values of gain and directivity are obtained, we have recorded 5.98 and 9.94 respectively.

III.2.2.3.4 Efficiency

Figure III. 16 shows the variation of efficiency (%) versus frequency of the proposed antenna with DGS.

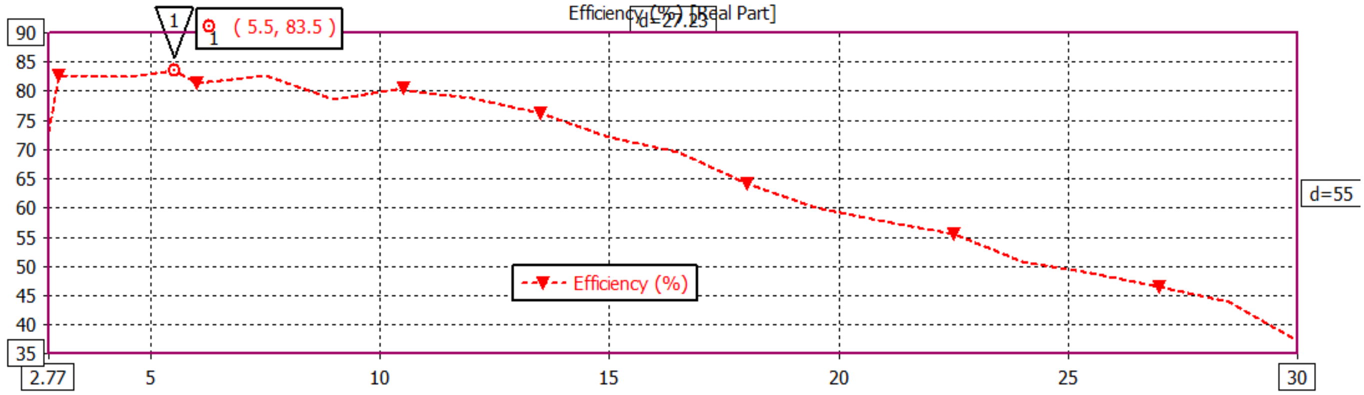


Figure III. 16 : Efficiency (%) versus frequency (GHz) plot of proposed antenna with DGS

The efficiency of this antenna is inversely proportional with frequency. The antenna has a good efficiency for frequencies less than 12 GHz (η (%)> 80%), an acceptable efficiency for frequencies between 12 GHz to 20GHz (60 % > η (%)> 80%), but is shows a weak efficiency for frequencies over 20 GHz (efficiency < 60%).

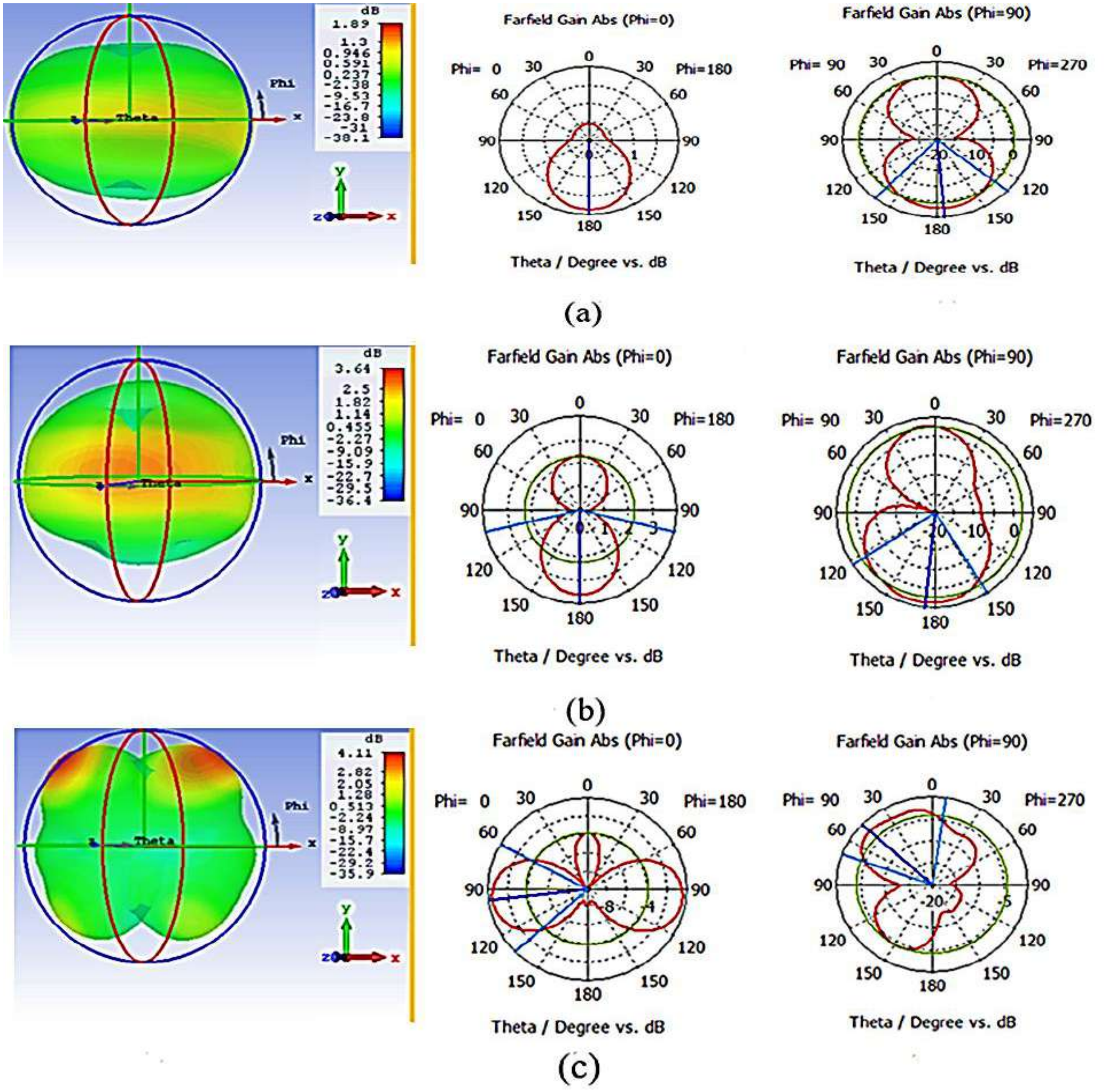
Table III. 1 : The variation of efficiency (%) versus the frequency (GHz) of the final proposed antenna

The proposed antenna with DGS	
Frequency (GHz)	Efficiency (%)
3.1	82.73
5.5	83.5
7.5	82.77
10.5	80.42
15	72.19
20	60.31

From the table above we can conclude that the efficiency value decrease as frequency increase, the best values of efficiency are obtained for frequencies less than 12 GHz.

III.2.2.3.5 Radiation pattern

The far field radiation patterns of the final structure in the E-plane (phi = 0°) and the H-plane (phi = 90°) were measured at three different frequencies (3.1, 5.5 and 10.5 GHz), results and clarification are shown below.



(a)

(b)

(c)

Figure III. 17 : Measured radiation patterns for proposed antenna with DGS in 3D and on the E-plane (phi = 0°) and the H-plane (phi = 90°) at: (a) 3.1 GHz, (b) 5.5 GHz, and (c) 10.5 GHz

The 3D radiation pattern of the proposed antenna with DGS shown in Figure III. 17 is simulated at different frequencies: 3.1 GHz, 5.5 GHz and 10.5 GHz. with a maximum value of gain for these frequencies are respectively 1.89 dB, 3.64 dB, and 4.11dBi. The same Figure shows the polar radiation pattern at the same frequencies in the two planes, the E-plane (phi = 0°) and the H-plane (phi = 90°).

At frequency 3.1 GHz, Figure III. 17 (a), for phi = 0° the radiation pattern has one main lobe toward direction 180°. And for phi = 90°, the radiation is symmetric and bidirectional. The main lobes are directed around 0° and 175°.

At frequency 5.5 GHz, Figure III. 17 (b), for phi = 0° the radiation is bidirectional with a near tilted back lobe, the main lobe in the direction theta = 180°. And for phi = 90°, there is a main lobe in the direction theta = 174° and a back lobe at 0°.

At frequency 10.5 GHz, Figure III. 17 (c), for phi = 0° radiation pattern represent two deformed main lobes the main lobe in the direction theta = 97°. And for phi = 90°, the radiation is symmetric and bidirectional in the direction theta = 47°, with a side lobe at 0.

III.2.2.3.6 Surface Current Distribution

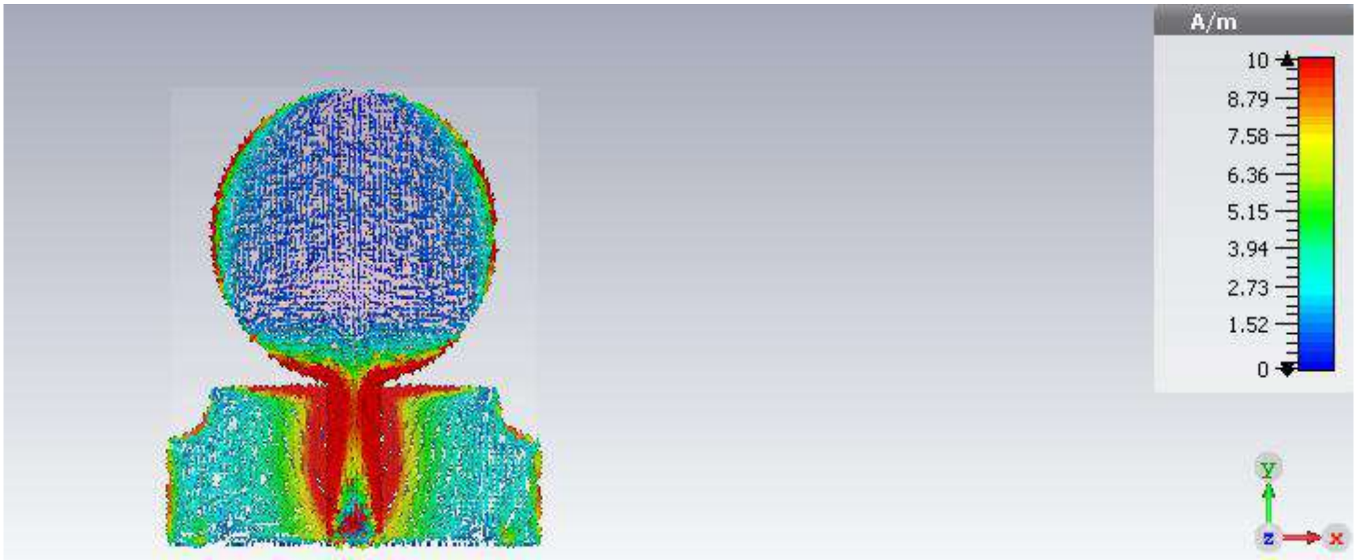


Figure III. 18 : surface current of antenna with DGS at f=5.5GHz

Figure III. 18 shows the current distributions on patch and ground where the currents are mainly concentrated on the edges of patch and DGS ground. Hence, the radiation of the patch is more along the edges which lead to effective radiation. The DGS in the ground plane increases the current path which in turn increases the electrical length of the microstrip line.

The current distribution was found to be minimum at the non- feeding port and at the DGS.

The Maximum surface current is localised at feeding port.

A summary of the results of The Proposed Antenna with DGS in the table below

Table III. 2 : The characteristic of the proposed antenna with DGS

Parameter	Proposed Antenna (with DGS)
Dimensions (mm^2)	25x30
Min S_{11} (dB)	-55.57
Bandwidth (%)	166.189
Min VSWR	1.003
Gain (dB) at 5.5 GHz	2.67
Directivity (dB) at 5.5 GHz	3.45
Efficiency (%)	83.5
Quality factor (Q)	0.60

From Table III. 2, we can see that the parameters of this antenna have improved compared to the first structure.

- A small antenna suitable to be used in mobile devices.
- There is an improvement and a high increase in bandwidth of proposed antenna.
- Good increase in Gain and Directivity.
- Efficiency is much better.

III.3 Comparison between antenna with and without DGS

In order to observe the effect of using DGS on the antenna, the simulation results were compared between the antenna without DGS antenna and the antenna with DGS

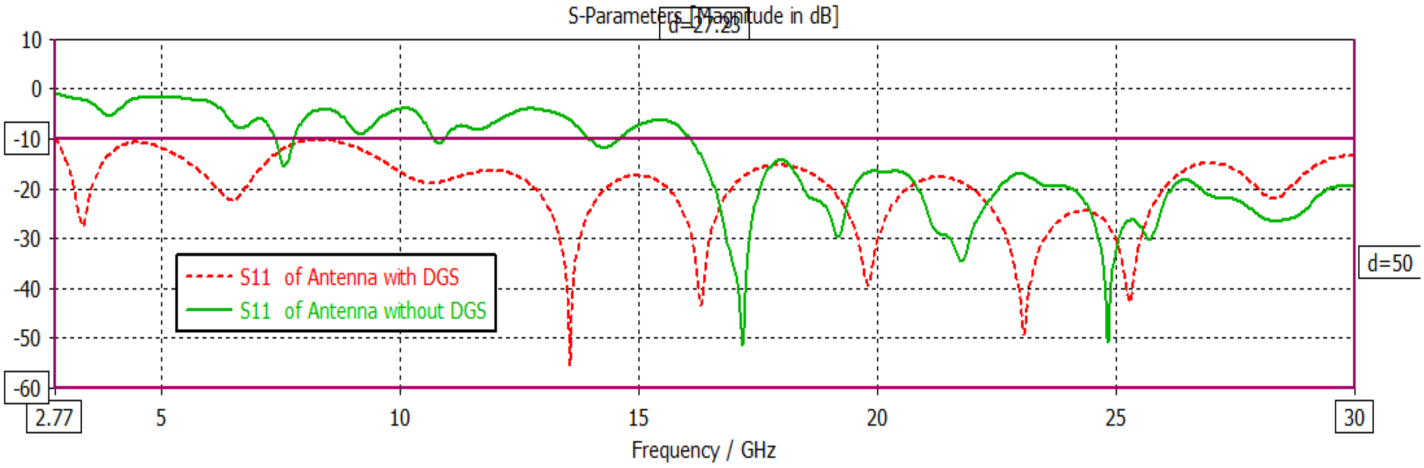


Figure III. 19 : Comparison of S_{11}-parameters between the proposed antenna without and with DGS.

We can clearly observe that the antenna with DGS has a wide bandwidth and satisfy the full UWB bandwidth, however the antenna without DGS has a very narrow bandwidth especially in UWB bandwidth.

Table III. 3 : Comparison table between the antenna with DGS and without DGS

Parameter	Antenna without DGS	Antenna With DGS
Dimensions (mm^2)	35x35	25x30
Min S_{11} (dB)	-49.687	-55.57
Min VSWR	1.005	1.003
Bandwidth (GHz)	Very narrowband	27.23 (166.189 %)
Gain (dB) at 5.5 GHz	-4.25	2.67
Directivity (dB) at 5.5 GHz	5.06	3.45
Efficiency (%)	11.72	83.5
Quality factor (Q)	high	0.60 (low)

Through the comparison Table III. 3 we conclude:

- The first proposed antenna without DGS has a large dimensions and a very narrow bandwidth and a very bad gain and efficiency.
- The proposed small antenna with a dimensions 25mm x 30mm with DGS has a better results than the conventional antenna without DGS.
- The proposed antenna with DGS has a good efficiency.
- The antenna with DGS has a very wide bandwidth (27.23 GHz)
- By comparing the characteristics of the antenna with and without DGS, we note a great improvement and increasing in the bandwidth, gain and efficiency after the application of DGS on the proposed antenna.

III.4 Comparison with other research work

Table III. 4 : Comparison of the main parameters between this antenna and other antennas

Parameters / **Antennas**	**Dimensions (mm^2)**	**Bandwidth (GHz)**	**Min S_{11} (dB)**	**Complexity**
This Work	25x30	27.23 (2.77~30)	-55.57	Low
[1]	35x77	17.36 (1.44 ~12)	-34.92	Very high
[2]	35x30	8.83 (3.14 ~11.92)	-47.63	High
[3]	26x30	11.5 (3 ~ 14.5)	-43.5	High
[4]	55x56	13.6 (1.25 ~14.86)	-30.08	Low

Through the Comparative Table (Table III. 4) between this work and other works in [1] [2] [3] [4] we conclude that our structure of antenna with DGS has:

- The widest bandwidth.
- The Smaller size.
- The Less complicated in design.
- The best value of S_{11}

III.5 Conclusion

In this chapter. The proposed circular microstrip patch antenna has been designed and simulated before and after using the DGS technique, then a comparative study between them has been presented.

We have successfully improved the bandwidth and also reduced the dimensions of the proposed antenna, the improvement is clearly demonstrated through the simulation results obtained using CST simulator.

The proposed antenna with DGS can achieve a very wide bandwidth with the return loss ($S11 < -10$) from 2.77 to 30 GHz giving an extremely wideband allowing the use of antenna in many applications, thus the antenna is suitable for UWB and SWB communication applications, because it covers both the short and the long range of communications frequencies.

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CONCLUSION

Conclusion

The fast growth in the number of connected items and the number of wireless systems users has opened the door to a racing to create a system with a large bandwidth that can serve those huge demands in data rate. An antenna operating over a very wide bandwidth with better radiation efficiency and reduced size is required to be adapted with those systems. Thus, several techniques for expanding bandwidth and optimizing characteristics of broadband antennas have been extensively studied.

Planar monopole antennas are the best candidates due to their wide width band, omnidirectional radiation pattern, compact and simple structure; price reduced and ease of construction.

Thus, our work is mainly focused on improving the bandwidth of a microstrip antenna in a DGS structure.

The antenna design steps and results are presented and discussed in the third chapter. After the choice of substrate material, a new microstrip antenna geometry is introduced, the applying of some modifications on the conventional antenna (defecting the ground plane with circular slots on the upper middle and the upper corners of the ground plan) and changing the dimensions allowed the design of the microstrip antenna satisfying the requested specifications. The different characteristics of the antenna are presented and commented. A parametric study of the proposed antenna is then performed. The effect of certain geometrical parameters of the antenna on the characteristics of the proposed antenna are shown, in order to better analyze the influence of the geometrical parameters of the antenna on the performances of the proposed antenna and in particular on the coefficient of reflection (adaptation of the antenna) and the radiation pattern.

After applying the DGS technique on the conventional antenna we have successfully improvedn its bandwidth to 166.189 % (2.77 GHz to 30 GHz), increase its efficiency to 83.5%, reduce its dimensions to (25mm*30mm), also we improved the others parameters such as VSWR , Gain and antenna radiation comparing with the conventional antenna. The simulation results are obtained by using a Computer Simulation Tool (CST) Design Environment software.

The antenna design is very simple, compact and it operates with a very good behavior from 2.77 GHz to 30GHz with the return loss (S11 < -10), giving an extremely wide band allowing to be used in many applications, making possible its integration into portable devices.

This proposed antenna bandwidth covers the frequency range of UWB and SWB so it is useful for point to point communication such as WVB (Wireless Video Broadcast), Satellite Communication and Radar Applications, WLAN applications “IEEE802.11a” in (5.12-5.825 GHz) and WiMAX system in (3.4–3.7 GHz) and for short range communication such as Biomedical applications .

This work allowed us to deepen our knowledge in the field of antennas, as we mastery the CST STUDIO SUIT software used to design this antenna. The redaction of this thesis helped us to learn the research terminology and the right way of using bibliography and referencing.

Future work

In future works, we can employ other technics such us the combination of CPW and DGS to enhance the antenna characteristics.

APPENDIX

Appendix N° 01:

➢ Electromagnetic (EM) Numerical Modelling Technique

The technology of wireless communications is established on the principles of electromagnetic (EM) fields and waves. Thus, numerical techniques are playing an important role in solving EM field problems especially when the problem is complexity increases.

Currently, several numerical techniques are available to solve the EM problems, such as Finite Element (FE) method, the Method of Moments (MoM), Finite-Difference Time-Domain (FDTD) method and Finite Integration Technique (FIT). FE and MoM solve the EM problems in frequency domain whilst FDTD and FIT solve the EM problems in time domain instead. A particular numerical technique is well suited for the analysis of a particular type of problem. Analyses have shown that FDTD/FIT is fast in computation and the resolution is better than other available numerical software package. Therefore, the CST Microwave Studio which is based on the FIT numerical method has been used as the modelling tool in this thesis.

Appendix N° 02:

➢ Overview of CST MICROWAVE STUDIO

CST MICROWAVE STUDIO is a complete software for analysis and design electromagnetic in the high frequency range. It simplifies the insertion of structures by providing a 3D solid to model each element at the end, it is an electromagnetic simulator based on the technique of finite integrations (FIT).

Finite Integration Technique (FIT) was first proposed by Weiland in 1977 [4]. Equivalent to FDTD, FIT (chapter III) is a time-domain numerical technique for solving Maxwell's equations. However, it discretises the integral form rather than the differential form of Maxwell's equations.

The first step of the FIT discretisation is to define the computation domain which contains the space region of interest. The computation domain is enclosed by the restriction of the electromagnetic field problem, which normally represents an open boundary problem to a bounded space region.

The next step is to decompose the computation domain into a finite number of the simplicial cell complex G, which serves as a computational grid. The primary grid *G* can be visualised in the CST Microwave Studio®, whilst internally a dual grid G̃ is set up orthogonally to the primary one. In the Cartesian system, the dual grid G̃ is defined by taking the foci of the cells of *G* as grid points for the mesh cells of as shown in Figure 1.

The electric voltages e and magnetic fluxes *b* are allocated on the primary grid *G* whilst the dielectric fluxes d and the magnetic voltages *h* are allocated on the dual grid G̃. A voltage is defined as the integral of a field strength value (electric or magnetic) along a (dual) mesh edge whilst a flux is defined as the integral of a flux density value (electric or magnetic) across a (dual) mesh cell facette.

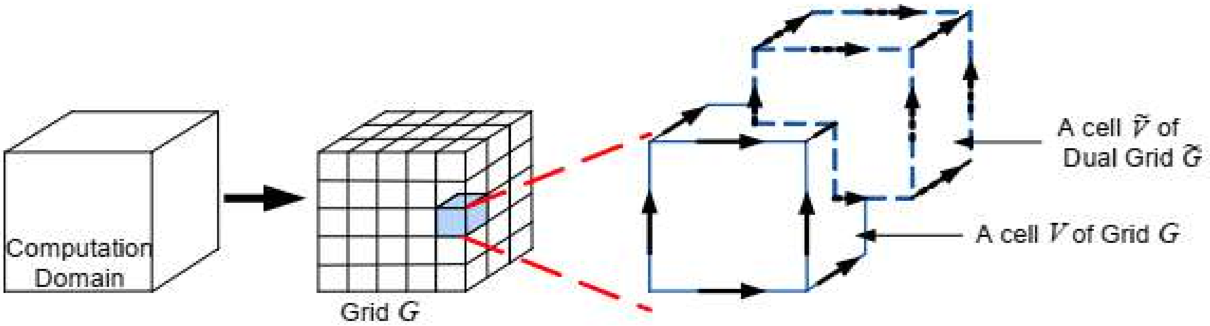


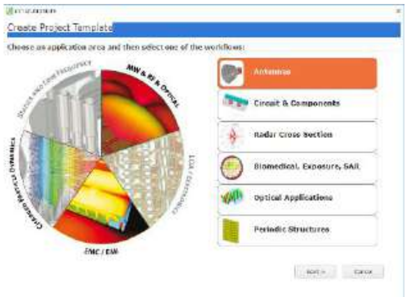
Figure 1 : FIT discretization

The figures showed below are for giving an idea about how to start CST microwave studio program and how it looks like.

To create a patch antenna project follow these steps:

- After launching the CST simulator with a double click, create a new project “New Template”. You will be prompted to select “MW & RF & OPTICAL” (Figure 2).
- After you choose "Antennas", Next → "Planar" as shown in (Figure 3).
- Then you click on next → Time Domain (Figure 4).

- Choose the parameters that define the units of dimensions, frequencies, time and temperature,etc (Figure 5)
- After that we select the minimum and maximum frequency and simulation field (Figure 6).
- Review your choice and click 'Finish' to create the template (Figure 7)
- At the end, the interface appears to do the modeling of the antenna structure (Figure 8).



Choose an application area and then select one of the workflows:

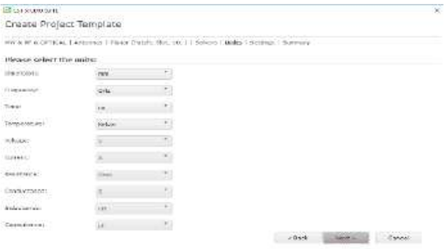
Figure 6

Please select a workflow:

Figure 5

The recommended solvers for the selected workflow are:

Figure 4



Please select the units:

Figure 3

Please select the Settings:

Figure 2

Please review your choice and click 'Finish' to create the template:

Figure 7

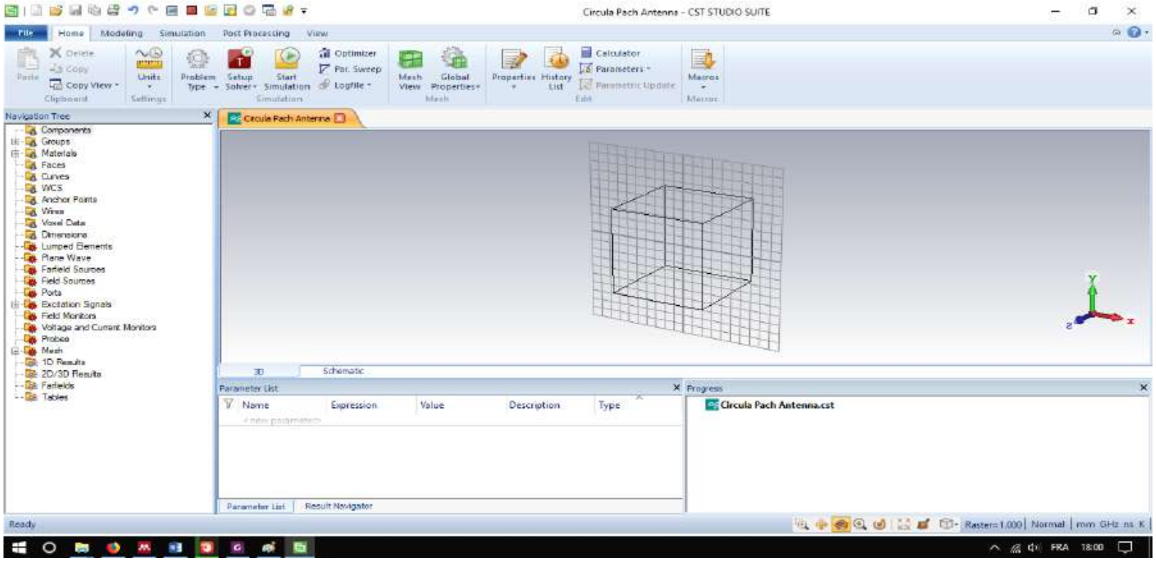


Figure 8