بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering

Electrical Engineering Department

Communication Engineering

Bachelor Thesis

Graduation Project

Comparative study of Two E-shaped Microstrip Antennas with Linear and Circular Polarizations

Project Team

Ala' Al-Haj Hasan　Marwa Abu Zeineh　Reem Qunaibi

Supervisor

Dr. Osama Ata

Hebron - Palestine

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جامعة بوليتكنك فلسطين
الخليل – فلسطين
كلية الهندسة والتكنولوجيا
دائرة الهندسة الكهربائية

اسم المشروع

Comparative study of Two E-shaped Microstrip Antennas with Linear and Circular Polarizations

أسماء الطلاب

الاء الحاج حسن　　مروة ابوزينة　　ريم اقنيبي

بناء على نظام كلية الهندسة والتكنولوجيا واشراف ومتابعة المشرف المباشر على المشروع ومتابعة أعضاء اللجنة الممتحنة ، تم تقديم هذا المشروع الى دائرة الهندسة الكهربائية والحاسوب ، وذلك استكمالا لمتطلبات درجة البكالوريوس في تخصص هندسة الاتصالات والالكترونيات

توقيع المشرف

توقيع اللجنة الممتحنة

توقيع رئيس الدائرة

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Special thanks to the wonderful mothers and fathers for their endless extraordinary support in every aspect in our life for worrying about us and always being available if we need help . Our deepest gratefulness goes to our husbands for their love , help and support during our study. We are really lucky that we couldn't have made it without their supports .Thanks to our brothers and sisters who wish us the best .

We would like to thank those amazing people we have met along the way who have helped us in major and small things.

Our deep appreciation to the light that gave us the enough to pass the way. The respected who gave us his attention and encouragement , our supervisor Dr. Osama Ata .

This graduation project has been supported by the Deanship of Graduate Studies and Scientific Research through "Distinguished Graduation Project Fund" – Palestine Polytechnic University. Special thanks go for Eng Sami Al-Salamein for the fabrication of the antennas, Eng Ihab Jaber from Al-Wataniya Mobile for the rturn loss measurements on the network analyzer, Eng Omar Abu Saif and Eng Osama Najajreh for the radiation pattern measurement, Eng Magdi Zalloum and Eng Jaser Mohtaseb for the Autocad drawings.

Last but not least our thanks for all lectures and particularly communication staff who spent their precious time and life to join them in their trip of human light and expertise.

Abstract:

A microstrip antenna is a kind of antenna used to radiate ultra-high frequency signals . Due to its advantages such as low weight ,low profile planar configuration so it can conform to planar and non-planar surfaces which fits the shape design and needs of modern communication equipment. It has low fabrication costs and capability to integrate with microwave integrated circuits technology, the microstrip antenna shape flexibility enables mounting them on a rigid surface which makes them mechanically robust.

Microstrip antennas can be mass produced using simple and inexpensive modern printed circuit board technologies. The use of printed circuit board manufacturing technologies also enables fabricating the feeding and matching networks with the antenna structure. From a designer point of view microstrip antenna presents a wide range of options. The designer can vary the choice of the substrate type, the antenna structure, type of perturbation and the feeding technique to achieve the antenna design objective .

Microstrip antennas have a narrow impedance bandwidth, low efficiency and they can only be used in low power applications . They also show high ohmic losses when used in an array structure,/ Polarization polarity given by microstrip antenna is poor. Most microstrip antennas radiate only in half-space, because they are implemented on double sided laminates where one side is used as a ground. The half space radiation limits their use in some application. The research in microstrip antenna design mainly focuses on how to overcome these disadvantages .

A microstrip antenna , in its basic form, consists of 4 parts ; metallic patch, dielectric substrate, ground plane, and feeding structure. The radiating metallic patch, usually gold or copper , acts approximately as a resonant cavity. Microstrip Antennas are very well suited for applications such as wireless communications system such as military GPS (at L1- band) , GSM services and satellite communications., cellular phones, pagers, Radar systems and satellite communications systems.

Our interest is in a type of microstrip antennas; an E-shaped patch antenna which looks like an alphabet (E).
The pattern has two resonating slots capable to generate dualband resonances, making the antenna useful and compact in serving more than a single band.

The E-shaped antenna is simpler to construct , can increase the gain of the antenna and enhance the bandwidth above 30% compared to a regular patch antenna by using the slotted radiating element and can produce reduced sizes and widebands
(5GHz/6GHz).

We will do a comparative study between two kinds of E-shaped antennas. Both will address different frequency bands and polarizations making them useful for different applications.

In our project, we are interested in analysis, fabrication and measurement of the performance of linear polarized E-shape antenna and compare it with the performance of circular polarized E-shape antenna.

There are three essential parameters for the design: the resonant frequency (f), the dielectric constant of the substrate (ε_r) and the height of the dielectric substrate (h).

الملخص

(Microstrip Antenna) هي نوع من الهوائيات المستخدمة لإشعاع إشارات عند ترددات عالية جدا. تتميز بأنها خفيفة الوزن , يمكن تصنيعها بكميات كبيرة باستخدام تقنيات بسيطة ، تكلفتها قليلة ، متينة ميكانيكيا و يمكن أن تتوافق مع السطوح المستوية وغير المستوية حسب شكل التصميم و معدات الاتصال الحديثة .

تتكون بشكل أساسي من أربعة أجزاء رئيسية ؛ طبقة معدنية (Patch) , طبقة عازلة و الطبقة الاساسية (grond) و جزء خاص للتغذية . الطبقة المعدنية تكون عادة من النحاس أو الذهب تعمل تقريبا مثل (resonant cavity)

(Microstrip Antenna) تستخدم للعديد من التطبيقات في أنظمة الاتصالات اللاسلكية ، مثل أنظمة (GPS) العسكرية و أنظمة (GSM) وفي مجالات الاقمار الصناعية وغيرها .

بالرغم من ذلك , هناك عدة مساوئ لاستخدام هذا النوع من الهوائيات . لأنها تعمل في نطاقات ضيقة للتردد , و كفاءتها قليلة حيث نسبة ضياع الطاقة فيها عالية .

محور اهتمامنا في نوع خاص من هذه الهوائيات وهو الهوائيات التي على شكل حرف (E) , للحصول على ترددي رنين وليس تردد واحد كالهوائيات المنتشرة , مما يجعلها أكثر فائدة و أنفع استخداما.

أيضا قمنا بعمل دراسة ومقارنة بين نوعين من الاستقطاب لهذا الهوائي , الاستقطاب الخطي و الاستقطاب الدائري كل منهما على نطاق مختلف من الترددات للاستفادة منها في مجالات وتطبيقات عديدة و مختلفة .

.في مشروعنا ، نحن مهتمون في تصنيع وتحليل وقياس أداء الهوائي على شكل حرف (E) في حالة الاستقطاب الخطي و مقارنته مع أداء الهوائي في حالة الاستقطاب الدائري.

لقد أخذنا بعين الاعتبار ثلاثة معايير أساسية للتصميم ؛ تردد الرنين , معامل العزل الكهربائي (ε_r) و سمك الطبقة العازلة.

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Chapter 1

Introduction

1.1Overview

The first antennas were built in 1888 by German physicist Heinrich Hertz in his pioneering experiments to prove the existence of electromagnetic waves predicted by the theory of James Clerk Maxwell. Hertz placed dipole antennas at the focal point of parabolic reflectors for both transmitting and receiving. He published his work in Annalen der Physik und Chemie (vol. 36, 1889).

An antenna is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an oscillating radio frequency electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, As the electromagnetic field strikes the receiving antenna, a voltage is induced into the antenna, which serves as a conductor. The induced RF voltages are then used to recover the transmitted RF information.

Typically an antenna consists of an arrangement of metallic conductors ("elements"), electrically connected (often through a transmission line) to the receiver or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields, when created in the proper proportions, radiate away from the antenna into space as a moving transverse electromagnetic field wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert force on the electrons in the antenna elements, causing them to move back and forth, creating oscillating currents in the antenna.

Antennas are essential components of all equipment that uses radio. They are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as wireless microphones, Bluetooth enabled devices, wireless computer networks, and baby monitors.

Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves which carry signals through the air (or through space) at the speed of light with almost no transmission loss. Radio transmitters and receivers are used to convey signals (information) in systems including broadcast (audio) radio, television, mobile telephones, wi-fi (WLAN) data networks, trunk lines and point-to-point communications links (telephone, data networks), satellite links, many remote controlled devices such as garage door openers, and wireless remote sensors, among many others. Radio waves are also used directly for measurements in technologies including RADAR, GPS, and radio astronomy. In each and every case, the transmitters and receivers involved require antennas, although these are sometimes hidden (such as the antenna inside an AM radio or inside a laptop computer equipped with wi-fi).

According to their applications and technology available, antennas generally fall in one of two categories:

1. Omnidirectional (or weakly directional) antennas

Antennas can be designed to transmit or receive radio waves in all directions equally. These are employed when the relative position of the other station is unknown or arbitrary. They are also used at lower frequencies where a directional antenna would be too large, or simply to cut costs in applications where a directional antenna isn't required. "omnidirectional" antennas usually have vertical polarization.
Even in omnidirectional, the gain can often be increased by concentrating more of its power in the horizontal directions.

2. Directional (or high gain) antennas

Antennas are intended to preferentially radiate in a particular direction or directional pattern and receive from that one direction only. "directional" antenna usually is intended to maximize its coupling to the electromagnetic field in the direction of the other station.

There are many types of antennas :

1. The isotropic radiator is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist, but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).

2. The dipole antenna is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna, it is also used as a reference model for other antennas; gain with respect to a dipole is labeled as dBd. Generally, the dipole is considered to be omnidirectional in the plane perpendicular to the axis of the antenna, but it has deep nulls in the directions of the axis. Variations of the dipole include the folded dipole, the half wave antenna, the ground plane antenna, the whip, and the J-pole.

3. The Yagi-Uda antenna is a directional variation of the dipole with parasitic elements added which are functionality similar to adding a reflector and lenses (directors) to focus a filament light bulb.

4. The random wire antenna is simply a very long (at least one quarter waveleng) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available . Typically, a random wire antenna will also require an antenna tuner, as it might have a random impedance that varies non-linearly with frequency.

5. The horn antenna is used where high gain is needed, the wavelength is short (microwave) and space is not an issue. Horns can be narrow band or wide band, depending on their shape. A horn can be built for any frequency, but horns for lower frequencies are typically impractical. They are also frequently used as reference antennas.

6. The parabolic antenna consists of an active element at the focus of a parabolic reflector to reflect the waves into a plane wave. Like the horn it is used for high gain, microwave applications, such as satellite dishes.

7. The patch antenna : The study of microstrip patch antennas has made great progress in recent years. Compared with conventional antennas, microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad band-width, feedline flexibility, beam scanning omnidirectional patterning.

A microstrip patch antenna (MPA) consists of a conducting patch of any planar or non - planar geometry on one side of a dielectric substrate with a ground plane on other side. It is a popular printed resonant antenna for narrow-band microwave wireless links that require semi-hemispherical coverage.

The rectangular and circular patches are the basic and most commonly used microstrip antennas.

These patches are used for the simplest and the most demanding applications. Rectangular geometries are separable in nature and their analysis is also simple. The circular patch antenna has the advantage of their radiation pattern being symmetric.

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1.2 Main idea of the project:

A microstrip antenna is a kind of antenna used to radiate ultra-high frequency signals. It is light weight, manufacturing technologies is enable, cost effective, and can take any shape .

A microstrip antenna , in its basic form, consists of 4 parts ; metallic patch, dielectric substrate, ground plane, and feeding structure. The radiating metallic patch, usually gold or copper , acts approximately as a resonant cavity. Microstrip Antennas are popular for many applications in wireless communication systems, such as, military GPS (at L bands (L1&L2)) ,GSM services and satellite communications.

Main disadvantages of microstrip antennas are narrowband , low efficiency ,and very high loss factor.

Our interest is in a type of microstrip antennas; an E-shaped patch antenna which looks like an alphabet (E).
The pattern has two resonating slots capable to generate dual wideband resonances, making the antenna useful and compact in serving more than a single band.

We will do a comparative study between two kinds of E-shaped antennas. Both will address different frequency bands and polarizations making them useful for different applications.

In our project, we are interested in analysis, fabrication and measurement of the performance of linear polarized E-shape antenna and compare it with the performance of circular polarized E-shaped antenna.

There are three essential parameters for the design: the resonant frequency (f), the dielectric constant of the substrate (Ɛr) and the height of the dielectric substrate (h).

1.3 Objectives :

1- To design, analyze , fabricate and measure an E-shaped microstrip antennas.

2- Perform parametric study to attempt Optimizing the design using HFSS Designer software.

3- Understand the performance of two kinds of E-shape antennas and the reference to wireless applications.

1.4 Motivation:

We now have facilities to design, analyze , fabricate and measure an E-shaped microstrip antennas in lab, so we are interested in designing antennas that used in real wireless communication applications .

The measurements will be performed on lab volt antennas range system. The fabrication accomplished using Protomat S62 machine and PCB prototype machine. The designing and analysis done using Ansoft and HFSS designer softwares.

1.5 Requirements:

** Ansoft Designer Software :

A highly accurate designing tool that allows the designer to precisely model and simulate complex analog, RF and mixed-signal applications , It is flexible, easy-to-use tool includes.

** HFSS (High Frequency Structure Simulator) Software :

An industry-standard simulation tool for 3-D full-wave electromagnetic field simulation and is essential for the design of high-frequency and high-speed component design. HFSS offers multiple state-of the-art solver technologies based on either the proven finite element method or the well established integral equation method. You can select the appropriate solver for the type of simulation you are performing.

Engineers rely on the accuracy, capacity, and performance of HFSS to design high-speed components including on-chip embedded passives, IC packages, PCB interconnects and high-frequency components such as antennas, RF/microwave components and biomedical devices. With HFSS, engineers can extract scattering matrix parameters (S,Y, Z parameters), visualize 3-D electromagnetic fields (near- and far-field) and generate Full-Wave SPICE models that link to circuit simulations. Signal integrity engineers use HFSS within established EDA design flows to evaluate signal quality, including transmission path losses, reflection loss due to impedance mismatches, parasitic coupling and radiation.

In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.

** Protomat S62 & PCB prototype machines for fabrication use.

** Dielectric substrates (Rogers / RT duroid 5880 and FR4).

**Accessories (SMA cables and connectors).

1.6 Time plan

Table 1.1 : Time plan of the first semester

Activity	2/9 - 9/9	9/9 - 23/9			23/9 - 21/10					21/10 - 28/10	28/10 - 25/11				25/11 - 1/12	1 /12 – 7/1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	🟩															
B		🟩	🟩	🟩												
C					🟩	🟩	🟩	🟩	🟩							
D										🟩						
E											🟩	🟩	🟩			
F					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
G															🟩	
H															🟩	
I																🟩

Activities description :

A : Information Collection.
B : lecture Summary & Preparing Proposal.
C : learning Software & designing Tutorial (Ansoft designer & CST).
D : learning Fabrication.
E : Design & Analysis.
F : Drafting Chapters.
G : Dr. Osama Deadline.
H : Dr. Osama final appeal of the report.
I : Submit of report to department.

Table 1.2 : Time plan of the second semester

Activity	**3/2-16/2**		**17/2-9/3**				**10/3-30/3**			**31/3-27/4**				**28/4 - 4/5**	**5/5-11/5**	**12/5 - 19/5**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
A	🟩	🟩														
B			🟩	🟩	🟩	🟩										
C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩							
D							🟩	🟩	🟩	🟩	🟩	🟩	🟩			
E										🟩	🟩	🟩	🟩			
F														🟩		
G															🟩	
H						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
I															🟩	
J																🟩

Activities description :

A : Software cracking & learning Software designing Tutorial (HFSS designer).

B : Parametric studies.

C : Demanding offers of wanted materials.

D : Antennas designing using HFSS software .

E : Analyze the results of the return loss & radiation pattern.

F : Fabrication the antennas using lab volt devices .

G : measuring the return Loss & radion pattern.

H : Documentation.

I : Dr. Osama final appeal of the report.

J : Submit of report to department.

Chapter 2

Microstrip Patch Antenna

Chapter 2

Microstrip Patch Antenna

2.1 Overview

In this chapter we will introduce a general idea about microstrip patch antennas and popular configurations that are used to feed them , also we will talk about the most important antenna parameters.

2.2 Microstrip Patch antenna

A microstrip antenna , in its basic form, consists of 4 parts ; metallic patch, dielectric substrate, ground plane, and feeding structure. The patch antenna's radiating elements (which usually gold or copper) and the feed lines are constructed on the dielectric substrate .

There are lots of shapes of the radiating patch, which are square, rectangular, thin strip (dipole), circular, elliptical, triangular, and other configuration. The patch antenna has a metal patch placed above a ground plane [1] .

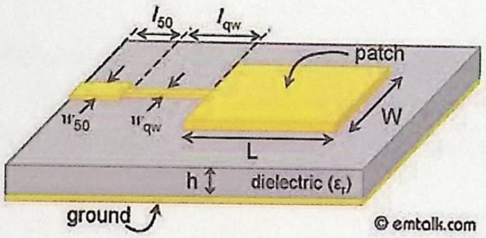

Fig 2.1 : Microstrip patch antenna

They have attracted much interest due to their low profile, light weight, simple and inexpensive to manufacture using modern printed circuit technology, mechanically robust when mounted on rigid surfaces, and they are very versatile in terms of frequency, polarization, pattern and impedance.
However, they also have some drawbacks, they have narrow bandwidth, low efficiency , high loss factor and have low gain.

There are four popular configurations that are used to feed microstrip antennas such that:

1. The 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 2.2. 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 .

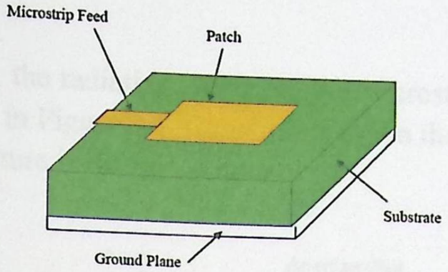

Fig 2.2 : The microstrip line feed

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 [2].

2. Coaxial probe feed.

The Coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas. As seen from Figure 2.3, 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.

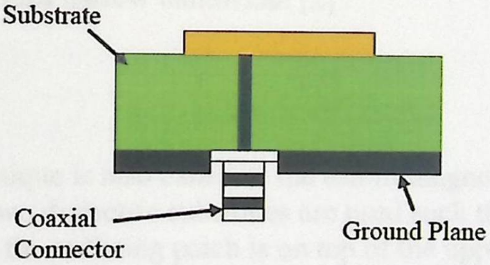

Fig 2.3 : Coaxial probe feed

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, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth [2].

3. Aperture coupling .

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.4. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

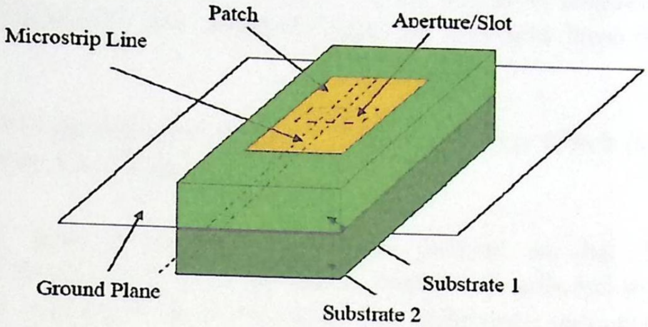

Fig 2.4 : Aperture - coupled feed

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. Generally, a high dielectric material is used for 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 [2] .

4. Proximity coupling.

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.5, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) , due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances [2] .

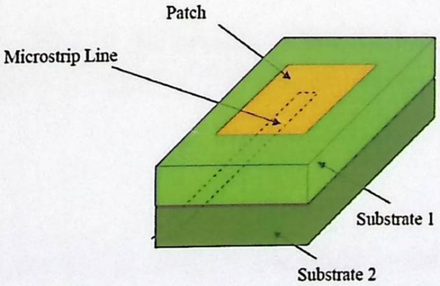

Fig 2.5 : Proximity coupling feed

2.3 Antenna Parameters :

2.3.1 Bandwidth :

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The bandwidth can be considered as the range of frequencies, which are on either side of the center frequency, also different types of antennas have different bandwidth limitations.

An antenna's bandwidth also specifies the range of frequencies over which its performance does not suffer due to a poor impedance match.

Input impedance, pattern, gain, polarization, etc. are defined as the characteristics. The characteristics of an antenna are not vary in the same manner or affected by the frequency, so there is no unique characterization of the bandwidth. For different cases, the specifications are set to meet the particular application's needs. The distinction is the variation between pattern and input impedance. And the pattern bandwidth and impedance bandwidth are use to emphasize this distinction. The bandwidth is usually formulated in terms of beamwidth, side lobe level, and pattern characteristics. Different types of antennas have different bandwidth limitations [3] .

2.3.2 Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave that antenna transmitted. Polarization is in general described by an ellipse.

The initial polarization of a radio wave is determined by the antenna, and different parts of the pattern may have different polarizations because the polarization of the radiated energy varies with the direction from the center of the antenna.

Polarization types :

1. Linear polarization :

In Linear polarization, electric filed direction remains constant.

2. Circular polarization :

In circular polarization, the electric field of the passing wave does not change strength but only changes direction in a rotary manner making one full turn for each RF cycle. This rotation may be right-hand or left-hand [4] .

The choice of polarization is one of the design choices available to the RF system designer.

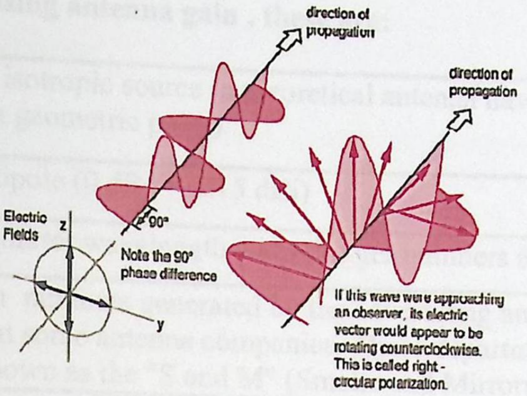

Fig 2.6 : Circular and linear Polarization.

2.3.3 Antenna Gain :

The gain is a parameter which measures the degree of directivity of the antenna's radiation pattern. A high-gain antenna will preferentially radiate in a particular direction. Specifically, the antenna gain, or power gain of an antenna is defined as the ratio of the intensity (power per unit surface) radiated by the antenna in the direction of its maximum output, at an arbitrary distance, divided by the intensity radiated at the same distance by a hypothetical isotropic antenna.

Since ,the total amount of energy radiated remains constant for a given transmitter output power. When this energy is focused, the energy radiated in one or more directions will be increased, and the energy radiated in other directions will decrease. This is what gives an antenna "gain".

The gain of an antenna is a passive phenomenon - power is not added by the antenna, but simply redistributed to provide more radiated power in a certain direction than would be transmitted by an isotropic antenna. An antenna designer must take into account the application for the antenna when determining the gain since the antenna's gain also takes into account the antenna's efficiency.

High-gain antennas have the advantage of longer range and better signal quality, but must be aimed carefully in a particular direction. Low-gain antennas have shorter range, but the orientation of the antenna is relatively inconsequential. For example, a dish antenna on a spacecraft is a high-gain device that must be pointed at the planet to be effective, whereas a typical Wi-Fi antenna in a laptop computer is low-gain, and as long as the base station is within range, the antenna can be in any orientation in space. It makes sense to improve horizontal range at the expense of reception above or below the antenna.

Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power [5] .

There are four ways of expressing antenna gain , these are:

dBi	Gain over an isotropic source (a theoretical antenna having no dimensions: a geometric point)
dBd	Gain over a dipole (0 dBd = 2.15 dBi)
dBq	Gain over a quarter wavelength whip (bigger numbers than dBi)
dBadv	Large random numbers generated by the advertizing and marketing departments at some antenna companies. These departments are sometimes known as the "S and M" (Smoke and Mirrors) groups

2.3.4 Beamwidth :

In telecommunication, the term beamwidth has the following meanings:

In the radio regime, of an antenna pattern, the angle between the half-power (-3 dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe.

Beamwidth is usually expressed in degrees, and expressed for the horizontal plane.

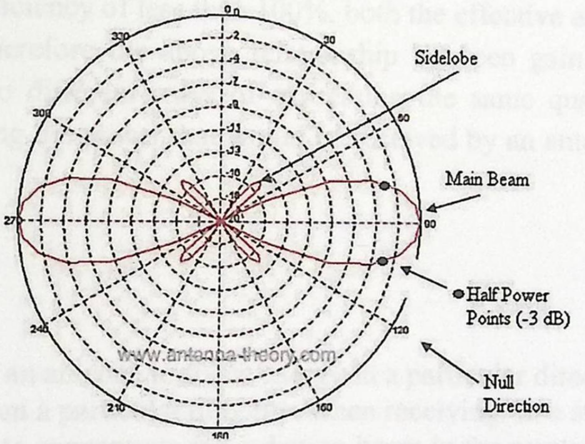

Fig 2.7 :Beamwidth of the antenna

The main beam is the region around the direction of maximum radiation (usually the region that is within 3 dB of the peak of the main beam). The main beam in this Figure is centered at 90 degrees.

The sidelobes are smaller beams that are away from the main beam. These sidelobes are usually radiation in undesired directions which can never be completely eliminated. The sidelobes in this Figure occur at roughly 45 and 135 degrees.

Also, the Sidelobe Level is another important parameter used to characterize radiation patterns. The sidelobe level is the maximum value of the sidelobes (away from the main beam). From the Figure , the Sidelobe Level (SLL) is -14.5 dB.

2.3.5 Effective area or aperture

The effective area or effective aperture of a receiving antenna expresses the portion of the power of a passing electromagnetic wave which it delivers to its terminals, expressed in terms of an equivalent area. For instance, if a radio wave passing a given location has a flux of (10−12) watts per square meter and an antenna has an effective area of 12 m2, then the antenna would deliver 12 pW of RF power to the receiver (30 microvolts rms at 75 ohms). Since the receiving antenna is not equally sensitive to signals received from all directions, the effective area is a function of the direction to the source.

The gain of an antenna used for transmitting must be proportional to its effective area when used for receiving. Consider an antenna with no loss, that is, one whose electrical efficiency is 100%. It can be shown that its effective area averaged over all directions must be equal to λ2/4π, the wavelength squared divided by 4π. Gain is defined such that the average gain over all directions for an antenna with 100% electrical efficiency is equal to 1. Therefore the effective area Aeff in terms of the gain G in a given direction is given by:

$$A_{eff} = \frac{\lambda^2}{4\pi} G$$

For an antenna with an efficiency of less than 100%, both the effective area and gain are reduced by that same amount. Therefore the above relationship between gain and effective area still holds. These are thus two different ways of expressing the same quantity. A_{eff} is especially convenient when computing the power that would be received by an antenna of a specified gain, as illustrated.

2.3.6 Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions as an omni-directional antenna.

2.3.7 Radiation pattern

The radiation pattern of an antenna is a plot of the relative field strength of the radio waves emitted by the antenna at different angles. It is typically represented by a three dimensional graph but measurements are presented in either a rectangular or a polar plots of the horizontal and vertical cross sections. The pattern of an ideal isotropic antenna, which radiates equally in all directions, would look like a sphere. Many non-directional antennas, such as monopoles and dipoles, emit equal power in all horizontal directions, with the power dropping off at higher and lower angles; this is called an omni-directional pattern and when plotted looks like a torus or donut.

The radiation of many antennas shows a pattern of maxima or "lobes" at various angles, separated by "nulls", angles where the radiation falls to zero. This is because the radio waves emitted by different parts of the antenna typically interfere, causing maxima at angles where the radio waves arrive at distant points in phase, and zero radiation at other angles where the radio waves arrive out of phase. In a directional antenna designed to project radio waves in a particular direction, the lobe in that direction is designed larger than the others and is called the "main lobe". The other lobes usually represent unwanted radiation and are called "sidelobes". The axis through the main lobe is called the "principal axis" or "boresight axis" [6].

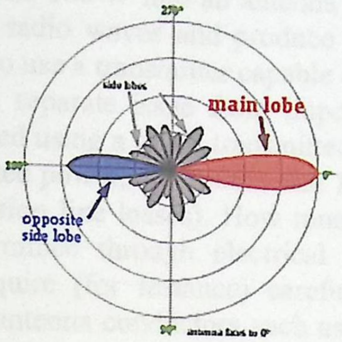

Fig 2.8 :Radiation Pattern of the antenna.

There are two kinds of radiation pattern:

1. Absolute radiation patterns : are presented in absolute units of field strength or power.
2. Relative radiation patterns : are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna, and then the gain transfer method is then used to establish the absolute gain of the antenna.

The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region.

For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength.

The accepted formula for this distance is:

$$r_{min}=2d / \lambda$$

where r min is the minimum distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

2.3.8 Efficiency

Efficiency of a transmitting antenna is the ratio of power actually radiated (in all directions) to the power absorbed by the antenna terminals. The power supplied to the antenna terminals which is not radiated is converted into heat. This is usually through loss resistance in the antenna's conductors, but can also be due to dielectric or magnetic core losses in antennas (or antenna systems) using such components. Such loss effectively robs power from the transmitter, requiring a stronger transmitter in order to transmit a signal of a given strength.

For instance, if a transmitter delivers 100 W into an antenna having an efficiency of 80%, then the antenna will radiate 80 W as radio waves and produce 20 W of heat. In order to radiate 100 W of power, one would need to use a transmitter capable of supplying 125 W to the antenna. Note that antenna efficiency is a separate issue from impedance matching, which may also reduce the amount of power radiated using a given transmitter. If an SWR meter reads 150 W of incident power and 50 W of reflected power, that means that 100 W have actually been absorbed by the antenna (ignoring transmission line losses). How much of that power has actually been radiated cannot be directly determined through electrical measurements at (or before) the antenna terminals, but would require (for instance) careful measurement of field strength. Fortunately the loss resistance of antenna conductors such as aluminum rods can be calculated and the efficiency of an antenna using such materials predicted.

However loss resistance will generally affect the feed point impedance, adding to its resistive (real) component. That resistance will consist of the sum of the radiation resistance Rr and the loss resistance R loss. If an rms current I is delivered to the terminals of an antenna, then a power of I2Rr will be radiated and a power of I2Rloss will be lost as heat.

Therefore the efficiency of an antenna is equal to Rr / (Rr + R loss) . Of course only the total resistance Rr + R loss can be directly measured.

The definition of antenna gain or power gain already includes the effect of the antenna's efficiency. Therefore if one is trying to radiate a signal toward a receiver using a transmitter of a given power, one need only compare the gain of various antennas rather than considering the efficiency as well. This is likewise true for a receiving antenna at very high (especially microwave) frequencies, where the point is to receive a signal which is strong compared to the receiver's noise temperature. However in the case of a directional antenna used for receiving signals with the intention of rejecting interference from different directions, one is no longer concerned with the antenna efficiency, as discussed above.

In this case, rather than quoting the antenna gain, one would be more concerned with the directive gain which does not include the effect of antenna (in)efficiency. The directive gain of an antenna can be computed from the published gain divided by the antenna's efficiency [7].

2.3.9 Impedance

As an electro-magnetic wave travels through the different parts of the antenna system (radio, feed line, antenna, free space) it may encounter differences in impedance (E/H, V/I, etc.). At each interface, depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave in the feed line. The ratio of maximum power to minimum power in the wave can be measured and is called the standing wave ratio (SWR).

A SWR of 1:1 is ideal. A SWR of 1.5:1 is considered to be marginally acceptable in low power applications where power loss is more critical, although an SWR as high as 6:1 may still be usable with the right equipment. Minimizing impedance differences at each interface (impedance matching) will reduce SWR and maximize power transfer through each part of the antenna system.

Complex impedance of an antenna is related to the electrical length of the antenna at the wavelength in use. The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer. More commonly, the impedance is adjusted at the load (see below) with an antenna tuner, a balun, a matching transformer, matching networks composed of inductors and capacitors, or matching sections such as the gamma match.

2.3.10 Return loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following:

Return Loss (in dB) = 20log10 (SWR/SWR-1).

2.3.11 S-parameter:

S-parameter describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port2) then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network.

In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as gamma: or return loss. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or deliverd to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated. See also VSWR, which is directly related to S11.

Chapter 3

E-Shaped Microstrip Antenna and Literature Survey

3.1 Overview

In this chapter we will introduce a general idea about E- shaped microstrip patch antenna and its' important , and we will talk about some previous studies that correspond to it .

3.2 E-Shaped Microstrip Antennas

A microstrip patch antenna is a type of antenna that offers a low profile, thin and easily manufacturability, which provides great advantages over traditional antennas .

However, patch antennas have a main disadvantage i.e. narrow bandwidth . Researchers have made many efforts to overcome this problem and many configurations have been presented to extend the bandwidth. Patch antennas are planner antennas used in wireless links and other microwave applications.

An E-shaped patch antenna is easily formed by cutting two slots from a rectangular shape . By cutting the slots from a patch, gain and bandwidth of microstrip antenna can be enhanced.

The geometry is shown .

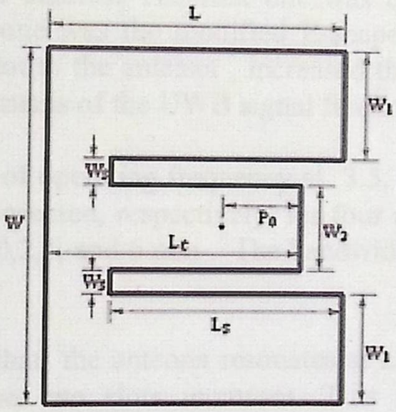

Fig 3.1 : E - shaped antenna

The E-shaped microstrip patch antenna has width (W), two outer patch strips of length L and width W1, one central patch strip of length Lc and width W2. Two slots of length Ls and width Ws are introduced symmetrically with respect to the probe position.

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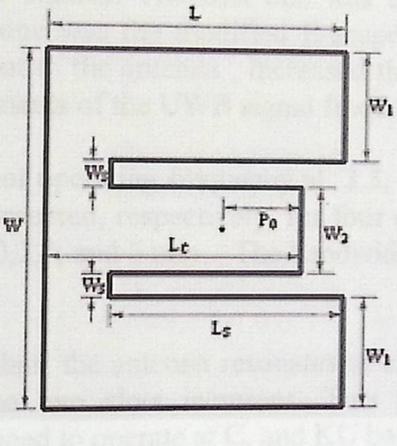

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The importance of an E-shaped antenna:

- Simpler to construct by only adjusting length, width and position of slots .
- Can increase the gain of the antenna .
- Can enhance the bandwidth above 30% compared to a regular patch antenna by using slotted radiating elements leading to multiple resonances .
- Can produce reduced sizes and widebands (5GHz/6GHz).

3.2 Literature surveys

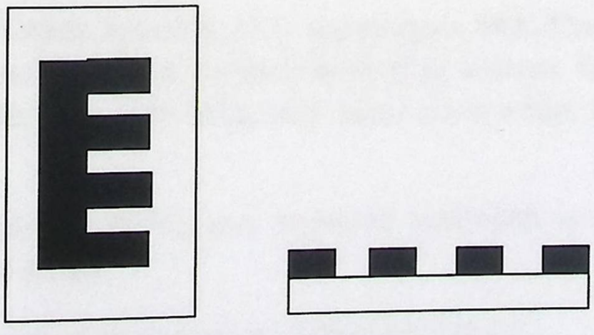
We examined several papers relating to an E-shaped microstrip antenna and its' applications , specially for wideband applications , and there are some papers and its' relation to our project .

M. M. Abd-Elrazzak, Ibrahim S. Al-Nomay [9] , a new modified E-shaped patch antenna for UWB and ISM bands wireless communication systems. The analysis was carried out using the finite difference time domain (FDTD) method to discretize the differential equations of Maxwell.

Two different structures were studied. The first one was the conventional E-shaped antenna geometry. While the second one was the modified E-shaped patch antenna ,the modification achieved by adding another slot to the antenna , increased the antenna operating frequency and bandwidth to meet the requirements of the UWB signal frequency and bandwidth.

In the authors work, antennas of operating frequency at 3.5, 3.75, and 4.1 GHz with bandwidth of 29.3%, 23%, 24% were presented, respectively, for four different values for the middle slot width were taken which were 0,2,4, and 6 mm . The bandwidth is measured for a return loss less than - 10 dB.

From this study we can note that the antenna resonates at higher frequencies as the slot width and the distance between the two slots increases. This is useful for the UWB wireless communications systems that need to operate at C, and KU bands.



(a) Top view (b) Side view

Fig 3.2 : The modified E-shaped patch antenna

Elangovan, G. and J. Rajapaul Perinbam [10] , in this study a single layer wideband E-shaped rectangular microstrip antenna for wireless sensor networks was proposed.

It was designed to cover the 5.33-5.71 GHz frequency band with 5.5GHz resonance frequency. The extra slot was included to reduce the size of the patch. The proposed patch was fed by a coaxial probe along the centerline of the patch.

The antenna geometry was an E - shaped microstrip patch Antenna supported by a low dielectric substrate (duroid) with dielectric permittivity εr =2.2 and thickness h =3.2 mm. An air-filled substrate was sandwiched between the substrate and ground plane. In this design, the use of thick air filled substrate in between the radiating patch and the ground plane provides the bandwidth enhancement.

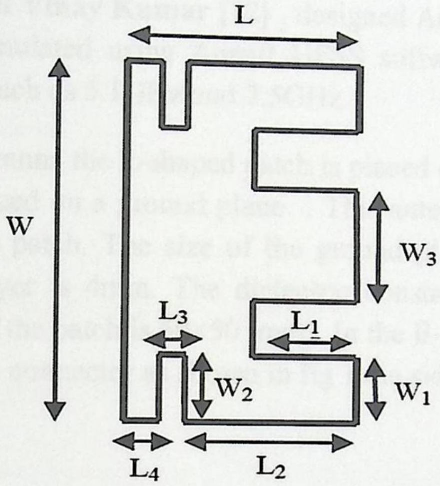


Fig 3.3 : Geometry of the proposed microstrip antenna

The wideband characteristic is due to large separation between the radiating patch and the ground plane and due to the use of low permittivity substrate with the proposed design.

G. Purnachandra Rao, Kshitiz Agarwal ,M.V. Kartikeyan, M.K.Thumm [11] ,the researcher studied a single wideband E-shaped compact microstrip antenna for high speed WLANs operating in the 5 – 6 GHz range. By using only single patch a high impedance bandwidth is achieved.

The simulated bandwidth is 25.9%, and measured bandwidth is approximately equal to 24.85%.the antenna gain is 8.5dB.

The parameters for the design of rectangular microstrip antenna are :

Frequency of operation (f0) ,The resonant frequency selected for rectangular patch is (5.8 GHZ).

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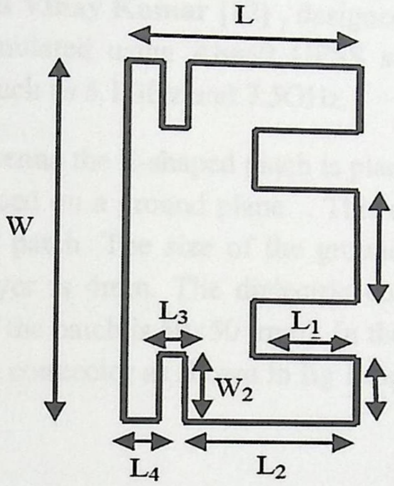

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Frequency of operation (f0) ,The resonant frequency selected for rectangular patch is (5.8 GHZ).

Two substrates are used for the fabrication of antenna which helps in optimizing the bandwidth. lower substrate has dielectric constant $\varepsilon_r1=1.25$ and and thickness $h_l= 2.6924$ mm. The upper substrate has dielectric constant $\varepsilon_{r2}= 6.15$ and thickness h2=1.27 mm. The researchers show the effect various parameters (W,L,W1,Lc,W2,Ws,Ls..) on the resonant frequency without changing the permittivity and height of the substrates, and frequency band.

But in our design , we designed an E- shaped antenna at dual band not wideband , and using two different resonant frequencies (900 & 1200) MHz , we designed a single layer E-shaped antenna from air $\varepsilon_r =1$ and thickness 29.5 mm , and from FR4 $\varepsilon_r =4.4$ and thickness 1.6 mm . Also , we designed a multilayer E-shaped antenna , the upper substrate from duroid has dielectric constant $\varepsilon_r = 2.2$ and thickness 1.6mm and the lower substrate from air has dielectric constant $\varepsilon_r = 1$ and thickness 25 mm.

Subodh Kumar Tripathi and Vinay Kumar [12] , designed An E- shaped Microstrip Antenna and designed structure is simulated using Ansoft HFSS software. Designed antenna can be operated in dual frequencies such as 5.1GHz and 7.5GHz.

In this designed microstrip antenna the E-shaped patch is placed on the top of the dielectric sheet and the dielectric sheet is placed on a ground plane . This antenna consists of a ground plane, dielectric layer and E-shaped patch. The size of the ground plane is 100×100 (mm), and the thickness of the dielectric layer is 4mm. The dielectric constant of the dielectric layer is in between 2.2 to 12. The size of the patch is 50×50 (mm). In the E-shaped patch probe is fed in the middle with the 50ohms-SMA connector as shown in fig 1.the side view of the E-shaped antenna is shown in Fig 3.4 .

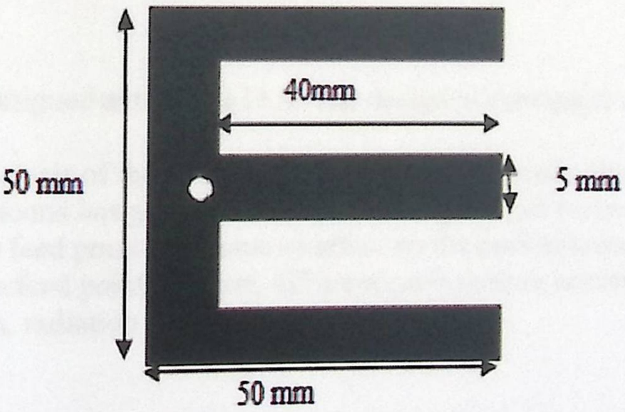


Fig. 3.4 : E-shaped microstrip antenna with middle probe feeding

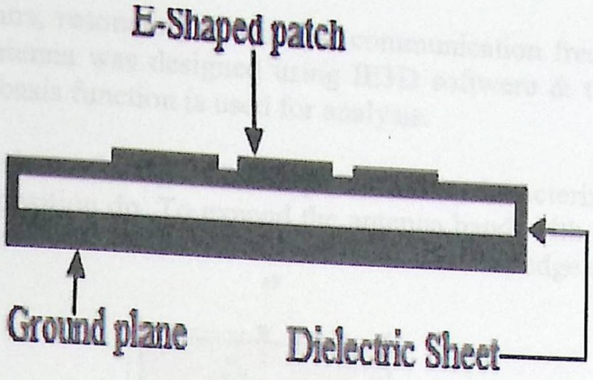


Fig. 3.5 : The side view of the E-shaped antenna

The researcher discuss the effect of parameters on the performance of designed E-shaped microstrip antenna. It has been observed that position of the feed line with specific antenna structure affects the various performance parameters such as gain, radiation pattern and return loss of the antenna. Variations in the dielectric constant also affect the performance parameters of the designed microstrip antenna.

Stimulated results:

1. If we take the feed point in the middle strip of E-shaped patch the simulated return loss is -14 dB.
2. If we take the feed point in end of the middle strip of E-shaped patch the simulated return loss is -18 dB .

3-If we take the feeding point as shown in fig 1. The return loss of the designed antenna is

-22 dB .

Also , the gain of the designed antenna is 11.5. The designed antenna is radiating all its power in one direction.
From the simulation analysis of the designed antenna it can be easily observed that the designed E-shaped microstrip antenna has good gain i.e. 11.5 and optimized return loss i.e.-22db. It has also been observed that feed point has a crucial effect on the performance of the designed antenna. By varying the feed point position, different performance parameters can be optimized such as return loss, gain, radiation pattern .

Naresh Kumar Joshi, Kamal Kumar Verma [13] , presents a single-patch dual band microstrip antenna: the E-shaped patch antenna on a single-layer foam substrate is investigated. The dualband mechanism is explored by investigating the behavior of the currents on the patch. Bandwidth enhancement of the antenna is achieved by inserting two parallel slots into its radiating patch. The effects of the following design parameters: the slot length, width, and position are optimized to achieve a broad bandwidth.

An E-shaped patch antenna, resonating at wireless communication frequencies of 1.5 and 2.9 GHz, is designed. The antenna was designed using IE3D software & the method of moments with the vector triangular basis function is used for analysis.

The antenna geometry is shown in Fig. 3.6 .The patch size is characterized by L, W, h and it is fed by a coaxial probe at position dp. To expand the antenna bandwidth, two wide slits have the same length l and the same width w1 and are inserted at the bottom edge of the patch.

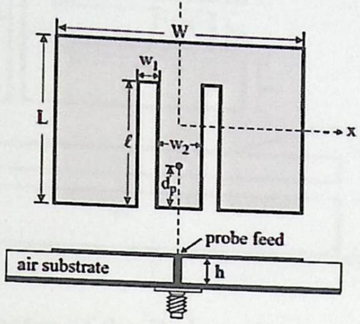


Fig. 3.6 : Geometry of E-Shaped Patch Antenna.

The effect of the slots, most importantly, the amplitudes of currents around the slots are different at low resonant frequencies and high resonant frequencies. It means that the effects of the slots at these two resonant frequencies are different. This is the key reason why the slots can extend the bandwidth.

The two resonant frequencies affected by different parameter antenna width & slots ,the antenna width controls the higher resonant frequency while the slots control the lower resonant frequency. Because of the dual resonant character, this kind of microstrip antenna can achieve a wide bandwidth.

In addition, the slot length is an important parameter to characterize the resonant frequencies of the E-shaped patch antenna. When the slot length is small, the antenna only has one resonant frequency. When the slot length increases, another lower resonant frequency appears. The longer the slot length, the lower the second resonant frequency.

Ahmad Bayat [15] , a single wideband, E-shaped, compact microstrip antenna is presented in this paper in order to be employed for high speed WLANs operating in the C band range. Employing only a single patch, a high impedance bandwidth is achieved. The simulated impedance bandwidth (VSWR<1.75) is 30%, and the momentum bandwidth is about 28.5%. The structure of the antenna consists of a perfect conductor on the top of a substrate (RT duroid 5880) with a dielectric constant of about 2.2 and a height of 20 mile, which is backed with a perfect conductor ground plane. The impacts of different parameter of antenna are also studied in this article.

The main disadvantages of microstrip antenna can be low efficiency, low throughput, narrow bandwidth and low frequency range. In this paper, by using some of the techniques of traditional microstrip antenna, bandwidth has been increased.. In this paper, using IE3D software, and deals with a single probe feed. Of the proposed antenna, the impedance bandwidth of 37 percent was achieved.

The geometry of this antenna is presented in this paper as below:

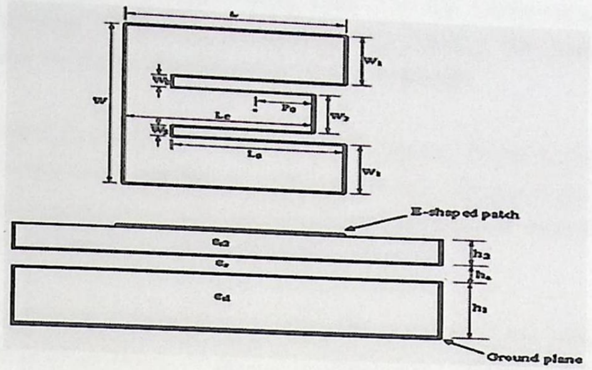


Fig. 3.7 : Geometry of the E-shaped microstrip patch antenna

Two dielectric substrate materials are employed to fabricate the antenna element. An air gap of 1mm is let between the two substrates. The upper substrate is selected to be with high dielectric constant (RT duroid 5880 is of the dielectric constant of εr1 =2.2 and the thickness of h1= 20mm) for compact size, and the lower substrate is foam dielectric material(εr2= 9.6 and the thickness of h2=30 mm) in order to provide ground plane. An air gap is let since the thickness of the foam material is fixed, and it helps in optimizing the wide bandwidth.

The paper deals with the effects of various parameters:

Length of the slots(Ls): By increasing Ls, the whole VSWR curve shifts towards lower frequencies. The change is higher in resonant frequency of higher mode, since the relative change in current path length for higher mode is greater than the lower mode current path.

width of the slots(Ws): The width Ws has a significant effect on the matching to the input port, while it marginally affects the resonant frequencies of the two modes.

Effect of length of the central patch strip (Lc): The resonant frequency of the higher mode decreases as Lc increases, while there is no significant change in resonant frequency of the lower mode.

The simulated 2:1 VSWR bandwidth is 30 % covering the (4.82 – 6.43 GHz) frequency band and the momentum 2:1 VSWR bandwidth is 28.8 % covering (4.91 – 6.4 GHz) frequency band, The shift in the frequency band is because of the decrease in the height of the upper substrate with high dielectric constant in the fabrication process. Decreasing the height of upper dielectric substrate is about 0.5 mm, which leads to this shift of frequency band. The radiation pattern was measured in anechoic chamber.

Differences in our project :

Firstly, we designed an E- shaped antenna, with two types of polarization, linear with dual band and circular with wideband at different frequencies using FEM for verify the results.

We also discussed the effect of antenna parameters on the performance of designed E-shaped microstrip antenna by varying different parameters including the position of the feed point , using coaxial cable in order to enhance the gain of the antenna.

We designed a single layer E-shaped Antenna with linear Polarization from air ($\varepsilon_r = 1$) and thickness 29.5 mm the result resonating at two different frequencies (900 & 1200)MHz, and from FR4 ($\varepsilon_r = 4.4$) and thickness 1.6 mm the result resonating at two frequencies (840 & 1200) MHz ,without carrying out any optimization.

Another design for linear polarization using a multilayer E-shaped antenna , the upper substrate from duroid has dielectric constant ($\varepsilon_r = 2.2$) and thickness 1.6mm and the lower substrate from air has dielectric constant ($\varepsilon_r = 1$) and thickness 25 mm the result resonating at two different frequencies (900 & 1200) MHz .

Finally, we designed a single layer E-shaped Antenna with Circular Polarization from air ($\varepsilon_r = 1$) and thickness 15 mm the result resonating (2.65)GHz, and from FR4 ($\varepsilon_r = 4.4$) and thickness 1.6 mm the result resonating at (2.61)GHz.

Chapter 4

Design of an E-Shaped Microstrip Antenna Using Ansoft Designer Software

4.1 Overview

In this chapter we will introduce the design of a microstrip transmission line antenna and dipole antenna , then we will introduce the design of E-shaped microstrip antenna with microstrip line feeding using Ansoft designer sv. software .

4.2 Design of microstrip antenna using matlab

Traditionally one can design a matlab code utilizing Maxwell equations and finite difference method to solve for single known microstrip patch antenna , we present a code for that in appendix [A] .

Here are a few results that determine return loss , directivity and feed point impedance. For more accomplished studies , Ansoft designer is an internationally known software that enables design and analysis of low profile antennas.

Maxwell's equations :

$$\nabla \times H = J + \frac{dD}{dt} \qquad (4.1)$$

$$\nabla \times E = \frac{-dB}{dt} \qquad (4.2)$$

$$\nabla . D = \rho v \qquad (4.3)$$

$$\nabla . B = 0 \qquad (4.4)$$

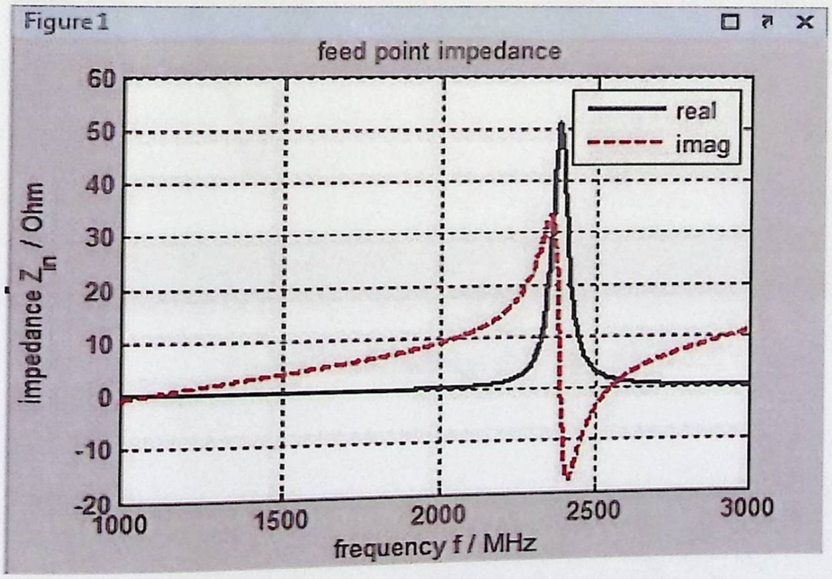


Fig 4.1: Feed point impedance

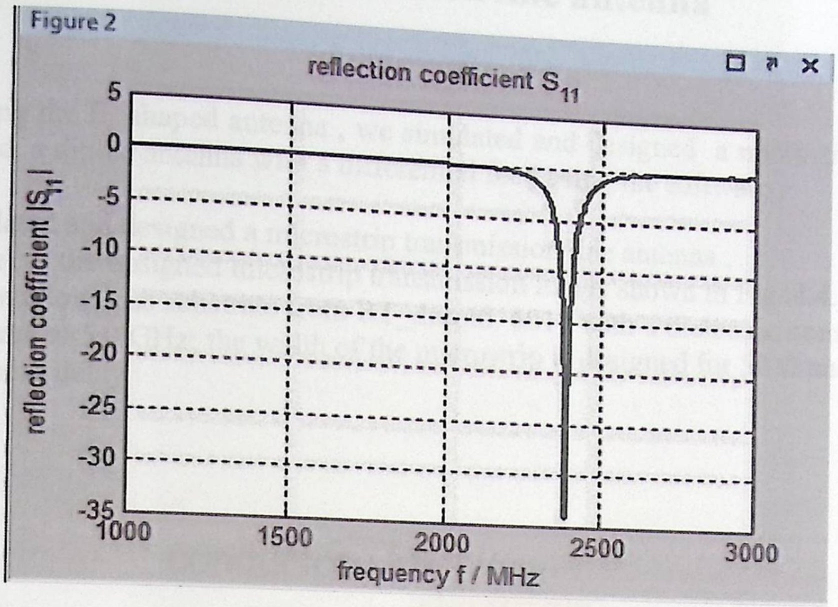


Fig 4.2: Reflection coefficient S_{11}

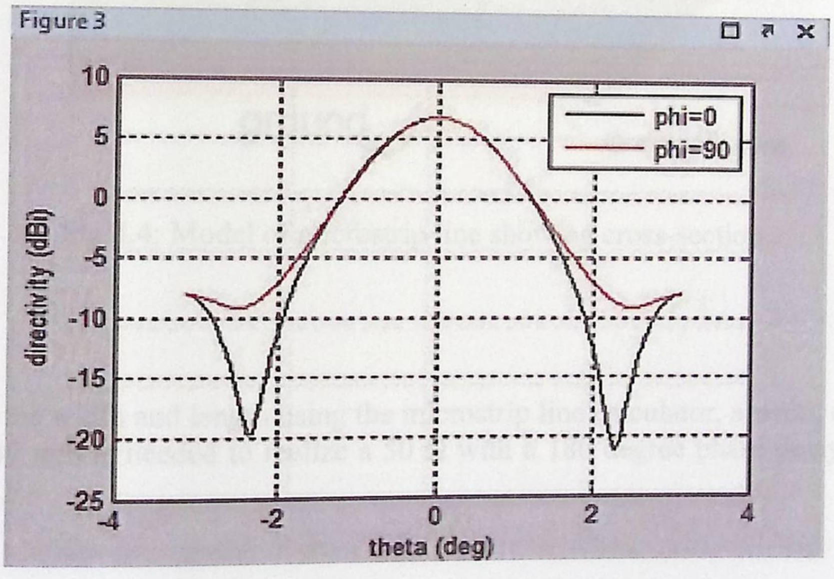


Fig 4.3: Normalized directivity

4.3 Design of microstrip transmission line antenna

Before designing the E- shaped antenna , we simulated and designed a microstrip transmission line antenna and a dipole antenna with a differential feed using the software .

First , we simulated and designed a microstrip transmission line antenna .
The basic model of the designed microstrip transmission line is shown in Fig. 4.4. The microstrip line designed on a low loss substrate from RT_duroid 6010 with a dielectric constant 10.2 and a height of 1.27 mm at 5.0 GHz; the width of the microstrip is designed for 50 Ω and the length for a 180 degree phase delay.

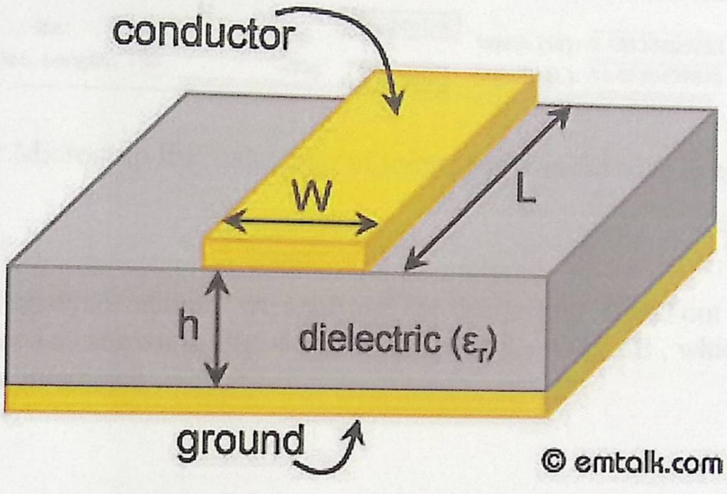
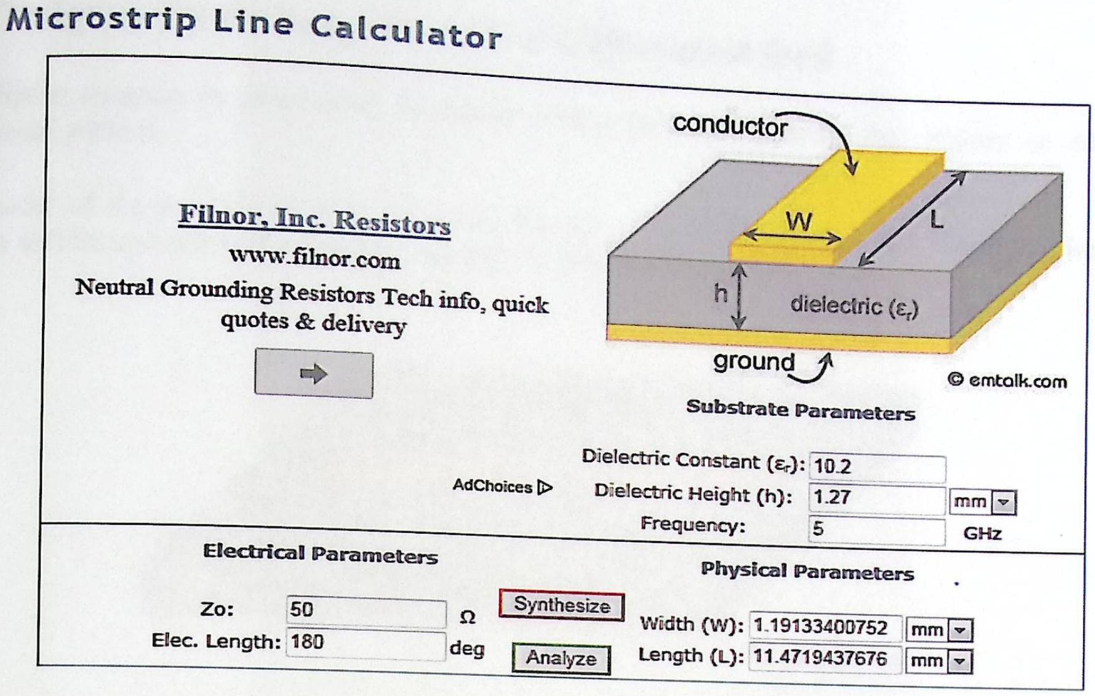


Fig 4.4: Model of microstrip line showing cross-section .

We determined the width and length using the microstrip line calculator, a width of 1.19 mm and a length of 11.47 mm is needed to realize a 50 Ω with a 180 degree phase delay at 5.0 GHz as shown in Fig. 4.5.



Microstrip Line Calculator

Substrate Parameters

Dielectric Constant (ε_r): 10.2
Dielectric Height (h): 1.27 mm
Frequency: 5 GHz

Electrical Parameters

Zo: 50 Ω
Elec. Length: 180 deg

Physical Parameters

Width (W): 1.19133400752 mm
Length (L): 11.4719437676 mm

Fig 4.5 : Microstrip line calculator of microstrip transmission line antenna

After excitation and analysis setup , we analyzed the design and found out the results of return loss (S_{11} – parameter) as shown in Fig. 4.6 , the value of $S_{11} < -10$ dB , which is accepted value for reflections due to mismatch .

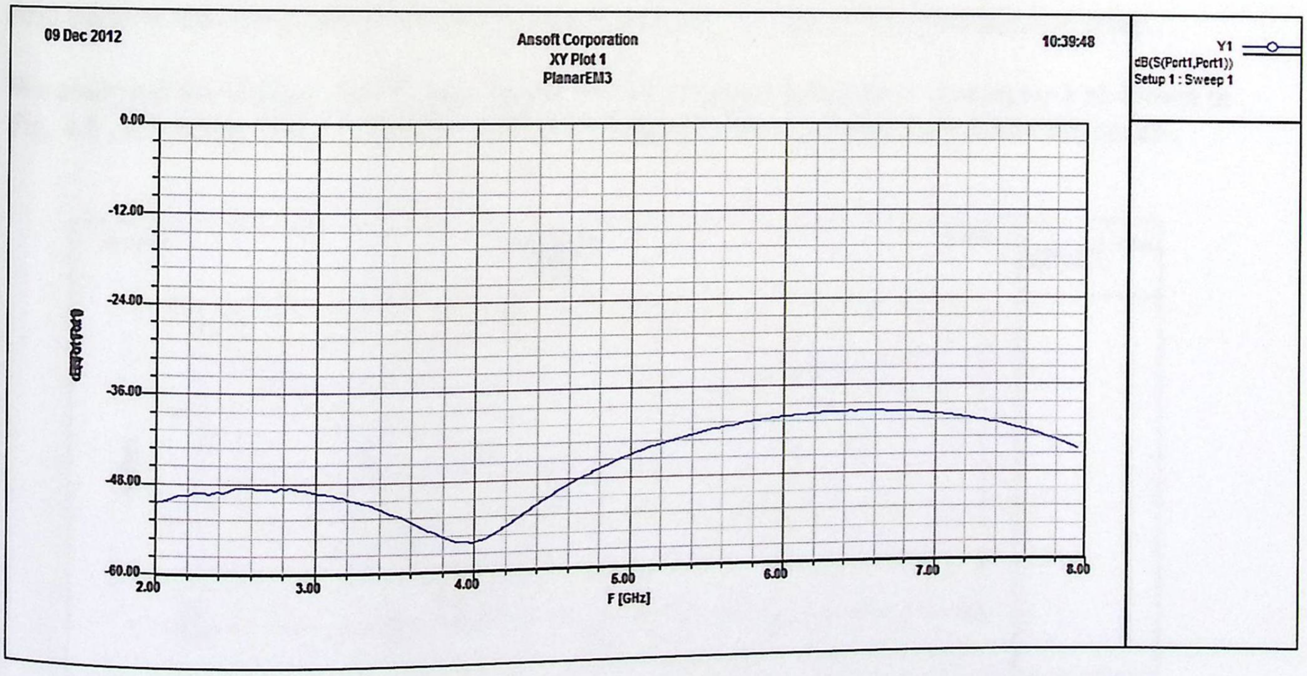
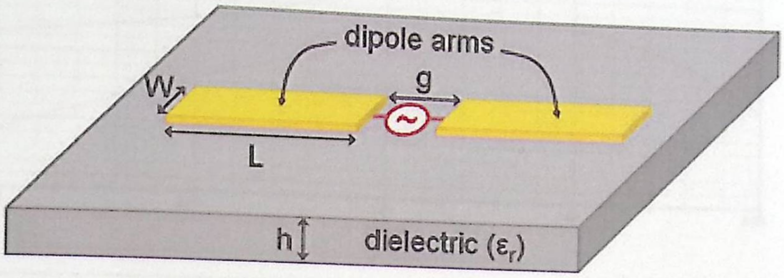


Fig 4.6: Return loss (S_{11} – parameter) in dB of microstrip transmission line antenna

4.4 Design a dipole antenna with a differential feed

The dipole antenna is often used in planar microwave applications that require an omni-directional pattern .

The model of the printed dipole is shown in Fig. 4.7 . The dipole arm's width 5 mm and length 50 mm will be optimized for 3.0 GHz operation, while the feed gap is 1mm .



© emtalk.com

Fig 4.7: Model of printed dipole antenna based on differential feeding

The dipole antenna designed on a low loss substrate from RT_duroid 5880 with a height of 0.010 inch with a dielectric constant of 10.2 at 3.0 GHz , with a 90 degree phase .

After excitation and analysis setup , we analyzed the design and found out the results of return loss (S_{11} – parameter) real and imaginary input impedance over (2 – 4) GHz range to confirm the resonant frequency .
The result show that the dipole resonates at 2.75 GHz (Imag (Zin = 0)) .
And because we use student version of Ansoft designer we can 't make optimization setup .

We analyzed the design and found out the results of return loss (S_{11} – parameter) as shown in Fig. 4.8 , the value of $S_{11} < -10$ dB , which is accepted value for reflections due to mismatch .

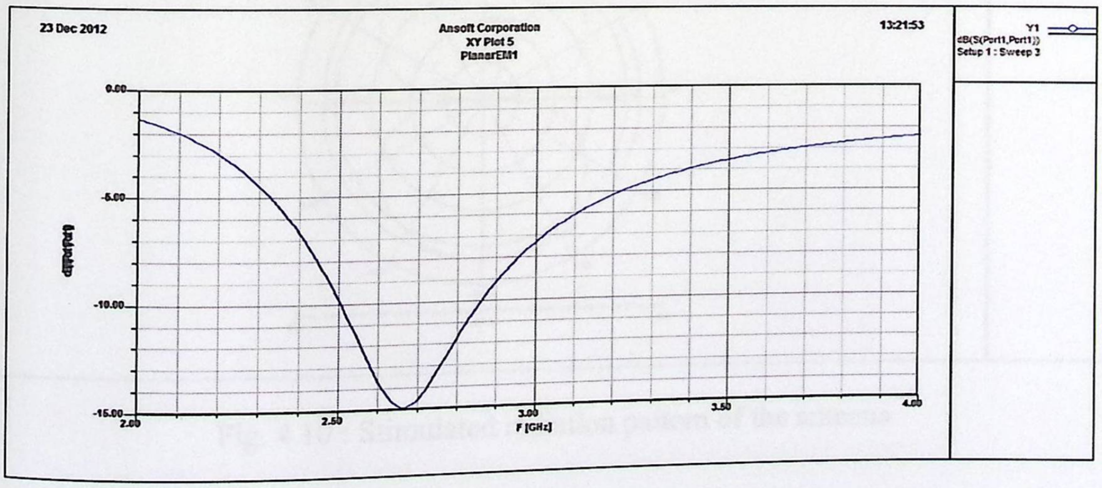


Fig 4.8: Return loss (S_{11}- parameter) of dipole antenna

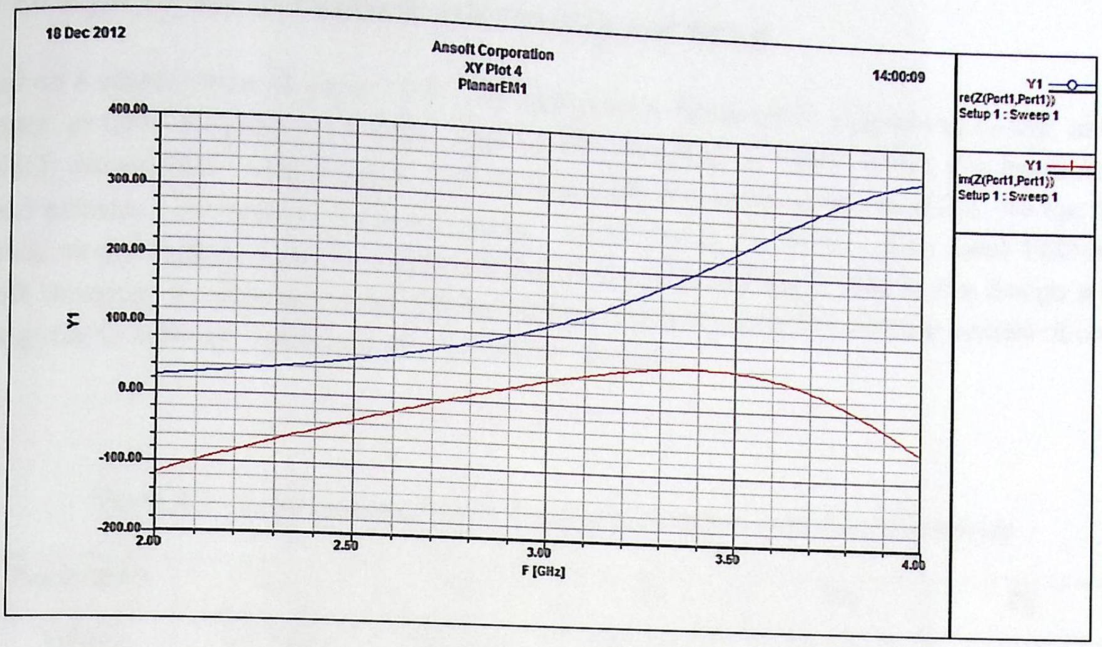


Fig 4.9: Input impedance of un-optimized printed dipole

And we also find the radiation pattern of the dipole antenna

We have two lobes at (0 and -180) degree and two nulls at (90 and -90) degree at Phi = 0 degree .

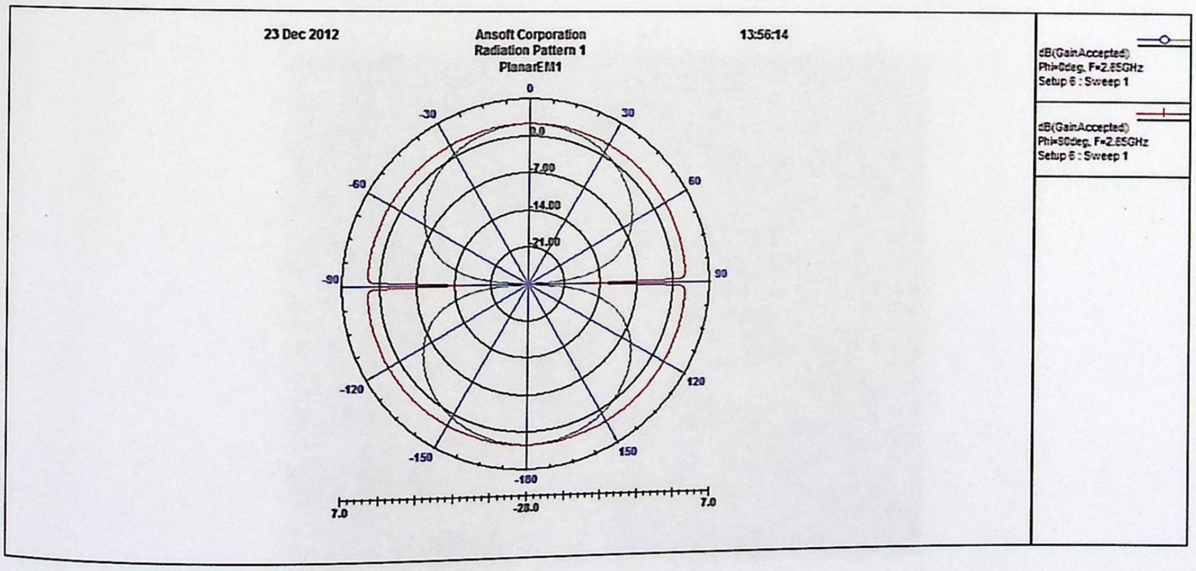


Fig. 4.10 : Stimulated radiation pattern of the antenna

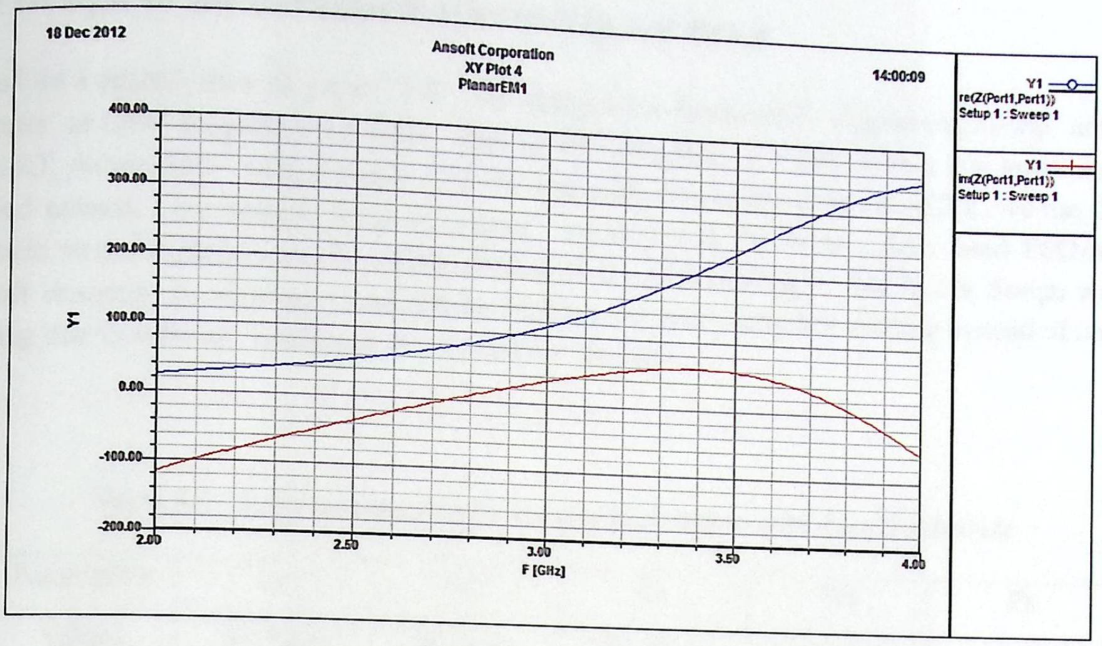


Fig 4.9: Input impedance of un-optimized printed dipole

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We have two lobes at (0 and -180) degree and two nulls at (90 and -90) degree at Phi = 0 degree .

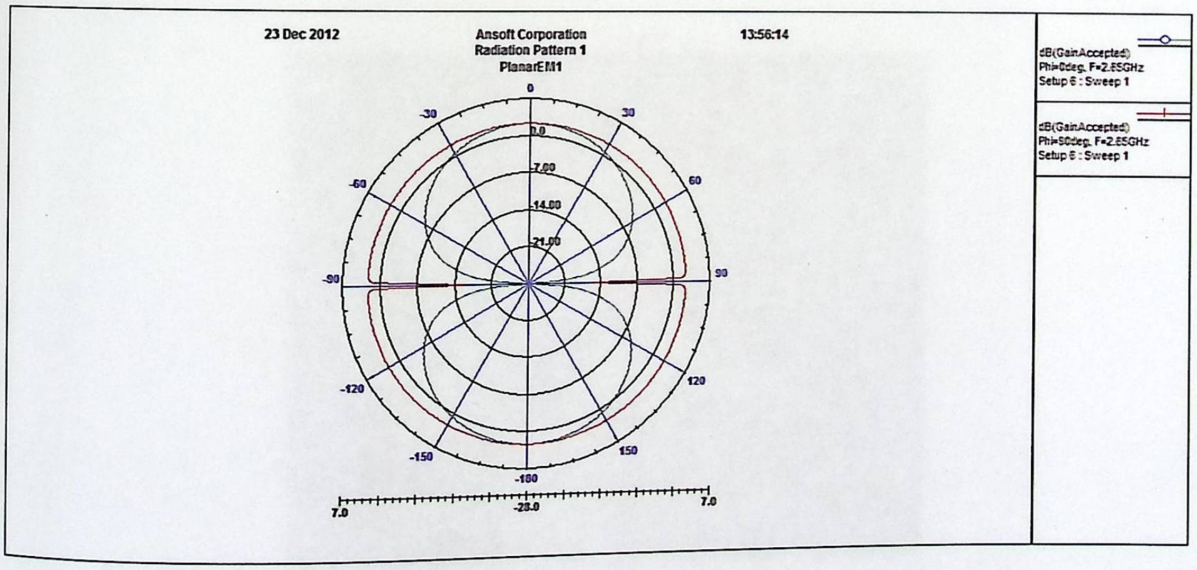


Fig. 4.10 : Stimulated radiation pattern of the antenna

4.5 Design of an E-shaped microstrip antenna

Based on a recent research paper [14] , we designed a dualband E- shaped microstrip antenna operates at GSM frequency 1.8 GHz and at wifi frequency 2.4 GHz with a low loss substrate from RT_duroid 5880 with a height of 0.787 mm with a dielectric constant of 2.2 .We use the E-shaped antenna parameters from the paper , as shown in the table , that used PSO-MOM (particle swarm optimization by using method of moment) software , but in our design we use Ansoft designer sv. software , and fed the antenna by microstrip line feeding instead of coaxial feeding due to software limitation of our student version.

Table 4.1 : E-shaped microstrip antenna parameters with duroid substrate

Parameters	Lp	Wp	Ls	Ws	Ps
Values	54.9mm	83.9mm	52.4 mm	17.4mm	11mm

Where :

Lp: patch length
Wp :patch width
Ls: slot length
Ws: slot width
Ps : slot position

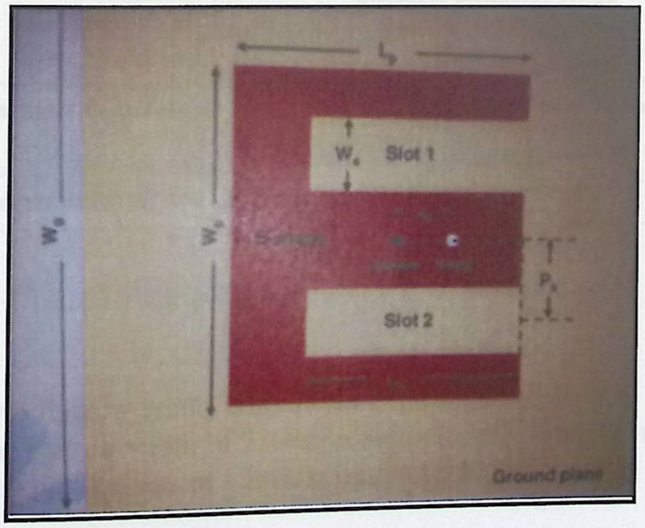


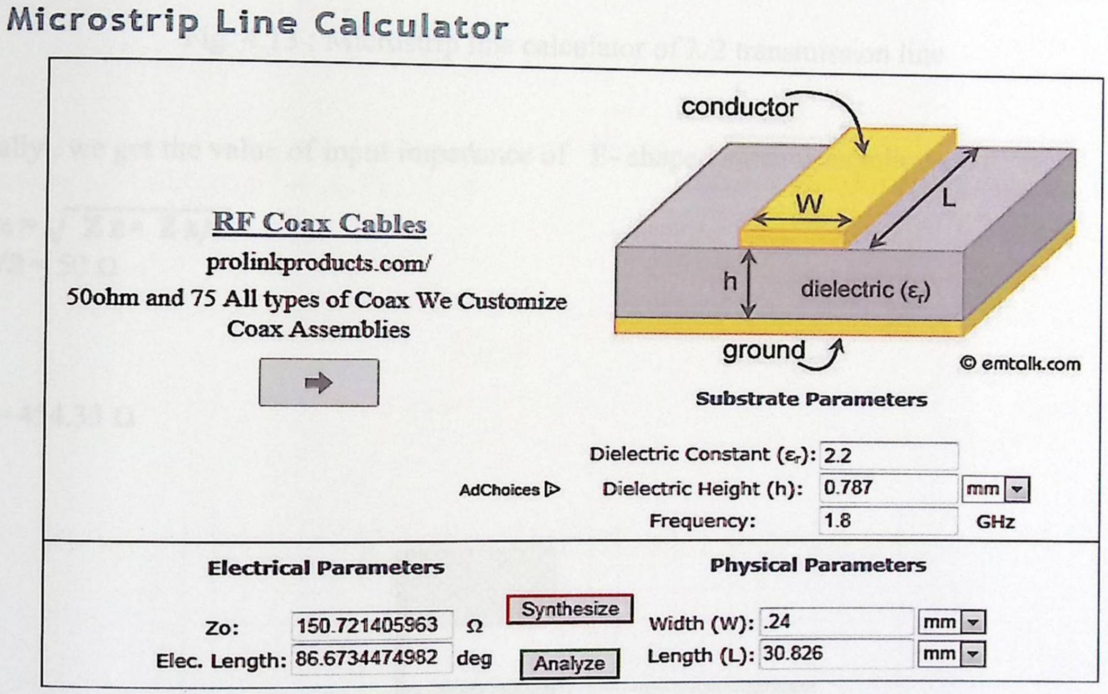
Fig 4.11: Geometry of designed E- shaped microstrip antenna

Feeding design :

To feed the E-shaped microstrip antenna we used microstrip line feeding method with a quarter wavelength line for matching .
Because there is no standard formula to determine the input impedance of the E- shaped microstrip antenna , we used 50Ω half wavelength transmission line connected to a quarter wavelength matching line. We did a few trials to change the impedance of the quarter wave line until it matched that of the E-shaped antenna by noting the best return loss.

Evaluating the impedance of the quarter wavelength transmission line :

Using the microstrip line calculator, we determined the output impedance of the quarter wavelength transmission line which equal 150.72 Ω to realize 0.24 width and 30.826 length as shown in Fig 4.12 .



Microstrip Line Calculator

RF Coax Cables
prolinkproducts.com/
50ohm and 75 All types of Coax We Customize Coax Assemblies

Substrate Parameters

Dielectric Constant (ε_r): 2.2
Dielectric Height (h): 0.787 mm
Frequency: 1.8 GHz

Electrical Parameters

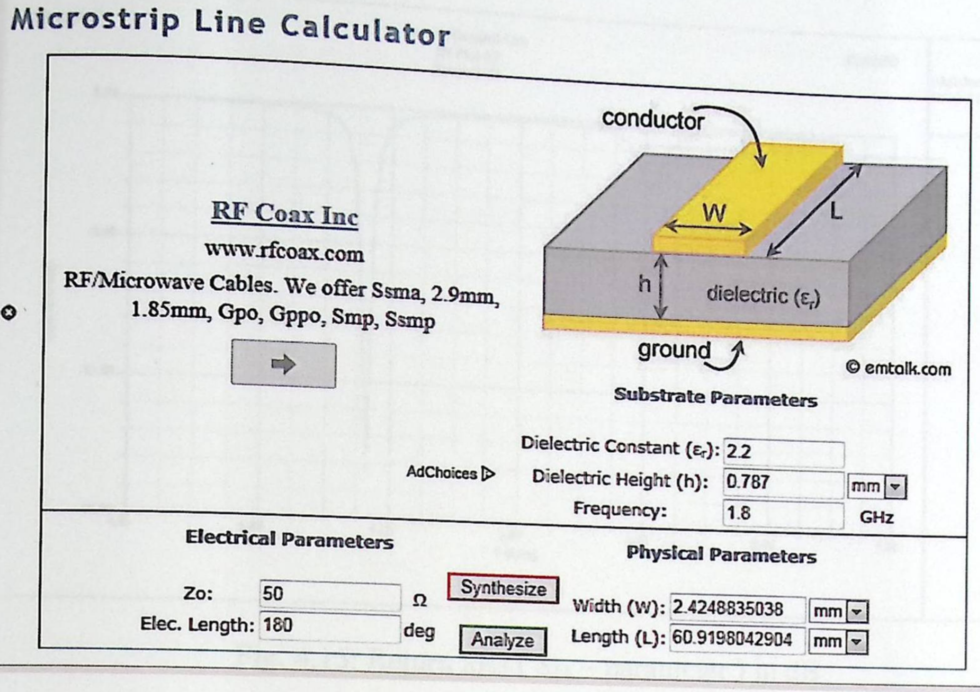
Zo: 150.721405963 Ω
Elec. Length: 86.6734474982 deg

Physical Parameters

Width (W): .24 mm
Length (L): 30.826 mm

Fig. 4.12: microstrip line calculator of λ/4 transmission line

And using the microstrip line calculator also , we determined the width and length of the half wavelength transmission line , a width of 2.24 mm and a length of 60.91 mm is needed to realize a 50 Ω with a 180 degree phase delay at 1.8 GHz as shown in Fig. 4.10 .



Microstrip Line Calculator

RF Coax Inc
www.rfcoax.com
RF/Microwave Cables. We offer Ssma, 2.9mm, 1.85mm, Gpo, Gppo, Smp, Ssmp

Substrate Parameters

Dielectric Constant (ε_r): 2.2
Dielectric Height (h): 0.787 mm
Frequency: 1.8 GHz

Electrical Parameters

Zo: 50 Ω
Elec. Length: 180 deg

Physical Parameters

Width (W): 2.4248835038 mm
Length (L): 60.9198042904 mm

Fig. 4.13 : Microstrip line calculator of λ/2 transmission line

Finally , we get the value of input impedance of E- shaped antenna as follows :

$$Z_{\lambda/4} = \sqrt{Z_E * Z_{\lambda/2}}$$

$Z_{\lambda/2} = 50\ \Omega$

So :

$Z_E = 454.33\ \Omega$

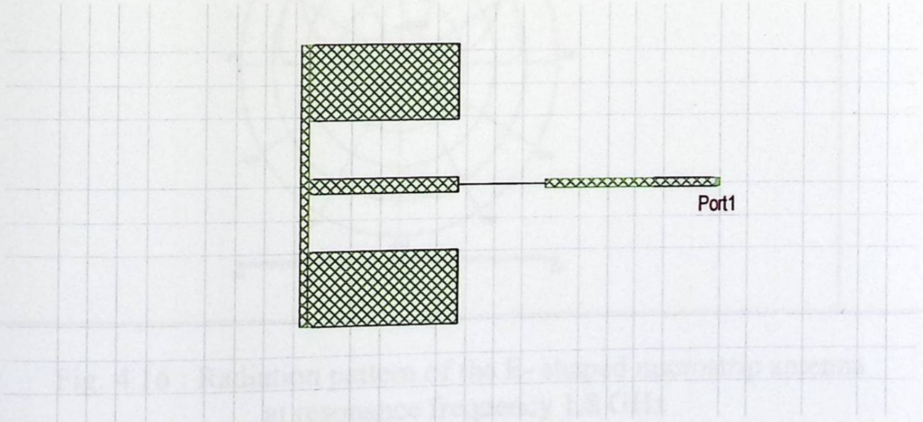


Fig. 4.14 : Designed E- shaped microstrip antenna

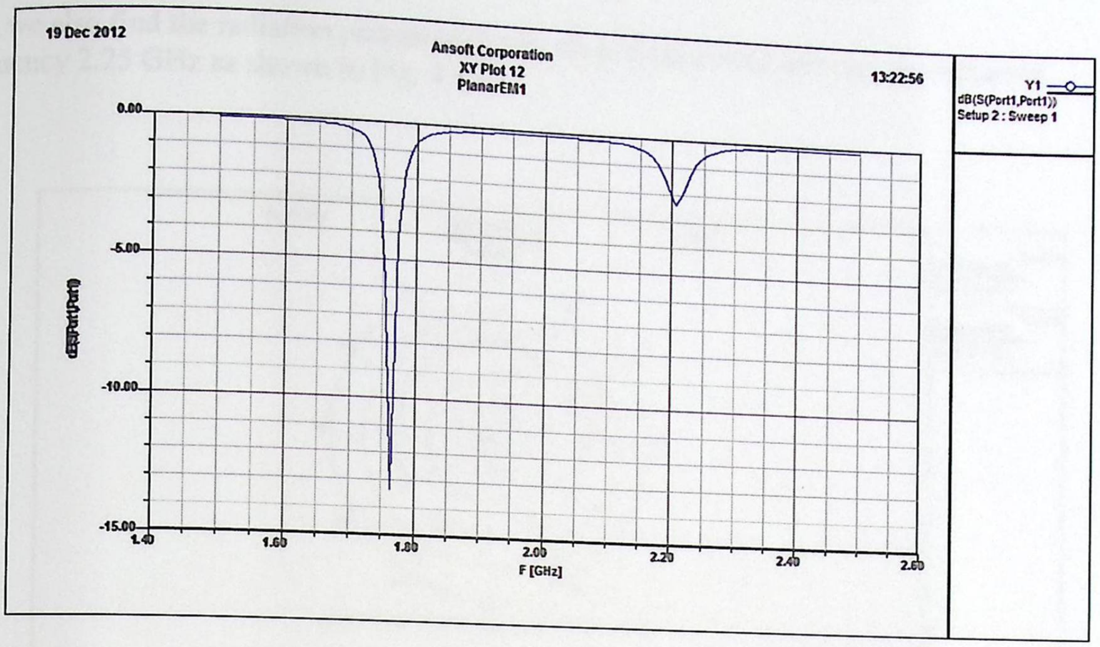


Fig. 4.15: Return loss (S_{11} – parameter) in dB

And we also found the radiation pattern of the E- shaped microstrip antenna at resonance frequency 1.8 GHz as shown in Fig. 4.16.

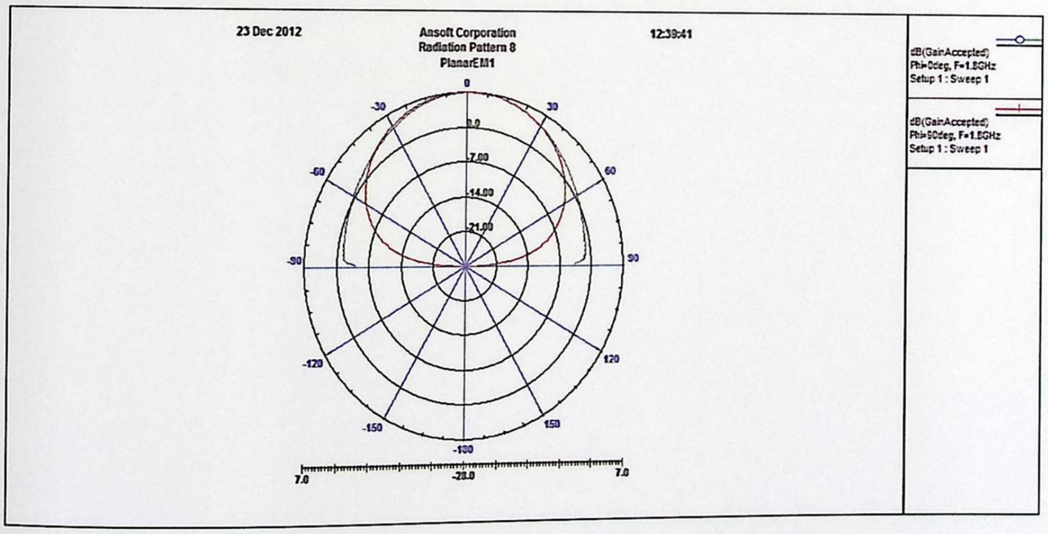


Fig. 4.16 : Radiation pattern of the E- shaped microstrip antenna at resonance frequency 1.8 GHz

And we also find the radiation pattern of the E- shaped microstrip antenna at resonance frequency 2.25 GHz as shown in Fig. 4.17.

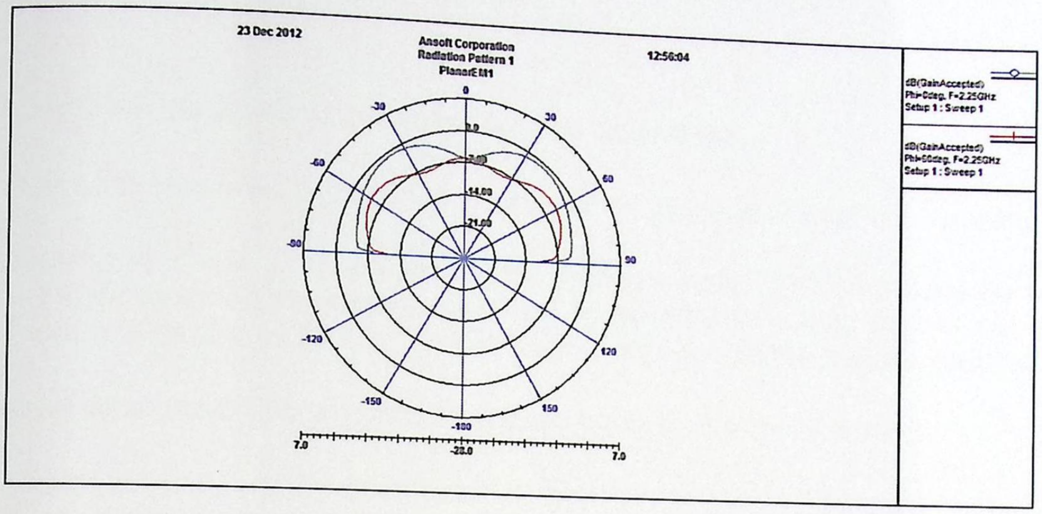


Fig. 4.17 : Radiation pattern of the E- shaped microstrip antenna at resonance frequency 2.25 GHz

Chapter 5

Parametric Study of the E-Shaped Microstrip Antenna

5.1 Overview

In this chapter we will introduce the design of an E-shaped microstrip antenna with a coaxial-probe feeding , using HFSS designer software .

5.2 Design of an E-shaped microstrip antenna

Based on a recent researched paper [14] ,we proposed the parameters in table 5.1 as states values.

We designed a dualband E- shaped microstrip antenna operates at GSM frequencies 1.8 MHz and at 2.4 GHz range which is commonly used by wireless local area devices and wireless personal area devices such as the 802.11 WIFI and the 802.15.4 Zigbee wireless systems.

We designed the antenna with a 15 mm air gap and using coaxial probe feeding .

Table 5.1: E-shaped microstrip antenna parameters with an air gap

Parameters	Lp	Wp	Ls	Ws	Ps	X_f	T
Values	51.9mm	95.6mm	43.4mm	21.3mm	14.7mm	13mm	15 mm

Where:

Lp: patch length
Wp :patch width
Ls: slot length
Ws: slot width
Ps : slot position
X_f: feed position
t:substrate thickness

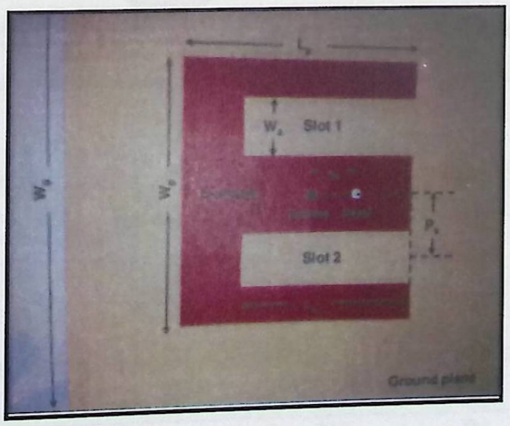


Fig 5.1 : Geometry of designed E- shaped microstrip antenna

5.1 Overview

In this chapter we will introduce the design of an E-shaped microstrip antenna with a coaxial-probe feeding , using HFSS designer software .

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Where:

Lp: patch length
Wp :patch width
Ls: slot length
Ws: slot width
Ps : slot position
X_f: feed position
t:substrate thickness

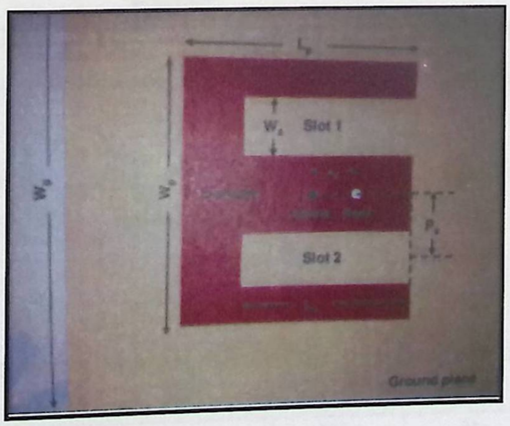


Fig 5.1 : Geometry of designed E- shaped microstrip antenna

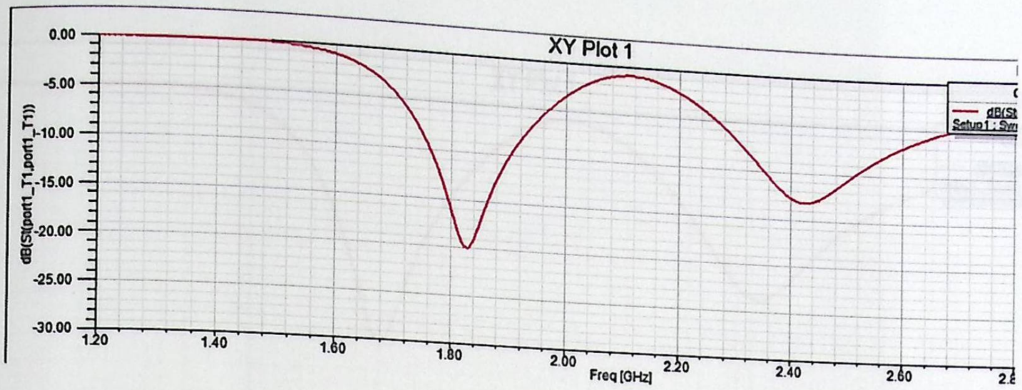


Fig 5.2 : Return loss (S_{11}- parameter in dB) of the designed E-shaped microstrip antenna at (1800 &2400)MHz

To get the resonance exactly at 1800 MHz and 2400 MHz the patch width (Wp) had to be scaled up , which made the frequencies down to the required values . That increased Wp from 95.6 mm to 98.6 mm .

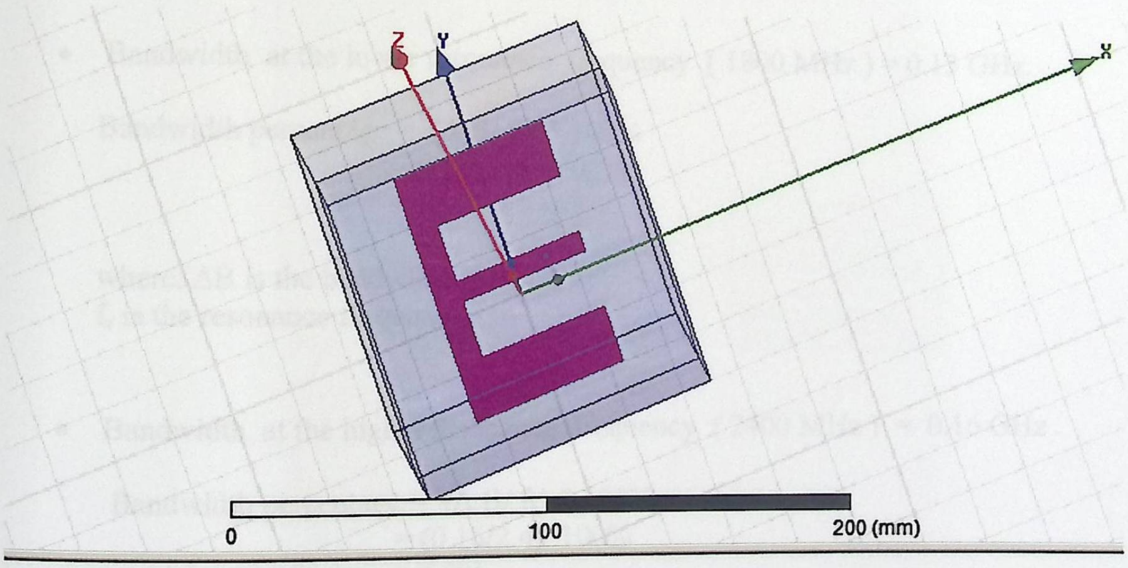


Fig 5.3 : Geometry of the optimized design of the E- shaped microstrip antenna using HFSS software

Table 5.2: Near - optimized E-shaped microstrip antenna parameters with an air gap

Parameters	Lp	Wp	Ls	Ws	Ps	X_f	t
Values	51.9mm	98.6mm	43.4mm	21.3mm	14.7mm	13mm	15 mm

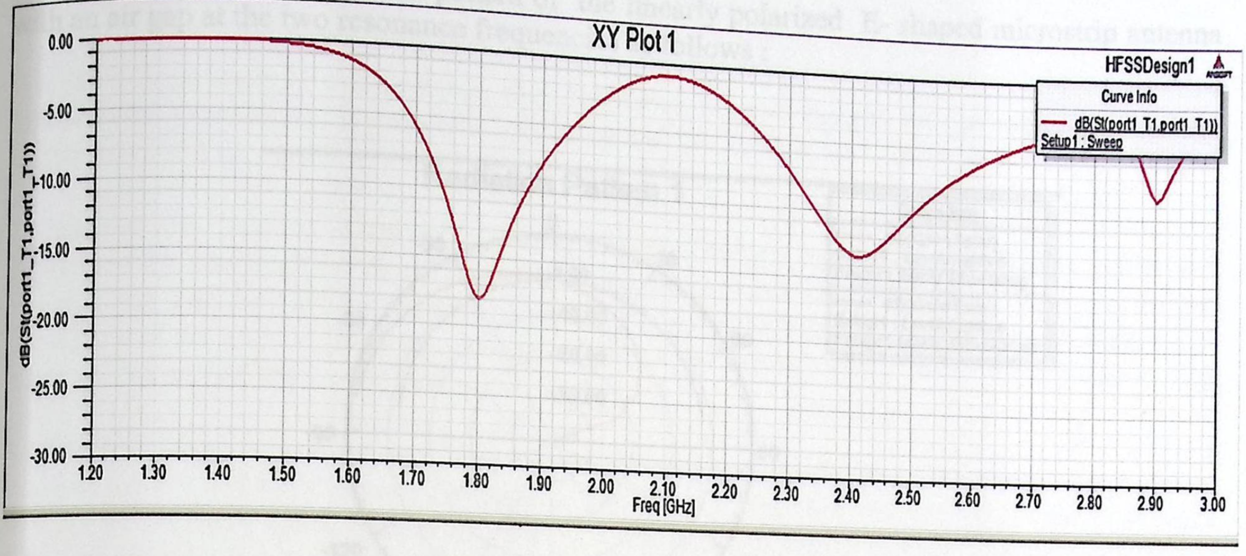


Fig 5.4 : Return loss (S_{11}- parameter in dB) of the optimized dimensions for the E- shaped microstrip antenna with an air gap at (1800 & 2400) MHz .

The results are summarized as follows:

- Bandwidth at the lower resonance frequency (1800 MHz) = 0.13 GHz.

  Bandwidth percentage = (Δ B/ fr) * 100%
  = (0.13/1.8)*100%
  = 7.2% .

  where: ΔB is the bandwidth.
  f_r is the resonance frequency.

- Bandwidth at the higher resonance frequency (2400 MHz) = 0.16 GHz .

  Bandwidth percentage = (Δ B/ fr) * 100%
  = (0.16/2.4)*100%
  = 6.7% .

- Return loss < -10 dB , this means we have a good matching and low reflection at the two resonance frequencies

  Return loss = - 13 dB at the higher resonance frequency and -18 dB at the lower resonance frequency .

And we also found the radiation pattern of the linearly polarized E- shaped microstrip antenna with an air gap at the two resonance frequencies as follows :

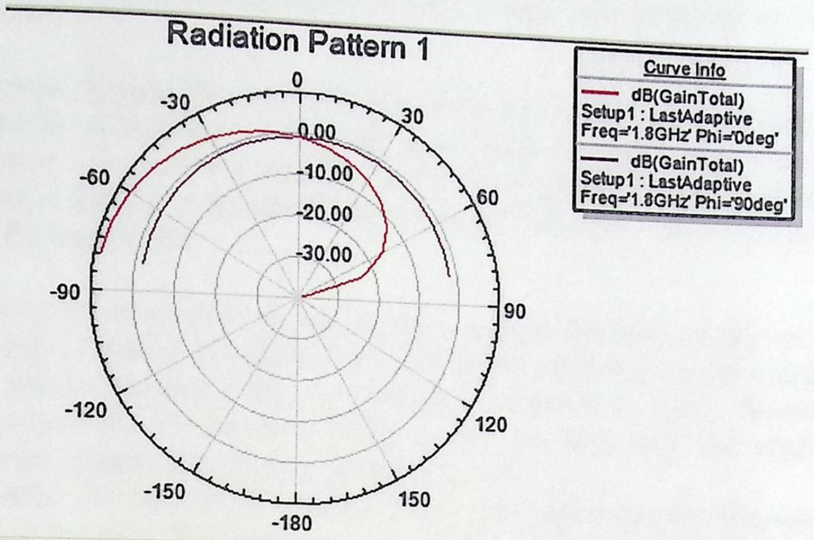


Fig. 5.5: Stimulated radiation pattern of the E-shaped microstrip antenna with an air gap at 1.8 GHz

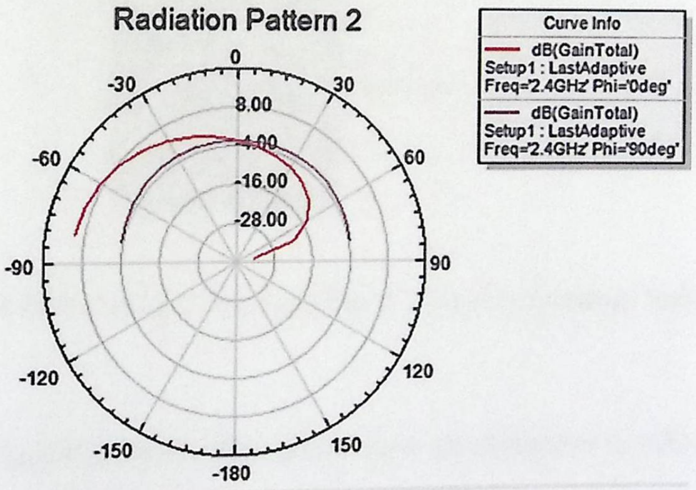


Fig. 5.6: Stimulated radiation pattern of the E-shaped microstrip antenna with an air gap at 2.4 GHz

5.3 Parametric studies

We have done manual optimization that provides a good insight on the effects of various dimensional parameters. It provides guidance on the design and optimization of E-shaped microstrip patch antenna.

To expand the antenna bandwidth, two parallel slots are incorporated into this patch and positioned symmetrically with respect to the feed point , since the amplitudes of currents around the slots are different at low resonant frequencies and high resonant frequencies. It means that the effects of the slots at these two resonant frequencies are different , this is the key reason why the slots can extend the bandwidth.

At the high frequency, the amplitudes of the currents around the slots are almost the same as those at the left and right edges of the patch. The effect of the slots are not significant. The patch works like ordinary patch. Therefore, the high resonant frequency is mainly determined by the patch width Wp , less affected by the slots. While at the low frequency, the amplitudes of the currents around slots are greater than those at high frequency.

Now it can be concluded that the antenna width controls the higher resonant frequency while the slots control the lower resonant frequency because of the dual resonant character, this kind of microstrip antenna can achieve a wide bandwidth .

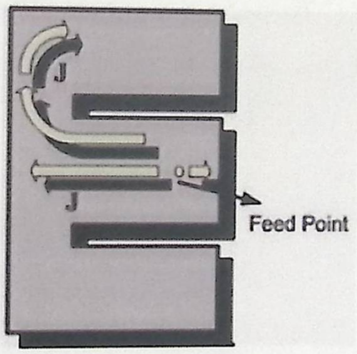


Fig 5.7: Current distribution of the designed E- shaped microstrip antenna

The slot length, width, and position and another parameters are optimized to achieve a wide bandwidth .

5.3.1 Parameters effects :

1. <u>**Length of the slots (Ls)**</u> :

By decreasing Ls, both resonant curves shift towards the higher resonance frequency and vise versa.

- Ls decreased to be equal 41.4 mm instead of 43.4 mm of an E- shaped antenna while other parameters were kept constant .

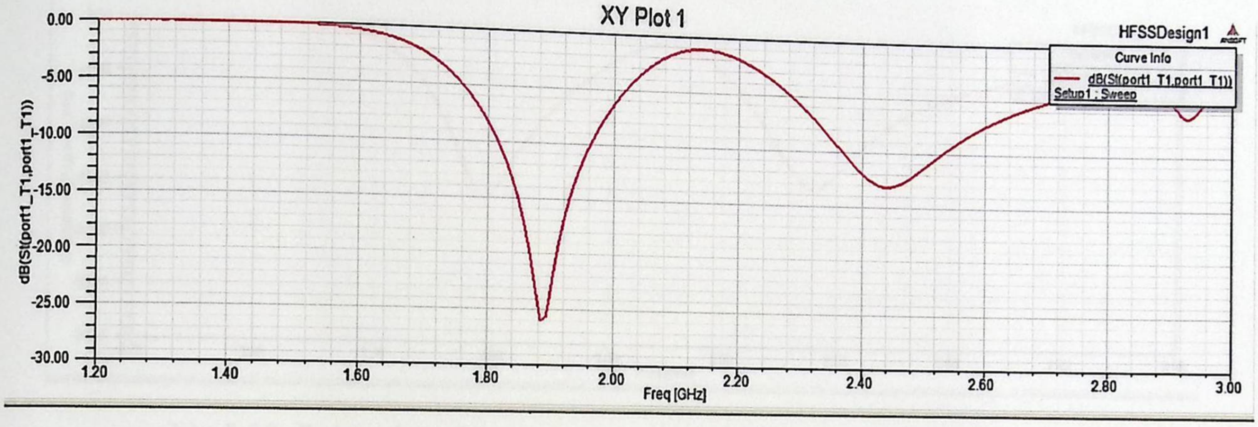


Fig 5.8: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after decreasing Ls

- Ls increased to be equal 45.4 mm instead of 43.4 mm, while other parameters were kept constant .

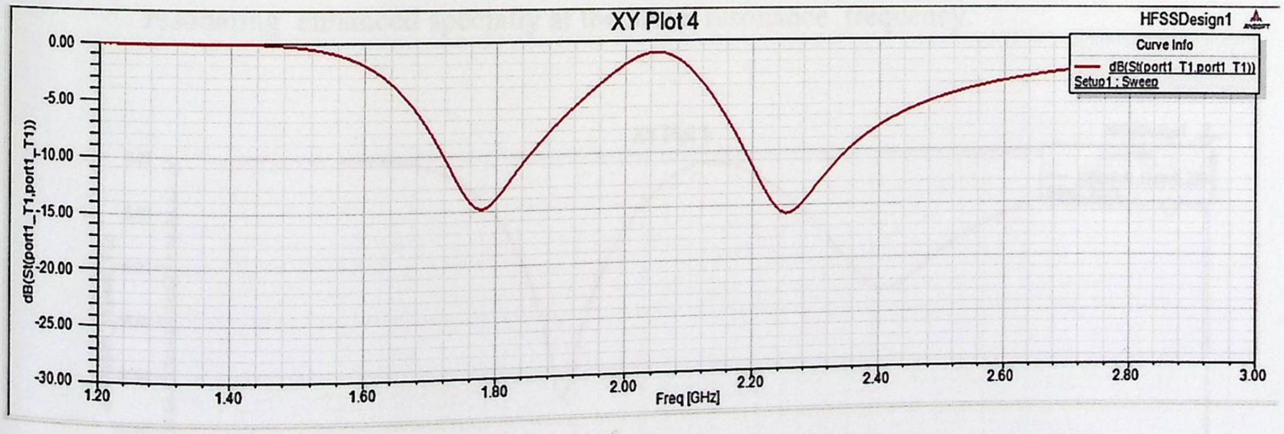


Fig 5.9: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after increasing Ls.

2. **Width of the slots (Ws):**

The slot width Ws is useful to adjust coupling and achieve good matching while it marginally affects the two resonance frequencies .

- Ws increased to be equal 22.3 mm instead of 21.3 mm , By changing the width of the middle slot of an E- shaped antenna only , the curve shifts toward the lower resonance frequency.

Fig 5.10: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after increasing Ws

- Ws increased to be equal 23.3 mm instead of 21.3 mm , by changing the upper & lower slots of an E- shaped antenna each by 2 while other parameters were kept constant ; the curve shifts toward the higher resonance frequency and the antenna resonating enhanced specially at the lower resonance frequency.

Fig 5.11: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after decreasing Ws

3. **Length of the patch (Lp)** :

The length of the patch can be changed to tune the frequency of the higher resonance mode, since it affects it more than the lower resonance mode.

- Lp decreased to be equal 47.9 mm instead of 51.9 mm while other parameters were kept constant ; the curve shifts toward the higher resonance frequency .

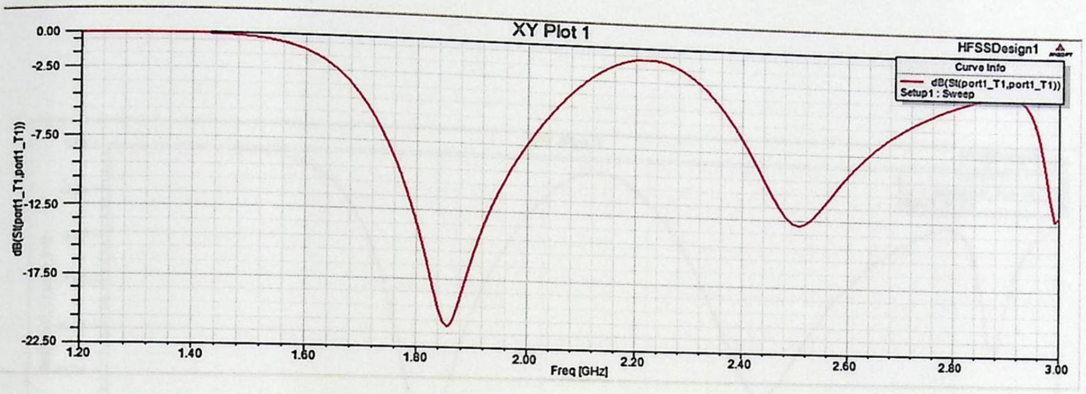


Fig 5.12: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after decreasing Lp.

- Lp increased to be equal 55.9 mm instead of 51.9 mm , while other parameters were kept constant ; the curve shifts toward the lower resonance frequency .

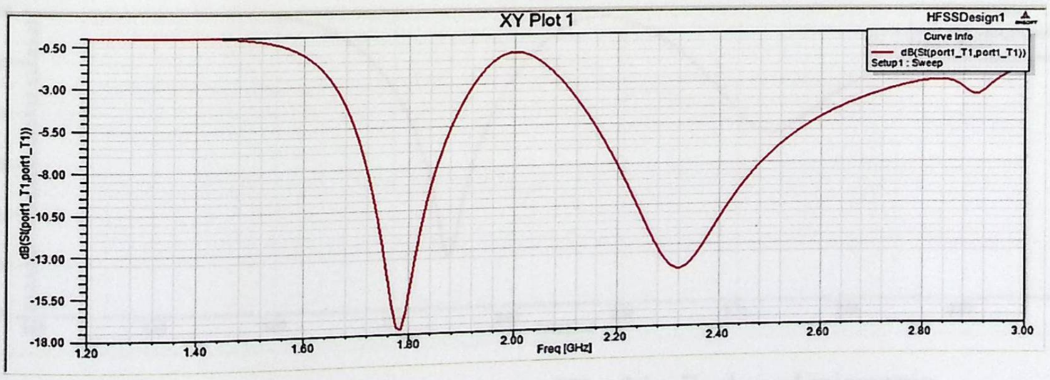


Fig 5.13: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after increasing Lp.

4. **Patch width (Wp) :**

The patch width Wp affects the resonance frequency of the lower mode more than the higher mode. By decreasing Wp ,the whole VSWR curve shifts towards the higher resonance frequency and vise versa .

- Wp increased to be equal 101.6 mm instead of 95.6 mm , while other parameters were kept constant .

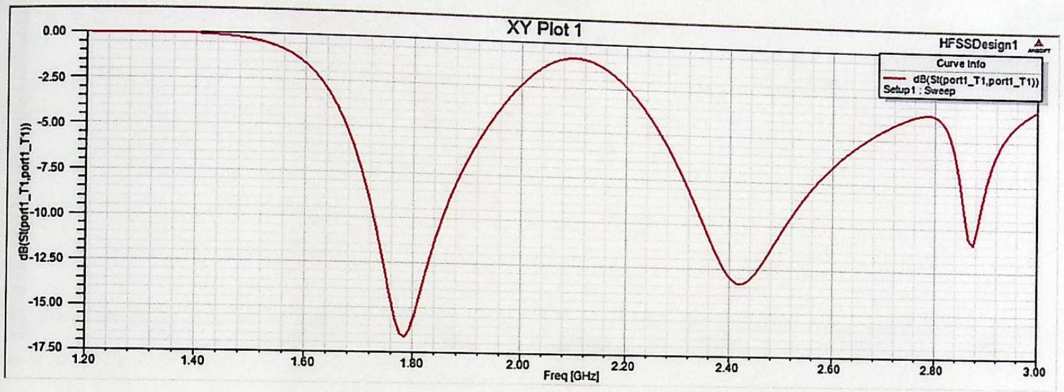


Fig 5.14: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after increasing Wp.

- Wp decreased to be equal 93.6 mm instead of 95.6 mm , while other parameters were kept constant .

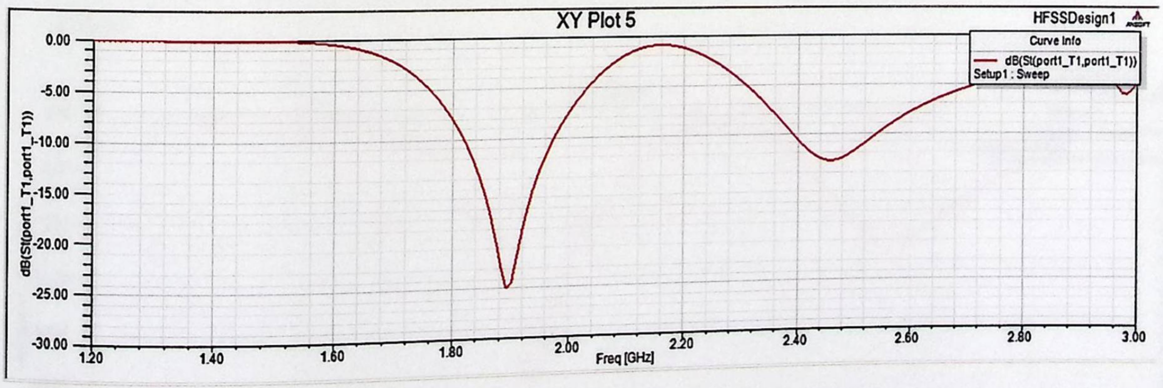


Fig 5.15: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after decreasing Wp.

5. **Feed position (X_f) :**

The position of the feed affects matching and various performance parameters such as gain, radiation pattern and return loss of the antenna.

- X_f was increased to be equal 16 mm instead of 13 mm , while other parameters were kept constant . The higher resonance frequency only shifted to the right , but the return loss magnitude remained the same of the two frequencies.

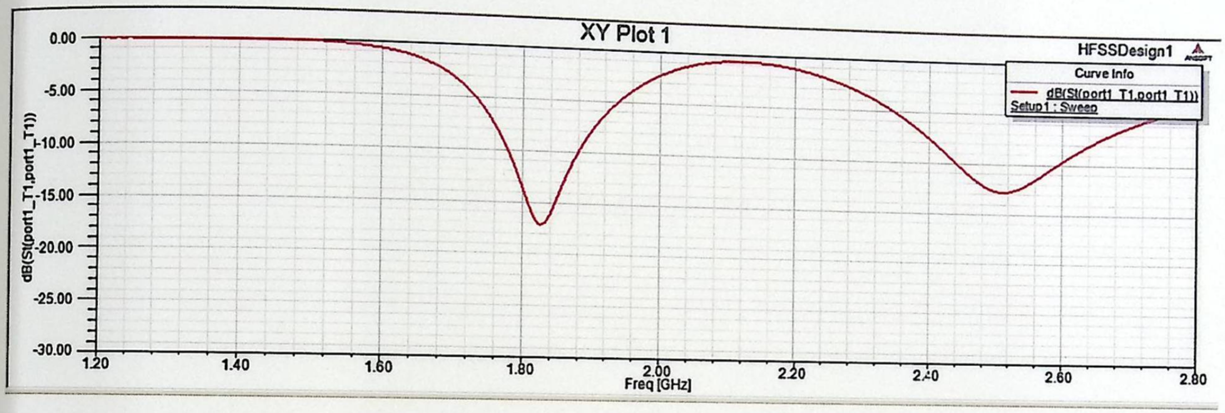


Fig 5.16: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after increasing X_f

- X_f decreased to be equal 10 mm instead of 13 mm , while other parameters were kept constant , the antenna becomes more resonating , i.e had a deeper resonating curve .

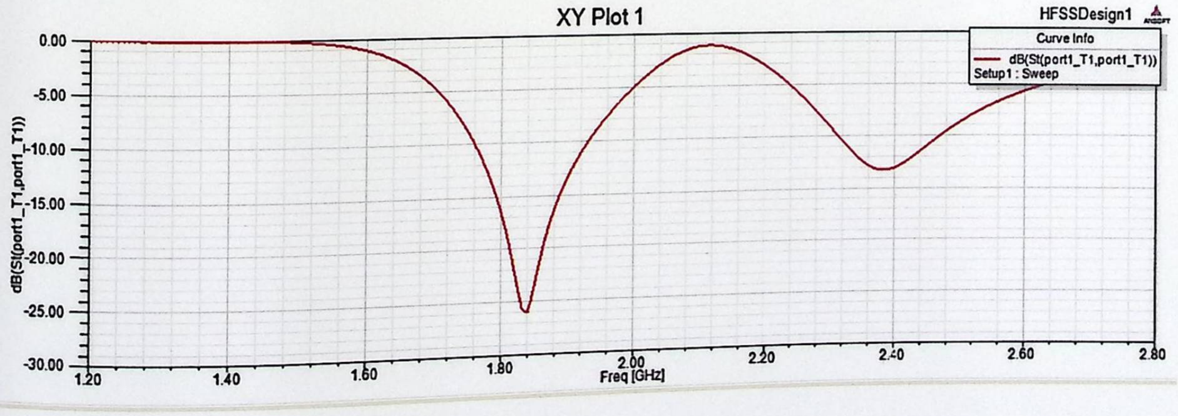


Fig 5.17: Return loss (S_{11}- parameter in dB) of the E- shaped microstrip after decreasing X_f

6. Substrate dielectric constant (ε_r) :

It is used for microstrip antenna generally at low value (typically $\varepsilon_r = 2.5$) and fringing field will be reduced . But for less critical applications this is to obtain a compact radiating structure that meets the demanding bandwidth specification. Since as εr increases the bandwidth will be decreases , so the bandwidth of the microstrip antenna will be increased using an air gap as a second substrate . However , dielectric substrate must be used if compact antenna size is required . The effects will be shown in the next chapter .

Chapter 6

Design of a Linearly Polarized E- Shaped Microstrip Antenna Using HFSS Designer Software

6.1 Overview

In this chapter we will introduce the design of a linearly polarized E-shaped microstrip antenna with coaxial feeding using HFSS designer software .We choose the dual resonating frequencies at (900 and 1200) MHz to enable radiation pattern measurement on the antenna lab volt range .

We will introduce the design of a single layer E-shaped antenna from air ($\varepsilon_r = 1$) with thickness t = 29.5 mm , and from FR4 ($\varepsilon_r = 4.4$) with thickness t = 1.6 mm .

Also, we will introduce the design of a multilayer E - shaped antenna , the upper substrate from Rogers RT/duroid 5880 ($\varepsilon_r = 2.2$) with thickness $t_1 = 1.6$mm and the lower substrate from air ($\varepsilon_r = 1$) with thickness $t_2 = 25$ mm.

6.2 Design of a single layer E- shaped microstrip antenna

6.2.1 Design of an E- shaped microstrip antenna with an air gap

We firs designed a dualband E- shaped microstrip antenna that operated at GSM frequency 1.8 GHz and at wifi frequency 2.4 GHz with a 15 mm air gap and using coaxial feeding. We scaled up the dimensions of the design to be radiated at GSM frequency 900 MHz , and L2 - band GPS frequency 1200 MHz .

We then fabricated the antenna using Protomat S62 machine , and measured it using lab volt antenna range system ; available in our university's lab which operates at limited range of frequencies from (750 – 1300) MHz.

Table 6.1 : Scaled dimensions of the E-shaped microstrip antenna with an air gap

parameters	Lp	Wp	Ls	Ws	X_f	t
Values	102.2mm	188.3mm	85.5mm	41.96mm	25.6mm	29.5 mm

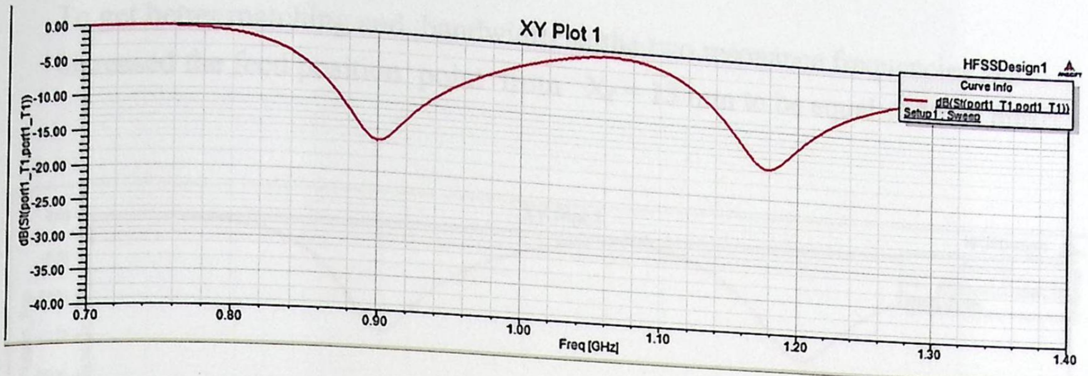


Fig 6.1: Return loss (S_{11}- parameter in dB) of the scaled dimensions for the E- shaped microstrip antenna with an air gap

To get resonating exactly at 1.2 GHz , we decreased the length of the middle slot to be equal 76 mm instead of 85.5 mm , and at $X_f = 13$ mm instead of 25.6 mm , and we noted that the antenna becomes more resonating .

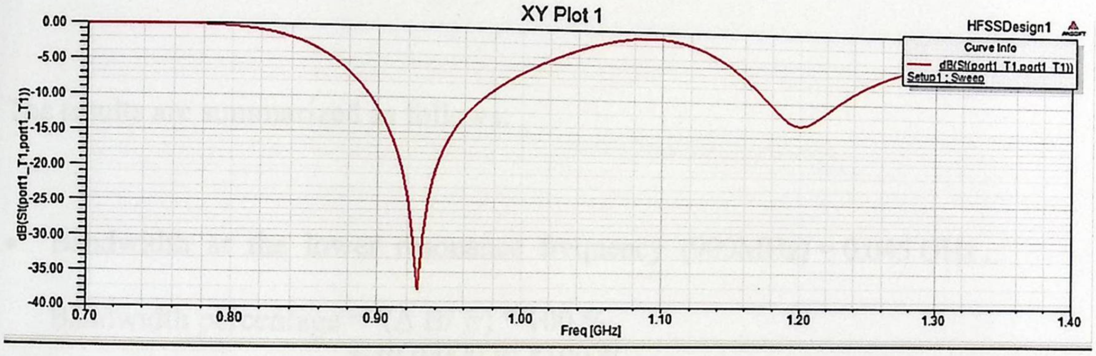


Fig 6.2: Return loss (S_{11}- parameter in dB) of the scaled dimensions for the E- shaped microstrip antenna with an air gap at 1200 MHz

To get resonating exactly at 900 MHz , we increased the patch width (Wp) to be equal 201.3 mm instead of 188.3 mm.

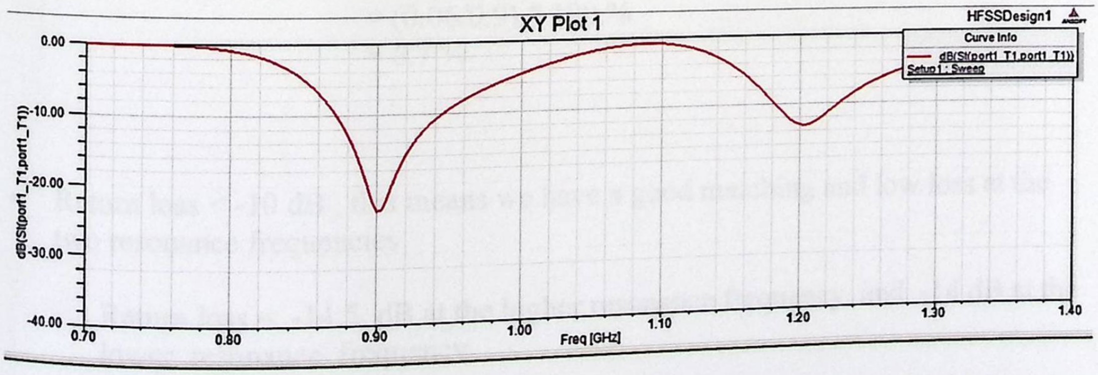


Fig 6.3: Return loss (S_{11}- parameter in dB) of the scaled dimensions for the E- shaped microstrip antenna with an air gap at (900 & 1200) MHz

To get better matching and bandwidth at the two resonance frequencies ,we increased the feed position point from $X_f = 13$ mm to be equal 15*1.97 mm.

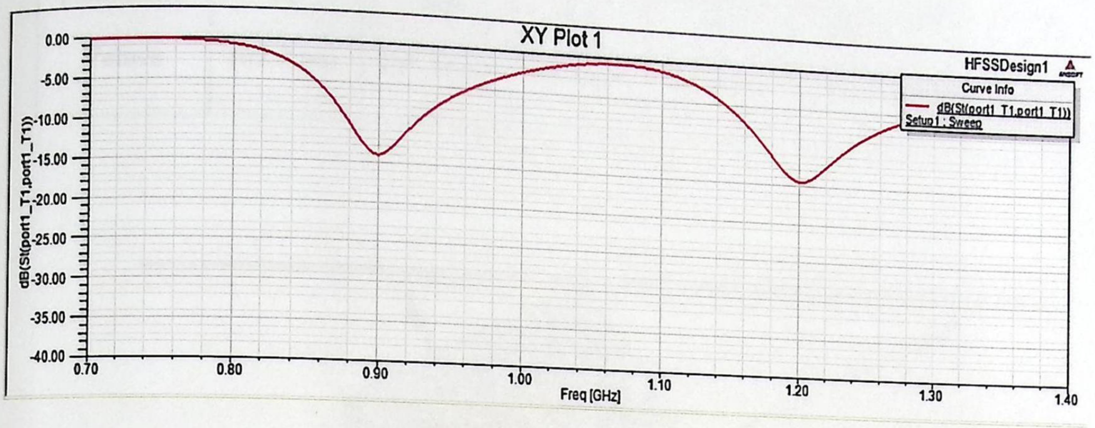


Fig 6.4: Return loss (S_{11}- parameter in dB) of the scaled dimensions for the E- shaped microstrip antenna with an air gap at (900 & 1200) MHz with better bandwidth

The results are summarized as follows:

- Bandwidth at the lower resonance frequency (900MHz) = 0.045 GHz .

  Bandwidth percentage = (Δ B/ fr) * 100 %
  = (0.045/0.9) *100 %
  = 5 %

- Bandwidth at the higher resonance frequency (1200 MHz) = 0.06 GHz .

  Bandwidth percentage = (Δ B/ fr) * 100 %
  = (0.06/0.9) * 100 %
  = 6.7 %

- Return loss < -10 dB , this means we have a good matching and low loss at the two resonance frequencies

  Return loss = -14.5 dB at the higher resonance frequency and -14 dB at the lower resonance frequency.

Table 6.2 :Optimized dimensions of E-shaped microstrip antenna with an air gap

parameters	Lp	Wp	Ls	Ws	X_f	t
Values	102.2mm	201.3mm	85.5mm	48.45mm	25.6mm	29.5mm

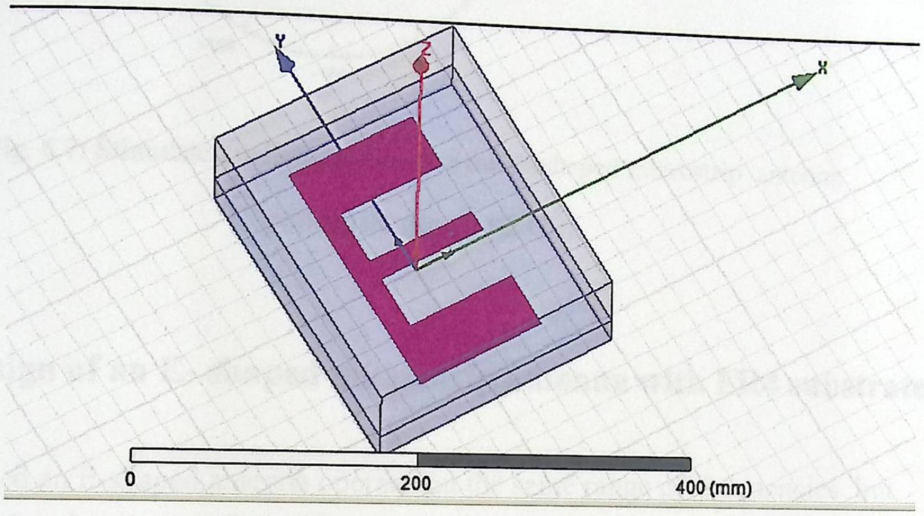


Fig 6.5 : Geometry of the optimized design of the E- shaped microstrip antenna with an air gap using HFSS software

And we also found the radiation pattern of the linearly polarized E- shaped microstrip antenna with an air gap at the two resonance frequencies as follows :

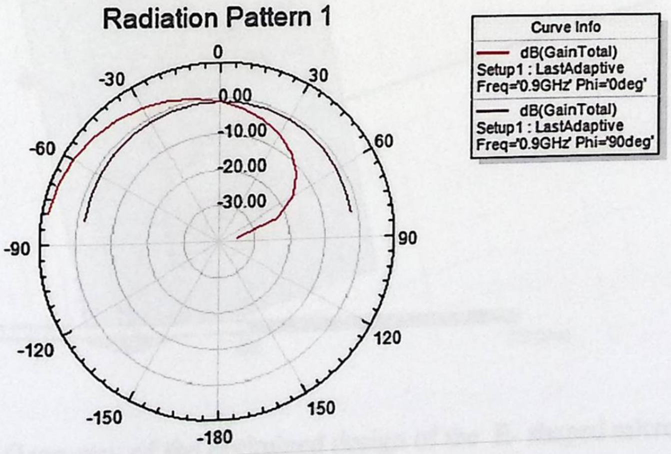


Fig. 6.6: Stimulated radiation pattern of the E- shaped microstrip antenna

with an air gap at 0.9 GHz

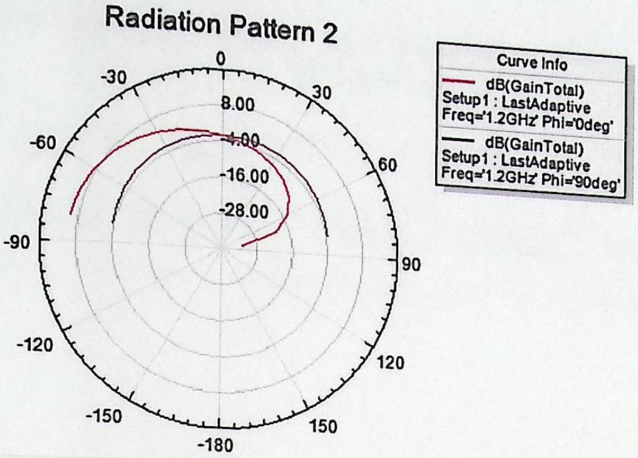


Fig. 6.7: Stimulated radiation pattern of the E- shaped microstrip antenna with an air gap at 1.2 GHz

6.2.2 Design of an E- shaped microstrip antenna with FR4 substrate

We designed an E-shaped antenna operated at the same range of frequencies but using a dielectric substrate from FR4 ($\varepsilon_r = 4.4$) with thickness t = 1.6 mm instead of the air gap .

FR4 has low cost, ease of availability ,and is more practical since it has compact size.

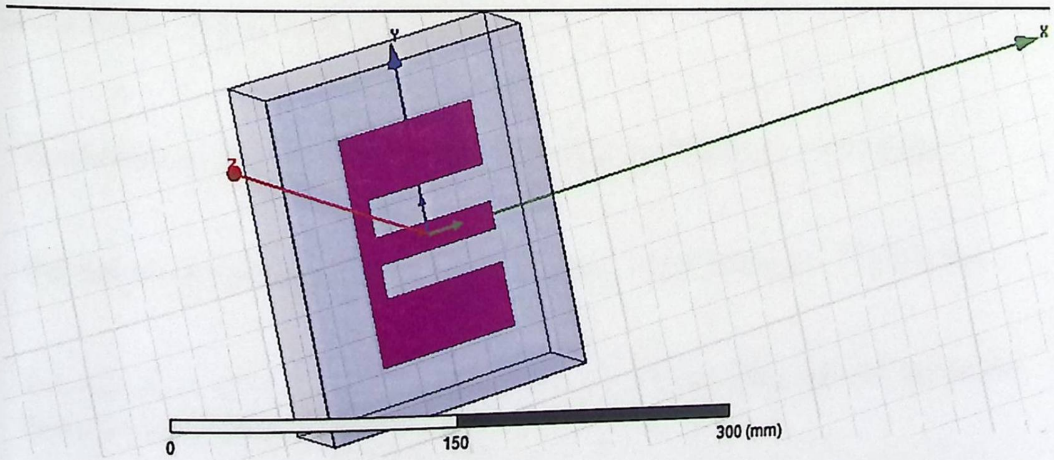


Fig 6.8 : Geometry of the optimized design of the E- shaped microstrip antenna with FR4 substrate using HFSS

Table 6.3 :Optimized dimensions of E-shaped microstrip antenna with FR4 substrate

parameters	Lp	Wp	Ls	Ws	X_f	t
Values	81.928mm	121.812mm	71.968mm	19.626mm	19.76mm	1.6mm

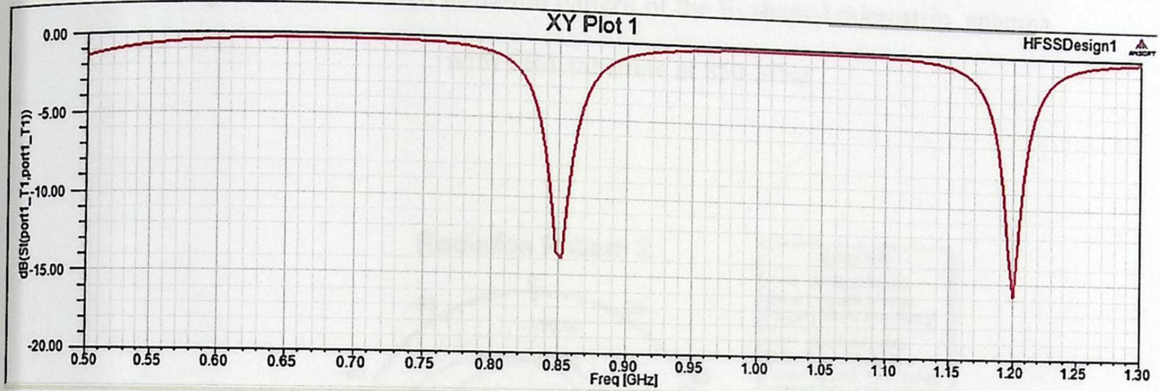


Fig 6.9: Return loss (S_{11}- parameter in dB) of the scaled dimensions for the E- shaped microstrip antenna with FR4 substrate at (850 & 1200) MHz

The results are summarized as follows:

- Bandwidth at the lower resonance frequency (850 MHz) = 0.01 GHz.
- Bandwidth at the higher resonance frequency (1200 MHz) = 0.012 GHz.
- Return loss < -10 dB , this means we have a good matching and low loss at the two resonance frequencies

Return loss = - 16 dB at the higher resonance frequency and - 14 dB at the lower resonance frequency.

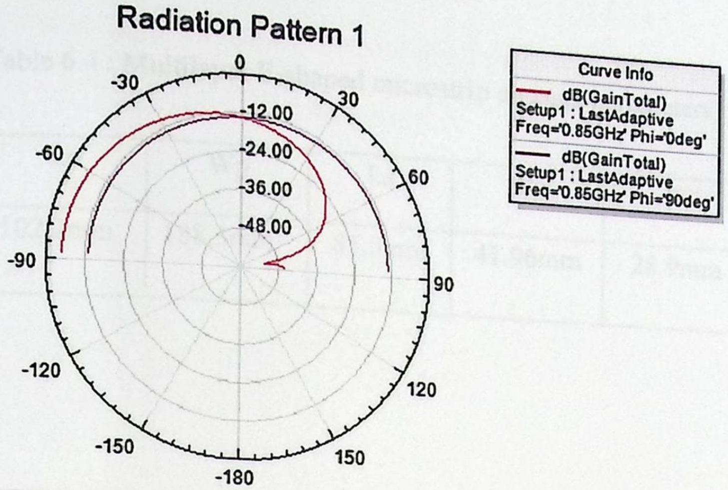


Fig. 6.10: Stimulated radiation pattern of the E- shaped microstrip antenna

with FR4 substrate at 850 MHz

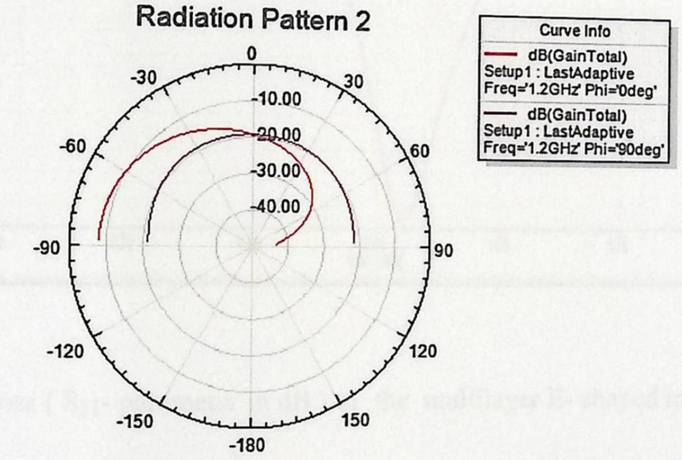


Fig. 6.11: Stimulated radiation pattern of the E- shaped microstrip antenna

with FR4 substrate at 1200 MHz

6.3 Design of multilayer E- shaped microstrip antenna

To get better resonance at the two desired resonance frequencies (900 & 1200) MHz we designed a multilayer E-shaped microstrip antenna .

The lower layer is an air substrate with thickness $t_2 = 25$ mm , and the upper layer is Rogers RT/duroid 5880 substrate with thickness $t_1 = 1.6$mm .

Table 6.4 : Multilayer E-shaped microstrip antenna parameters

parameters	Lp	Wp	Ls	Ws	Ps	X_f
Values	102.2mm	188.3mm	85.5mm	41.96mm	28.9mm	25.6mm

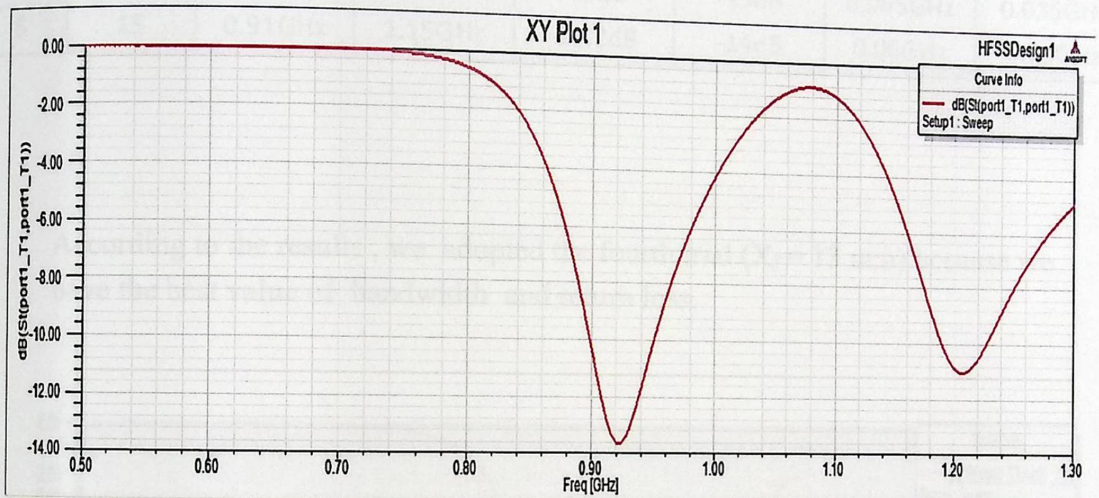


Fig 6.12: Return loss (S_{11}- parameter in dB) of the multilayer E- shaped microstrip antenna

We adopted the mentioned parameters at table 6.4 of the E-shaped antenna and changed the feed position in order to get better resonance and bandwidth at the two desired resonant frequencies (900 & 1200) MHz , we get the following results :

Table 6.5 : Multilayer E-shaped microstrip antenna with different values of feed position

No.of trials	X_f (mm)	1^{st} resonant frequency	2^{nd} resonant frequency	Return loss for first frequency	Return loss for second frequency	Bandwidth for 1^{st} freq	Bandwidth for 2^{nd} freq
1	13*1.97	0.92GHz	1.21GHz	-13.9dB	-11dB	0.035GHz	0.02GHz
2	14*1.97	0.92GHz	1.21GHz	-13dB	-11dB	0.065GHz	0.03GHz
3	15*1.97	0.92GHz	1.23GHz	-12.5dB	-10.5dB	0.035GHz	0.025GHz
4	13	0.905GHz	1.12GHz	-15dB	-15.2dB	0.075GHz	0.035GHz
5	13.5	0.905GHz	1.12GHz	-15dB	-15dB	0.065GHz	0.035GHz
6	15	0.91GHz	1.15GHz	-15.2dB	-14dB	0.06GHz	0.03GHz

According to the results , we adopted the fourth trial (X_f= 13 mm) because we have the best value of bandwidth and return loss.

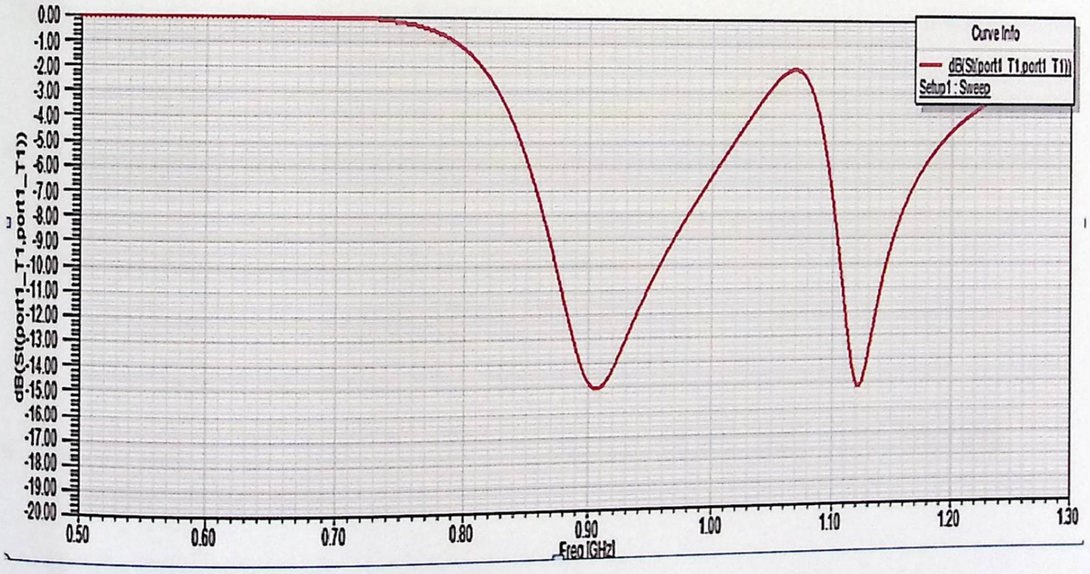


Fig 6.13: Return loss (S_{11}- parameter in dB) of the multilayer E- shaped microstrip antenna at X_f= 13 mm

To get the resonance exactly at 900 MHz and 1200 MHz we changed the patch width (Wp) to be equal 213mm instead of 188.332mm , and the slot length (Ls) to be equal 82.5mm instead of 85.5 mm.

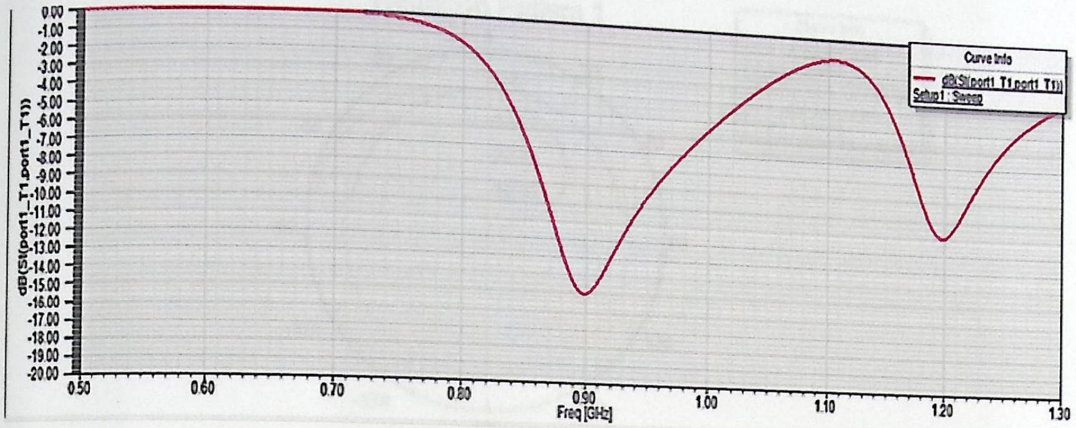


Fig 6.14: Return loss (S_{11}- parameter in dB) of the multilayer E- shaped microstrip antenna after decreasing Ls and increasing Wp , resonating at (900 & 1200) MHz

The results are summarized as follows:

- Bandwidth at the lower resonance frequency (900 MHz) = 0.065 GHz instead of 0.075 GHz

  Bandwidth percentage = $(\Delta B / fr) * 100\ \%$
  $= (0.06/0.9) * 100\ \%$
  $= 7.2\ \%$

- Bandwidth at the higher resonance frequency (1200 MHz) = 0.025 GHz instead of 0.035 GHz.

  Bandwidth percentage = $(\Delta B / fr) * 100\ \%$
  $= (0.025/1.2) * 100\ \%$
  $= 2.08\ \%$

- Return loss equals -11 dB at the higher resonance frequency and -15 dB at the lower resonance frequency ,which is acceptable since it is less than -10 dB.

Also we found the radiation pattern of the multilayer layer linearly polarized E-shaped microstrip antenna at the two resonance frequencies as follows :

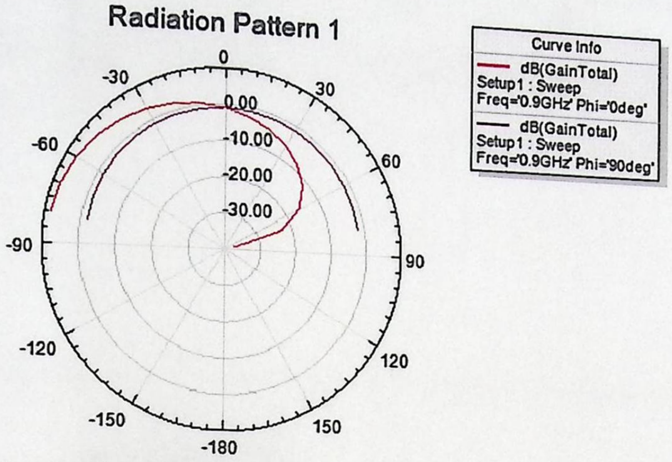


Fig. 6.15: Stimulated radiation pattern of multilayer E- shaped microstrip antenna at 0.9GHz

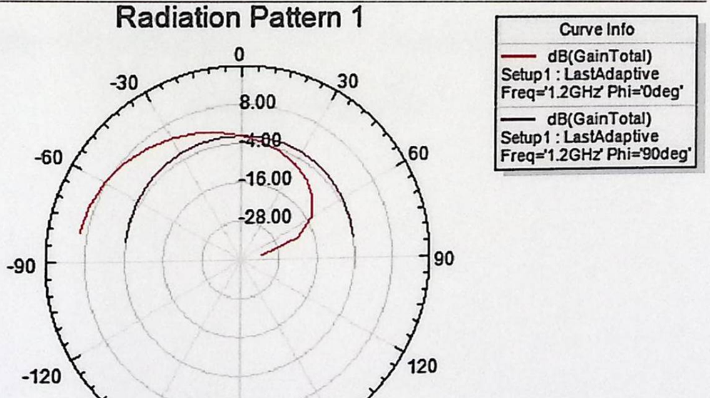


Fig. 6.16: Stimulated radiation pattern of multilayer E- shaped microstrip antenna at 1.2 GHz

Table 6.6 : Optimized dimensions of the multilayer E-shaped microstrip antenna

parameters	Lp	Wp	Ls	Ws	X_f
Values	102.2mm	213 mm	82.5mm	41.96mm	25.6mm

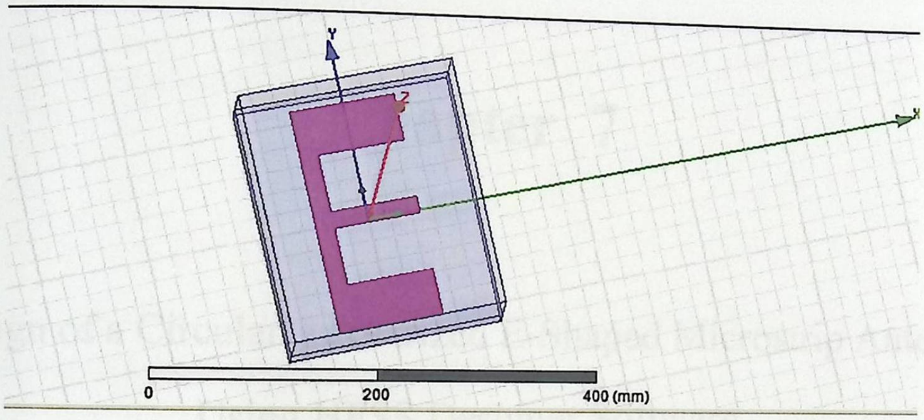


Fig 6.17 : Geometry of the optimized design of the multilayer E- shaped microstrip antenna using HFSS

Chapter 7

Design of a Circularly Polarized E-Shaped Microstrip Antenna Using HFSS Designer Software

7.1 Overview

Circularly polarized (CP) microstrip antennas have been widely used in different wireless applications such as GPS and RFID systems as they combine the advantages of both microstrip antennas and circular-polarization characteristics.

Microstrip antennas have a planar profile, low cost, and mechanical robustness, while circular polarization can reduce the transmission loss caused by the misalignment between antennas of stationary and mobile terminals , and it is an attractive solution to achieve polarization match which allows for more flexibility in the angle between transmitting and receiving antennas, reduces the effect of multipath reflections, enhances weather penetration and allows for the mobility of both the transmitter and the receiver.

Circular polarization can thus be used in broadband applications , provides better polarization flexibility , alleviates multipath fading, reduces delay spread, compared to linearly polarized antenna for line of sight applications and maximizes performance in terms of S_{11} bandwidth.

7.2 Design of a circularly polarized E-shaped microstrip antenna

After having encouraging results for linearly polarized E - shaped antenna , we designed a circularly polarized E-shaped microstrip antenna using HFSS designer software which is based on FEM (Finite Element method) .

To generate circular polarization , we introduced a bar , that generates asymmetric orthogonal currents with a quadrature phase , to the designed linearly polarized E - shaped microstrip antenna .This way the radiation field decomposes to two components right hand circularly polarized (RHCP) E-field and left hand circularly polarized (LHCP) E-field.

7.2.1 Design of an E- shaped microstrip antenna with an air gap

We designed a single layer circularly polarized E-shaped antenna with an air gap of thickness t=20mm.The resonance frequency measured 2.65 GHz and coaxial feeding was used in the design to reduce losses.

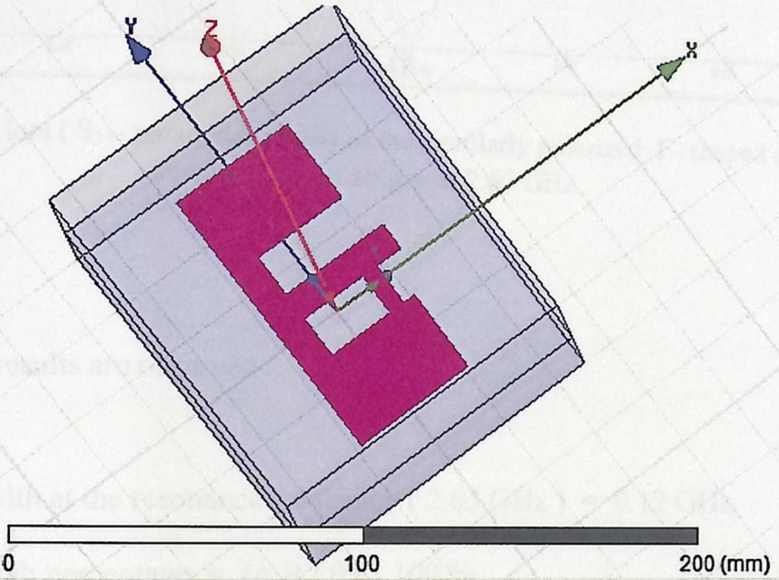


Fig 7.1 : Geometry of the optimized design of the circularly polarized E- shaped microstrip antenna with an air gap

Table 7.1 : Circularly polarized E-shaped microstrip antenna parameters with an air gap

parameters	Lp	Wp	Ls	Ws	Xf	Lb	T
Values	39.2mm	94.8mm	35.2mm	21.3mm	18mm	14.5 mm	20 mm

The length of the middle slot was increased to 35.2 mm from 30.2 mm to get the resonance at 2.65 GHz .

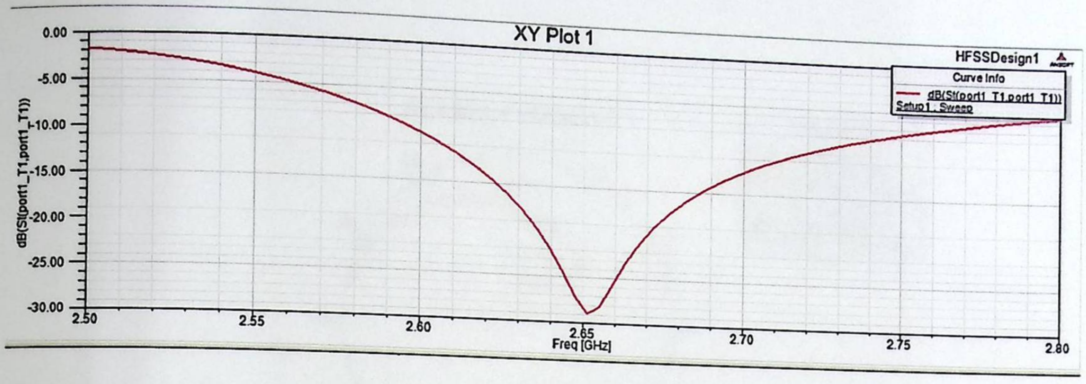


Fig 7.2: Return loss (S_{11}- parameter in dB) of the circularly polarized E- shaped microstrip antenna with an air gap at 2.65 GHz

The following results are observed :

- Bandwidth at the resonance frequency (2.65 GHz) = 0.12 GHz.

  Bandwidth percentage = (Δ B / fr) * 100 %

  = (0.12/2.65) * 100 %
  = 4.5 %

- Return loss = -29 dB , much less than -10 dB , this means we have a good matching and very low loss at the resonance frequency.

And we also find the radiation pattern of the circularly polarized E- shaped microstrip antenna with an air gap at the resonance frequency as follows :

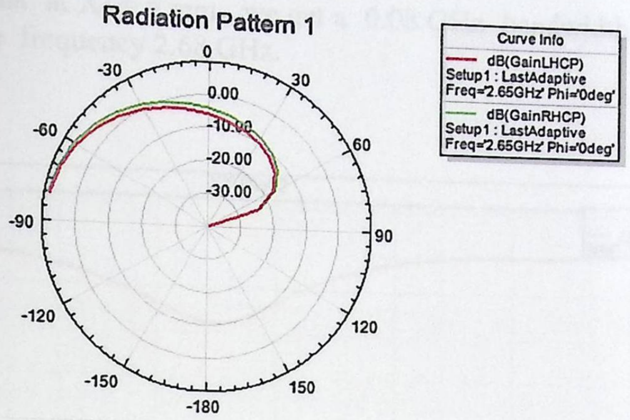


Fig 7.3: Stimulated radiation pattern of the circularly polarized E-shaped microstrip antenna with an air gap at 2.65 GHz & Phi=0°

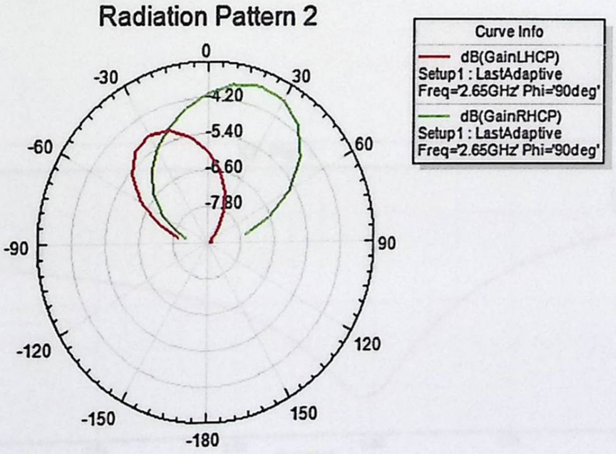


Fig 7.4: Stimulated radiation pattern of the circularly polarized E-shaped microstrip antenna with an air gap at 2.65 GHz & Phi=90°

7.2.2 Design of an E- shaped microstrip antenna with FR4 substrate

We designed a single layer circularly polarized E-shaped antenna from FR4 substrate (ε_r =4.4) , with thickness t = 1.6 mm at 2.61 GHz resonance frequency using coaxial feeding .

We designed the antenna at X_f = 5 mm , we get a 0.08 GHz bandwidth and -14 dB return loss at resonance frequency 2.68 GHz.

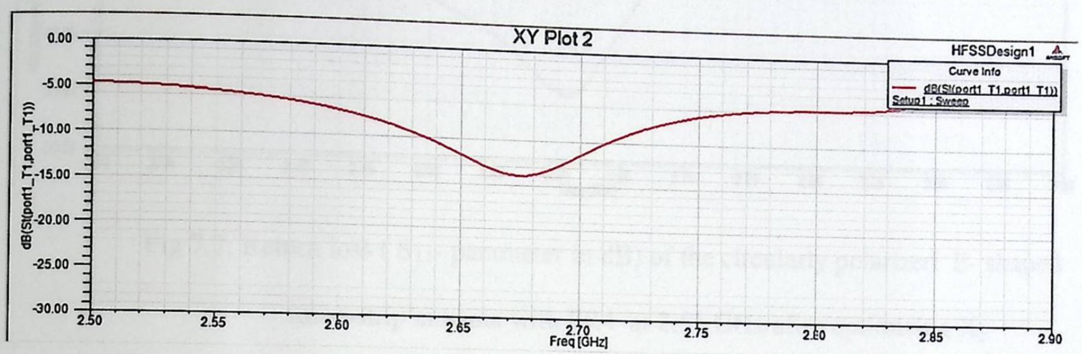


Fig 7.5: Return loss (S_{11}- parameter in dB) of the circularly polarized E- shaped microstrip antenna with FR4 at 2.68 GHz

When we increased the feed position point (X_f) to become 10 mm , the bandwidth enhanced and became 0.2 GHz. We observed better matching; return loss = - 26 dB at lower resonance frequency 2.65 GHz.

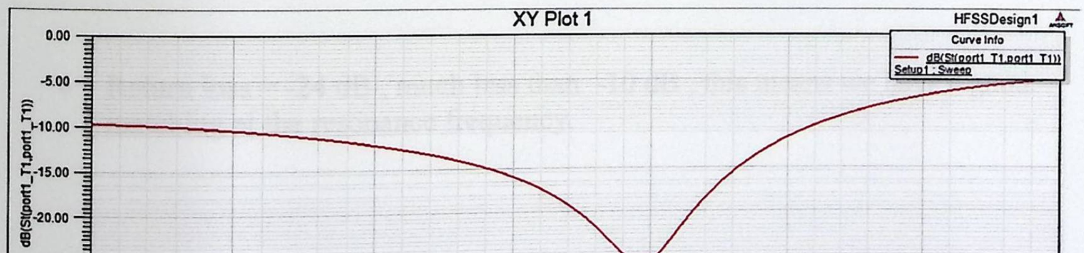


Fig 7.6: Return loss (S_{11}- parameter in dB) of the circularly polarized E- shaped microstrip antenna with FR4 at 2.65 GHz

We tried to enhance the bandwidth by optimizing the feed position point (X_f) to be equal 15 mm :

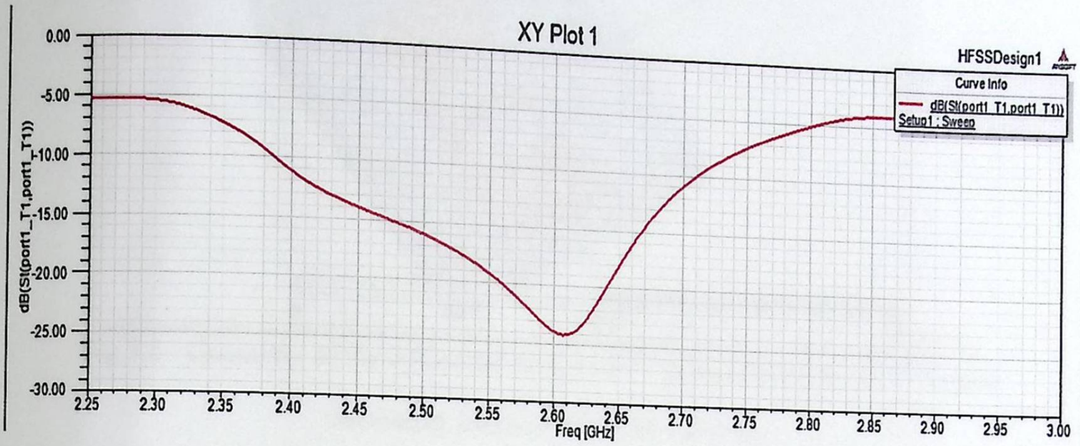


Fig 7.7: Return loss (S_{11}- parameter in dB) of the circularly polarized E- shaped microstrip antenna with FR4 at 2.61 GHz after optimizing X_f

The following results are observed :

- Bandwidth at the resonance frequency (2.61 GHz) = 0.32 GHz.

  Bandwidth percentage = (Δ B / fr) * 100 %

  = (0.12/2.61) * 100 %
  = 12.26 %

- Return loss = -24 dB , much less than -10 dB , this means we have a good matching at the resonance frequency.

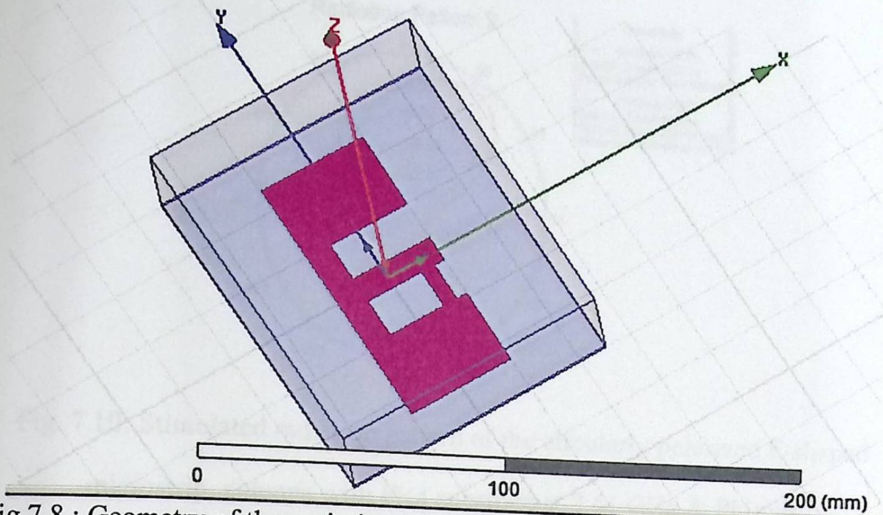


Fig 7.8 : Geometry of the optimized design of the circularly polarized E- shaped microstrip antenna with FR4 substrate

Table 7.2 : Circularly polarized E-shaped microstrip antenna parameters with FR4 substrate

parameters	Lp	Wp	Ls	Ws	X_f	Lb	t
Values	39.2mm	94.8mm	30.2mm	21.3mm	15mm	14.5 mm	1.6mm

And we also find the radiation pattern of the circularly polarized E- shaped microstrip antenna with FR4 substrate as follows :

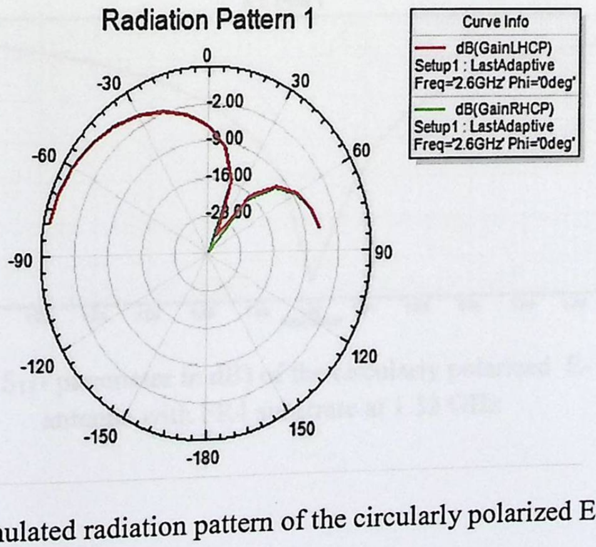


Fig. 7.9: Stimulated radiation pattern of the circularly polarized E-shaped microstrip antenna with FR4 substrate at 2.61 GHz & Phi=0°

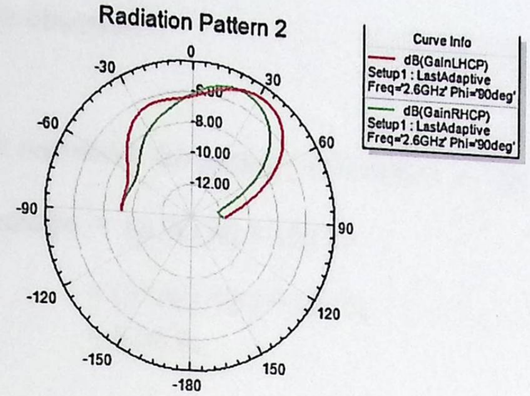


Fig. 7.10: Stimulated radiation pattern of the circularly polarized E-shaped microstrip antenna with FR4 substrate at 2.61 GHz & Phi=90°

We scaled up the dimensions of the design to measure it at the lab volt range system. We found the return loss and radiation pattern of the circularly polarized E- shaped microstrip antenna with FR4 substrate at the resonance frequency 1.32 GHz

Table 7.3: Scaled dimensions of the E-shaped microstrip antenna with FR4 substrate

parameters	Lp	Wp	Ls	Ws	X_f	t
Values	78.4mm	189.6mm	60.4mm	29mm	30mm	1.6 mm

Fig 7.11: Return loss (S_{11}- parameter in dB) of the circularly polarized E- shaped microstrip antenna with FR4 substrate at 1.32 GHz

The following results are observed :

- Bandwidth at the resonance frequency (1.32 GHz) = 100 MHz.

  Bandwidth percentage = (Δ B / fr) * 100 %

  = (0.08/1.32) * 100 %
  = 6.06 %

- Return loss = -32 dB , much less than -10 dB , this means we have a good matching and very low loss at the resonance frequency.

And we found the radiation pattern at the resonance as follows :

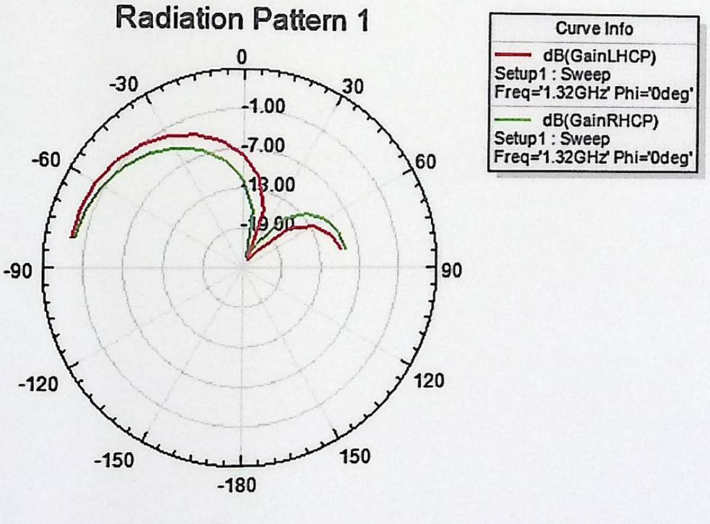


Fig 7.12: Stimulated radiation pattern of the E- shaped microstrip antenna

with FR4 substrate at 1.32 GHz & Phi = 0°

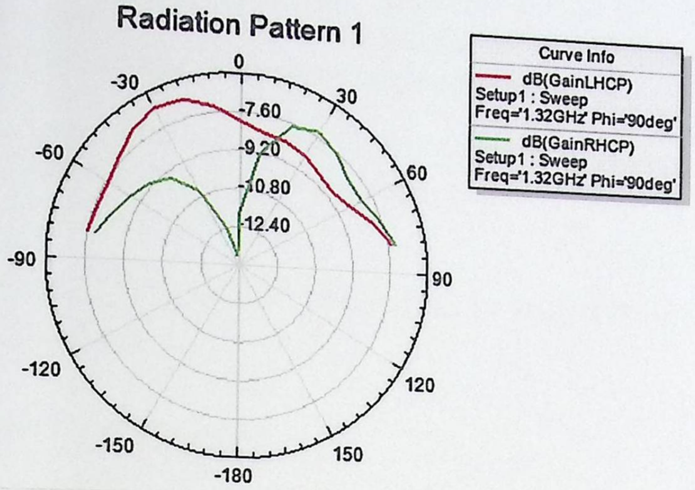


Fig 7.13: Stimulated radiation pattern of the E- shaped microstrip antenna with FR4 substrate at 1.32 GHz & Phi = 90°

Chapter 8

Measurements

8.1 Overview

In this chapter, we will introduce our measured results of the return loss and radiation pattern for two E-shaped microstrip antennas operates at two different types of polarizations , linearly and circularly polarization.

The two antennas were fabricated using FR4 substrate ($\varepsilon_r = 4.4$) with thickness t = 1.6 mm using Protomat S62 & PCB prototype machines.

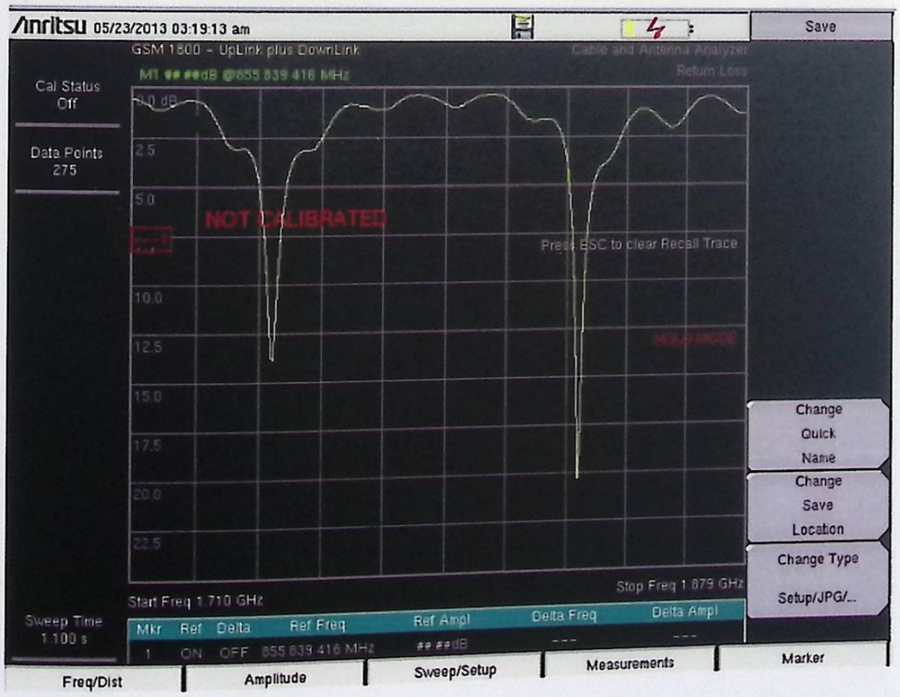
8.2 Measurement results of the linearly polarized E- shaped microstrip antenna

8.2.1 Measured return loss

We measured the return loss of the E-shaped microstrip antenna using Site Master system at al-wataniya mobile company because this system isn't available in our university.

The system was first calibrated for open circuit load , short circuit load and matched load (50 Ω) in order to establish the required reference points for the frequency range required. After words the microstrip antenna was connected to the Site Master via an SMA/N_1 connector.

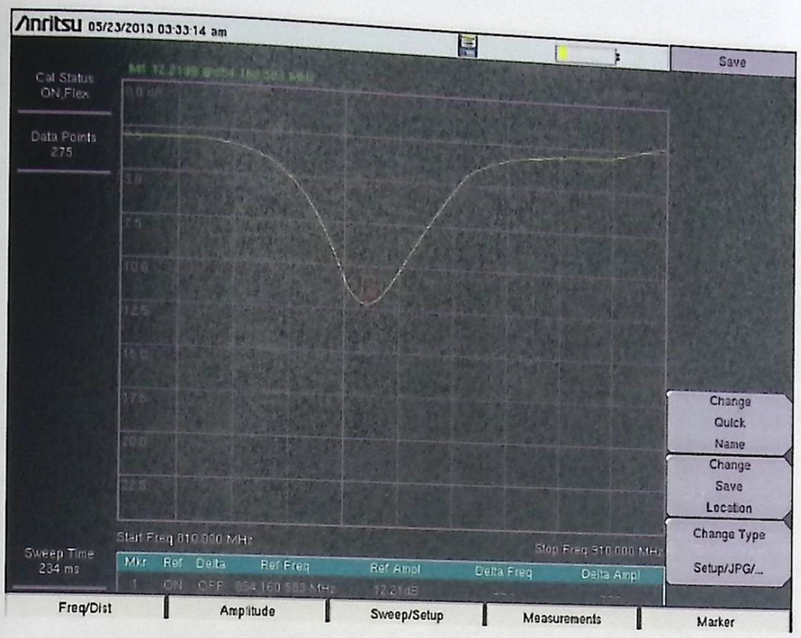
Here are the results that determine the return loss at the two resonance frequencies



Mkr	Ref	Delta	Ref Freq	Ref Ampl	Delta Freq	Delta Ampl
1	ON	OFF	855 839 416 MHz	## ##dB	---	---

Fig 8.1: Measured return loss (S_{11}- parameter in dB) of the E- shaped microstrip antenna with FR4 substrate at(854.16 & 1206.569) MHz

Zooming the first resonance curve required calibration through (810 – 910) MHz :



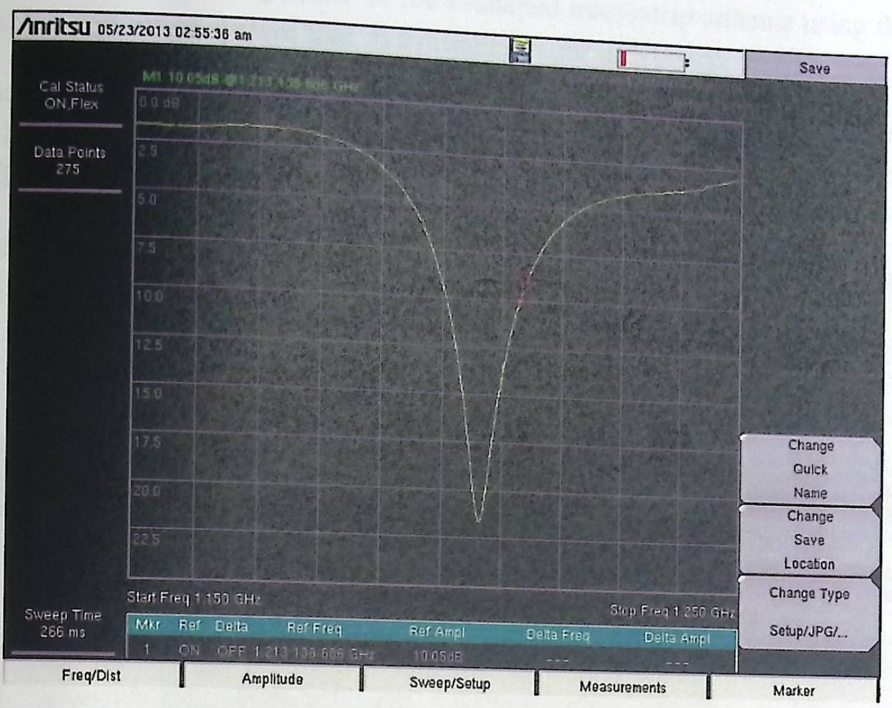
Mkr	Ref	Delta	Ref Freq	Ref Ampl	Delta Freq	Delta Ampl
1	ON	OFF	854.160 [illegible] MHz	12.21dB	---	---

Fig 8.2: Measured return loss (S_{11}- parameter in dB) of the E- shaped microstrip antenna with FR4 substrate at 854.16 MHz

The results are summarized as follows:

- Return loss at the lower resonance frequency (854.16 MHz)= -12.4 dB less than -10 dB , this means we have a good matching.
- Return loss at the left limit frequency (848.704 MHz) = -10 dB.
- Return loss at the right limit frequency (860.583 MHz) = -10 dB.
- Bandwidth = 12 MHz .

Zooming the second resonance curve required calibration through (1150 – 1250)MHz:



Cal Status ON,Flex

Data Points 275

Sweep Time 266 ms

Start Freq 1.150 GHz

Stop Freq 1.250 GHz

Mkr	Ref	Delta	Ref Freq	Ref Ampl	Delta Freq	Delta Ampl
1	ON	OFF	1.213 136 606 GHz	10.05dB	---	---

Fig 8.3: Measured return loss (S_{11}- parameter in dB) of the E- shaped microstrip antenna with FR4 substrate 1206.569 MHz

The results are summarized as follows:

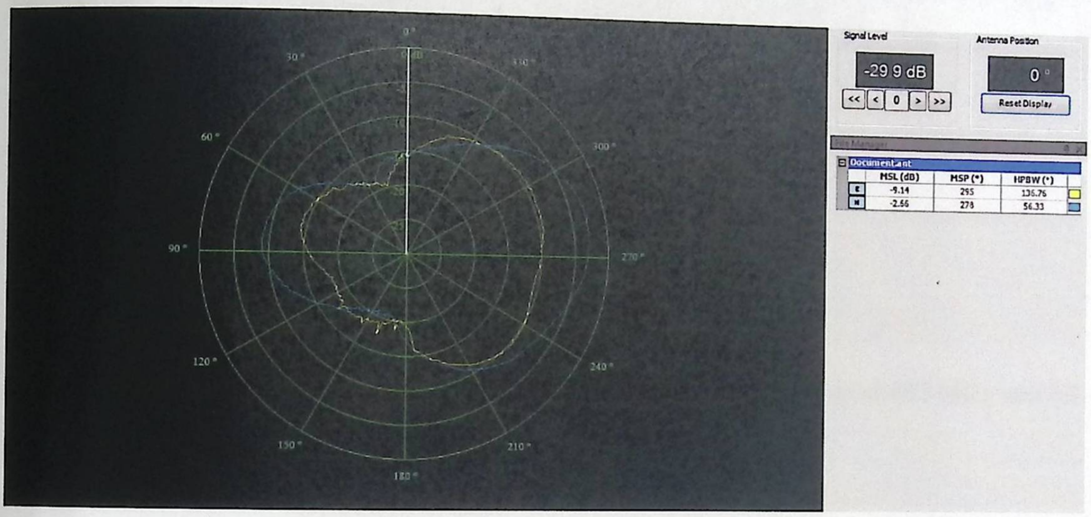
- Return loss at the higher resonance frequency (1206.569 MHz) equals -21.6 dB less than -10 dB , this means we have a good matching.
- Return loss at the left limit frequency (1200.729 MHz) = -10 dB.
- Return loss at the right limit frequency (1213.136 MHz) = -10 dB.
- Bandwidth = 13 MHz .

8.2.2 Measured radiation pattern

We measured the radiation pattern of the E-shaped microstrip antenna using the antenna lab volt range system that is available in our university.

The microstrip antenna was first measured without any calibration of the system , then we used SMA/ BNC adapter to make calibration and change the default frequency (915 MHz) to get the required frequencies.

We measured the radiation pattern of the linearly polarized E-shaped microstrip antenna before making calibration and get the following results :



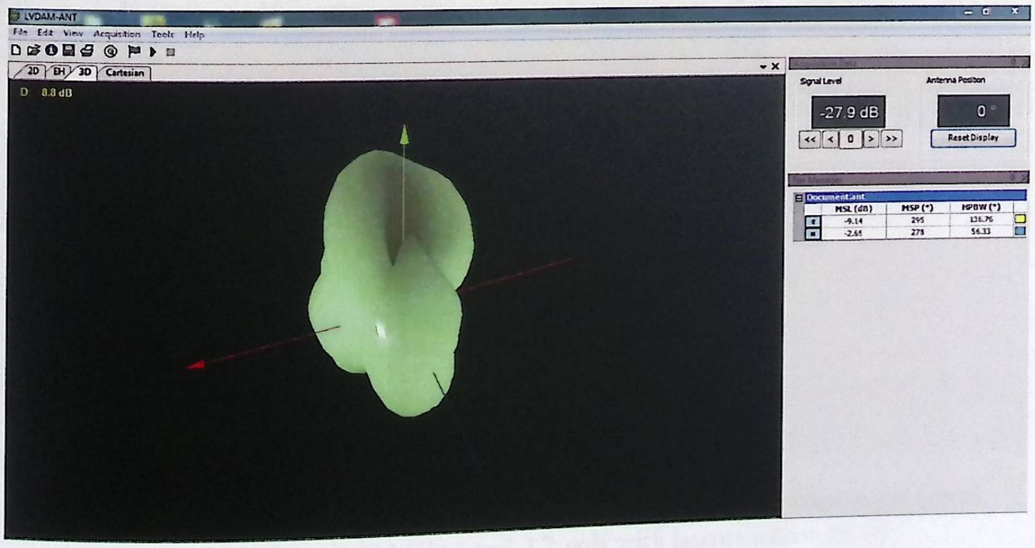
Signal Level: -29 9 dB

Antenna Position: 0 °

Document.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-9.14	295	136.76	🟨
H	-2.66	278	56.33	🟦

Fig 8.4: Measured radiation pattern of the E- shaped microstrip antenna at 915 MHz with beamwidth = 136.76 °



D 8.8 dB

Signal Level: -27 9 dB

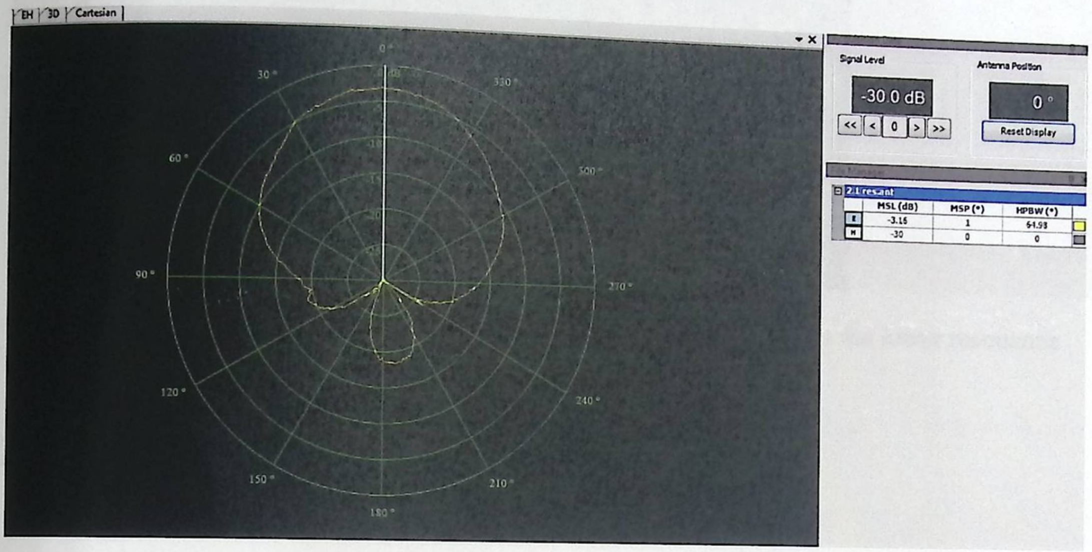
Antenna Position: 0 °

Document.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-9.14	295	136.76	🟨
H	-2.65	278	56.33	🟦

Fig8.5: 3D - radiation pattern of the E- shaped microstrip antenna at 915 MHz

After that, we make calibration of the antenna lab volt range system using a DC voltage generator , but we couldn't change the frequency less than 0.1 step because we haven't an accurate generators, so the variation couldn't be less than 8 MHz each 0.1 volt.



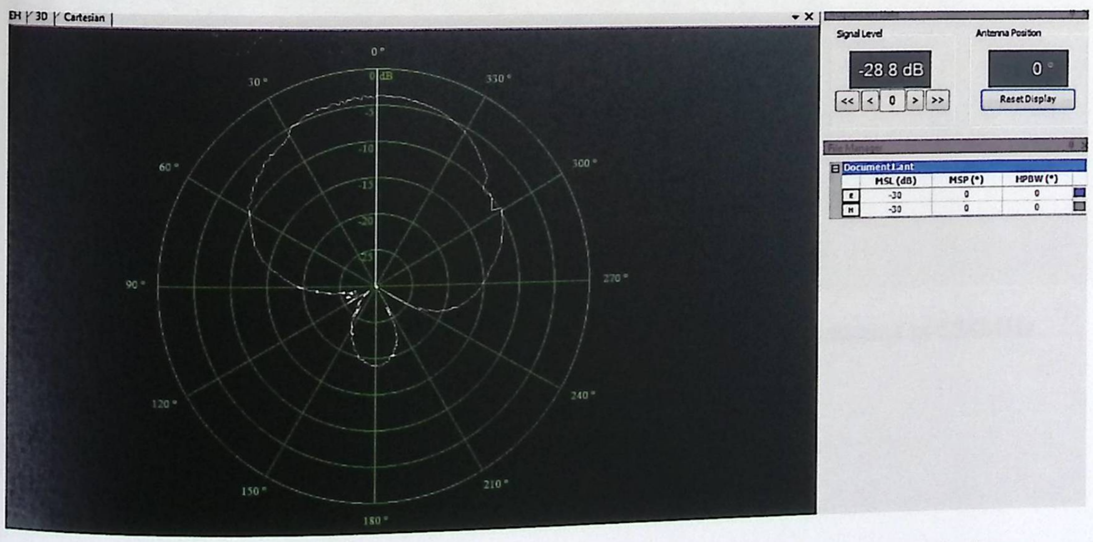
Signal Level: -30.0 dB

Antenna Position: 0°

2.1 res.ant

	MSL (dB)	MSP (°)	HPBW (°)
E	-3.16	1	64.93
H	-30	0	0

Fig 8.6: Measured radiation pattern of the E- shaped microstrip antenna at 842 MHz and 2.1 volt with beamwidth = 65°



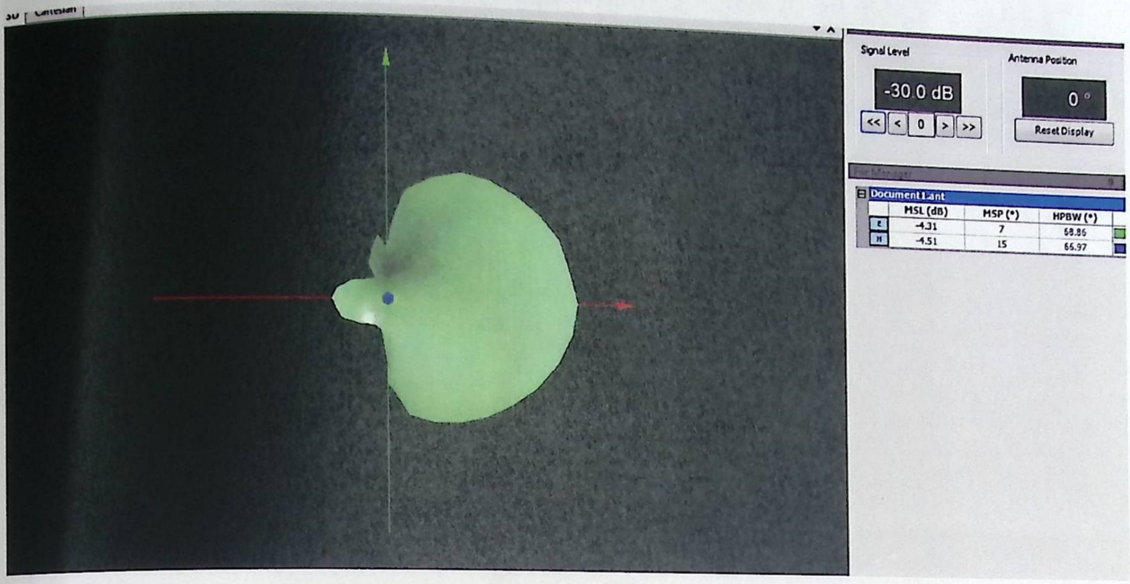
Signal Level: -28.8 dB

Antenna Position: 0°

Document1.ant

	MSL (dB)	MSP (°)	HPBW (°)
E	-30	0	0
H	-30	0	0

Fig 8.7: Measured radiation pattern of the E- shaped microstrip antenna at the lower resonance frequency (850 MHz) and 2.2 volt with beamwidth = 68.86 °



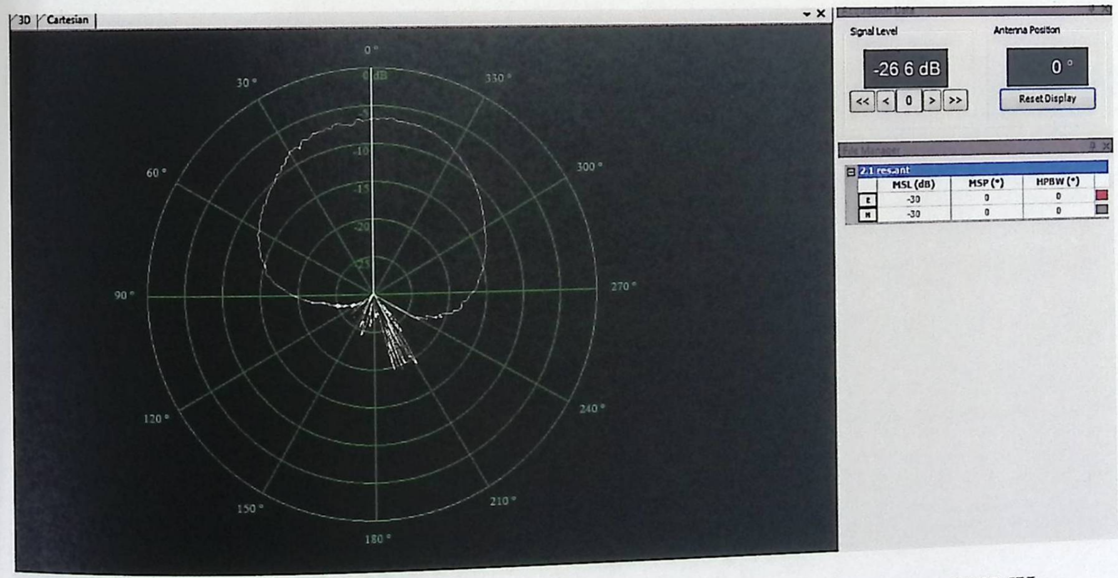
Signal Level: -30.0 dB

Antenna Position: 0 °

Document1.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-4.31	7	68.86	🟩
H	-4.51	15	65.97	🟦

Fig 8.8: 3D -radiation pattern of the E- shaped microstrip antenna at the lower resonance frequency (850 MHz) and 2.2 volt



Signal Level: -26 6 dB

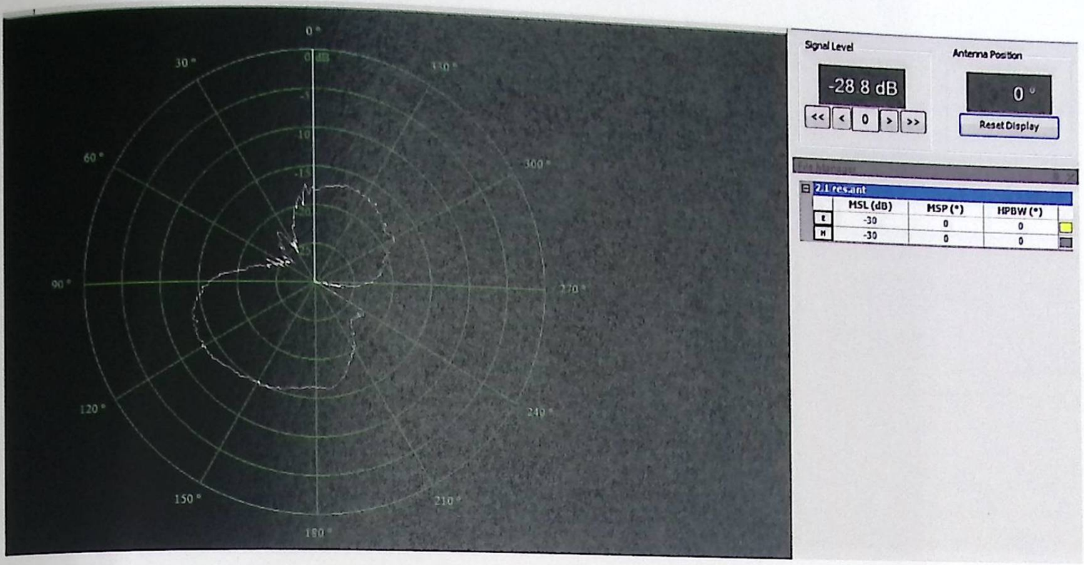
Antenna Position: 0 °

2.1 res.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-30	0	0	🟥
H	-30	0	0	⬜

Fig 8.9: Measured radiation pattern of the E- shaped microstrip antenna at 858MHz

and 2.3 volt

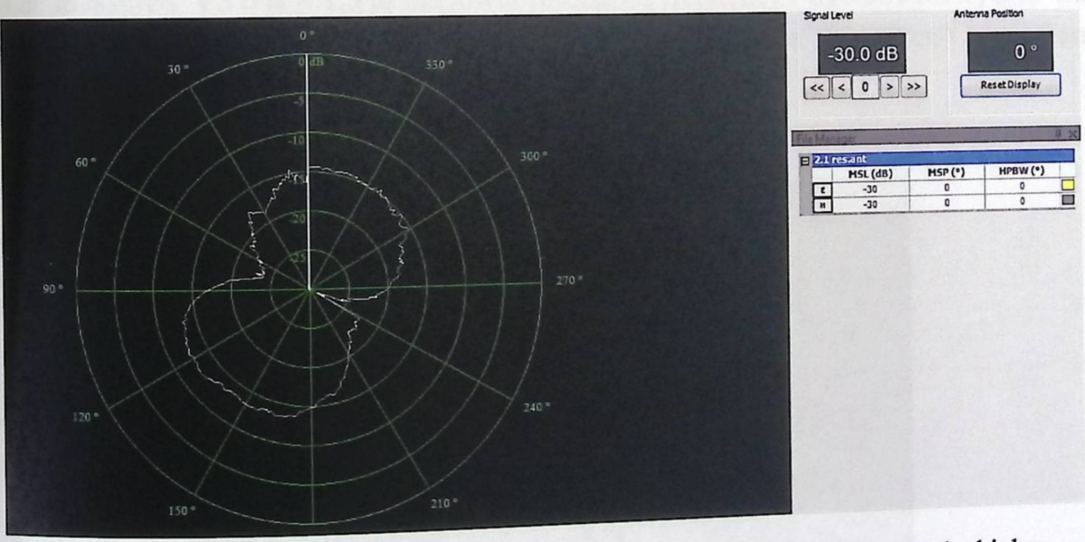


Signal Level: -28.8 dB

2.1 res.ant

	MSL (dB)	MSP (°)	HPBW (°)
E	-30	0	0
H	-30	0	0

Fig 8.10: Measured radiation pattern of the E- shaped microstrip antenna at 1200.73 MHz and 6.6 volt



Signal Level: -30.0 dB

2.1 res.ant

	MSL (dB)	MSP (°)	HPBW (°)
E	-30	0	0
H	-30	0	0

Fig 8.11: Measured radiation pattern of the E- shaped microstrip antenna at the higher resonance frequency (1206.57 MHz) and 6.7 volt

	MSL (dB)	MSP (°)	HPBW (°)	
E	-30	0	0	🟨
H	-30	0	0	▨

Fig 8.12: Measured radiation pattern of the E- shaped microstrip antenna at 1213.14 MHz and 6.8 volt

8.2.3 Measured voltage standing wave ratio (VSWR)

We also measured the VSWR of the E- shaped antenna and get the results as follows:

The measured VSWR = 1.5 at the lower resonance frequency (845.069 MHz) and 1.25 at the higher resonance frequency (1206 MHz) , which is acceptable since it isn't more than 1.5.

Mkr	Ref	Delta	Ref Freq	Ref Ampl	Delta Freq	Delta Ampl
1	ON	OFF	854 744 525 MHz	1.63	---	---

Fig 8.13: Measured VSWR of the linearly polarized E- shaped antenna

8.3 Measurement results of the circularly polarized E- shaped microstrip antenna

8.3.1 Measured return loss

We measured the return loss of the circularly polarized antenna using the same device (Site Master).

Here are the results that determine the return loss at the resonance frequency (1100 MHz) :

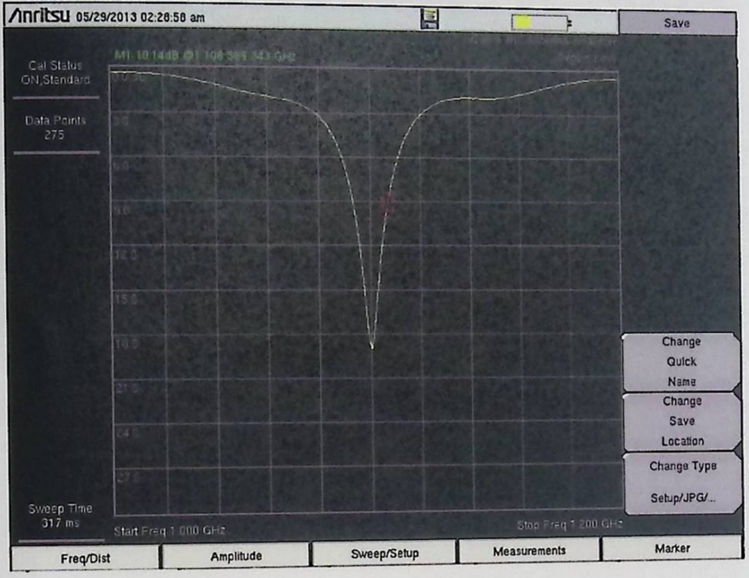


Fig 8.14: Measured return loss (S_{11}- parameter in dB) of the E- shaped microstrip antenna with FR4 substrate at the resonance frequency (1100 MHz).

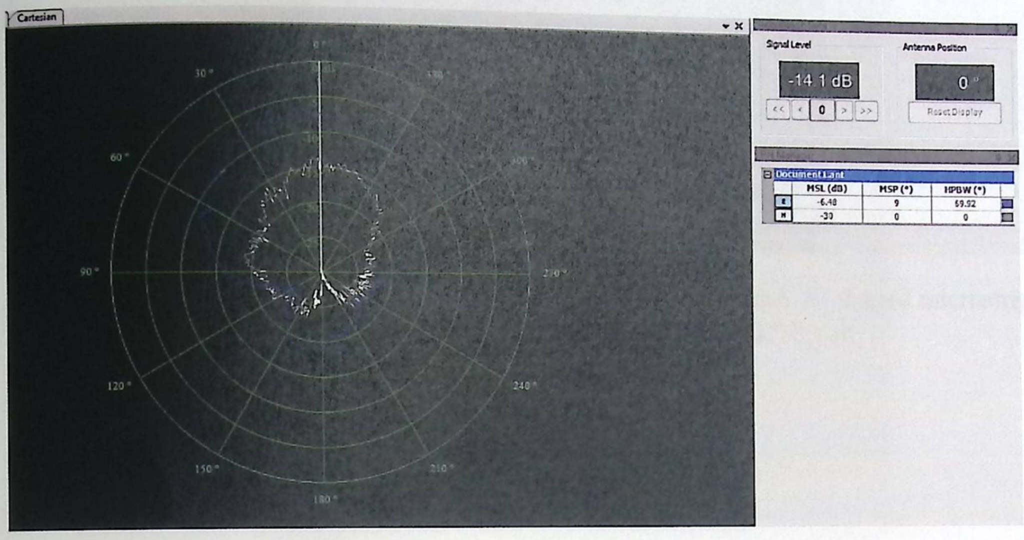
The measured return loss equals -19.15 dB

Measured bandwidth $f_2 - f_1 = 1106 - 1094$

$= 12$ MHz

8.3.2 Measured radiation pattern

We measured the radiation pattern of the circularly polarized E-shaped microstrip antenna after making calibration of the lab volt range system and get the following results :



Signal Level: -14.1 dB

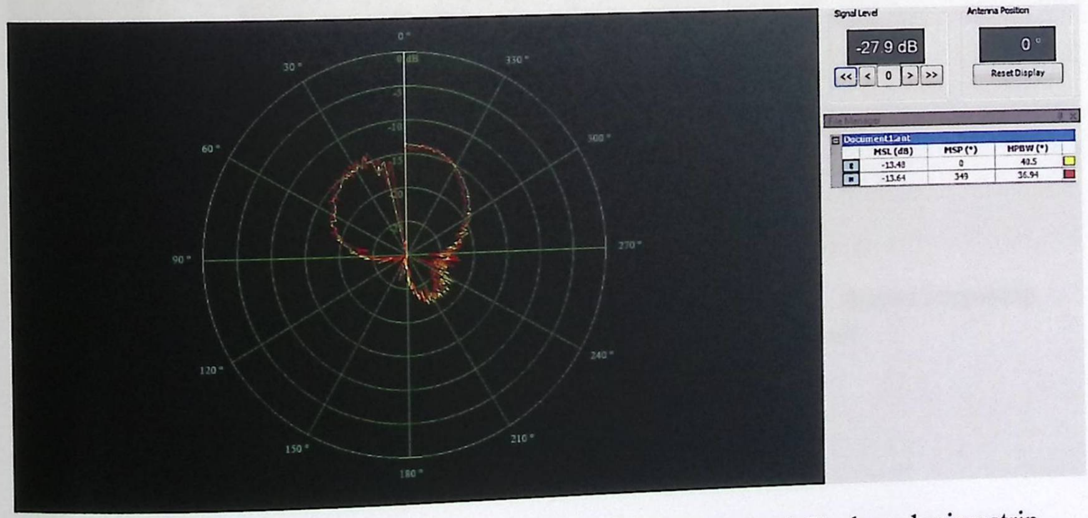
Antenna Position: 0°

Document1.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-6.48	9	69.92	🟪
H	-30	0	0	▨

Fig 8.15: Measured radiation pattern of the circularly polarized E- shaped microstrip antenna (RHCP & LHCP) at the resonance frequency (1100 MHz) and 5.4 volt

with beamwidth = 70 °



Signal Level: -27.9 dB

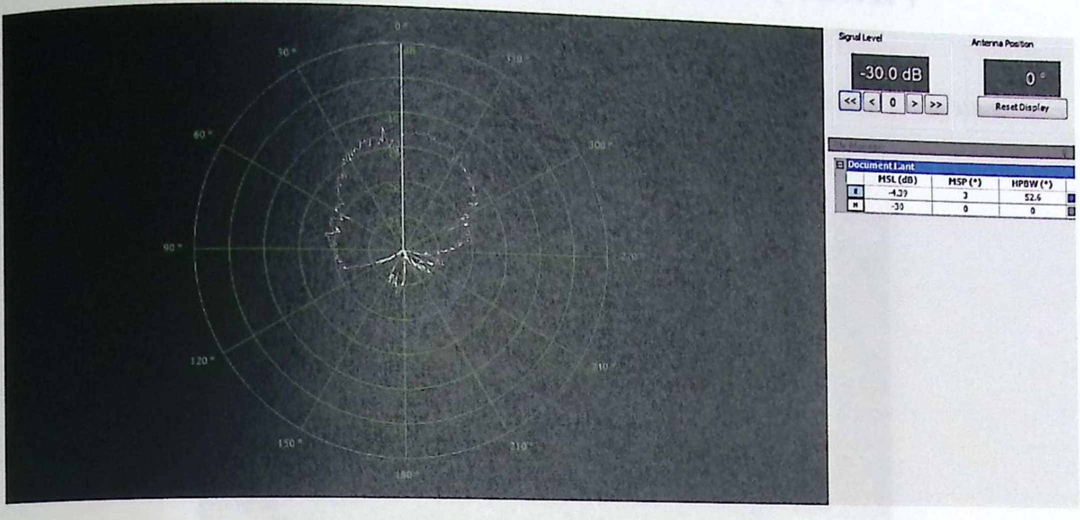
Antenna Position: 0°

Document1.ant

	MSL (dB)	MSP (°)	HPBW (°)	
E	-13.48	0	40.5	🟨
H	-13.64	349	36.94	🟥

Fig 8.16: Measured radiation pattern of the circularly polarized E- shaped microstrip antenna (E & H plane) at the resonance frequency (1100 MHz) and 5.4 volt

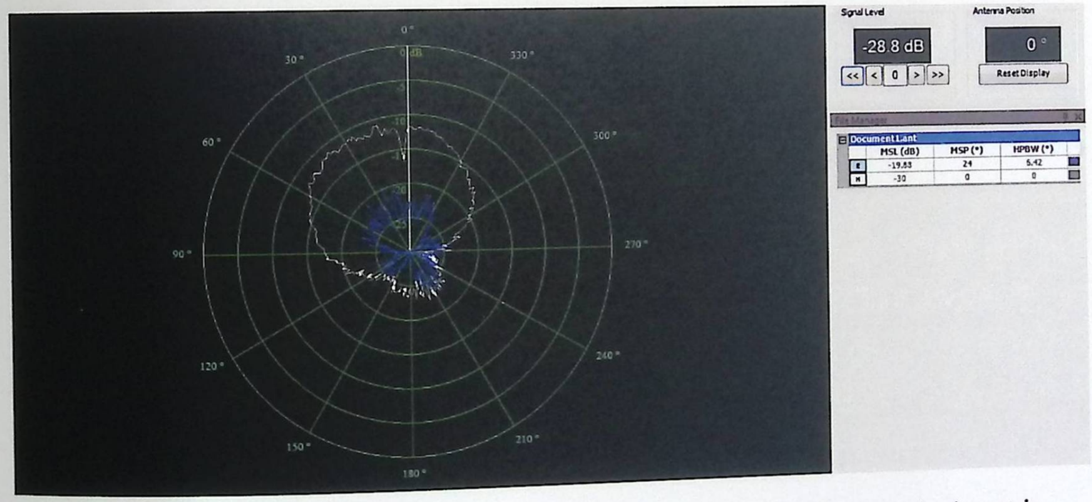
with beamwidth = 41 °



	MSL (dB)	MSP (°)	HPBW (°)
E	-4.39	3	52.6
H	-30	0	0

Fig 8.17: Measured radiation pattern of the circularly polarized E- shaped microstrip antenna (RHCP & LHCP) at 1094 MHz and 5.3 volt

with beamwidth = 52.6 °



	MSL (dB)	MSP (°)	HPBW (°)
E	-19.83	24	5.42
H	-30	0	0

Fig 8.18: Measured radiation pattern of the circularly polarized E- shaped microstrip antenna (RHCP & LHCP) at 1106 MHz and 5.5 volt

with beamwidth = 64.2 °

8.3.3 Measured voltage standing wave ratio (VSWR)

We also measured the VSWR of the E- shaped antenna and get the results as follows:

The measured VSWR = 1.26 , which is acceptable since it less than 1.5

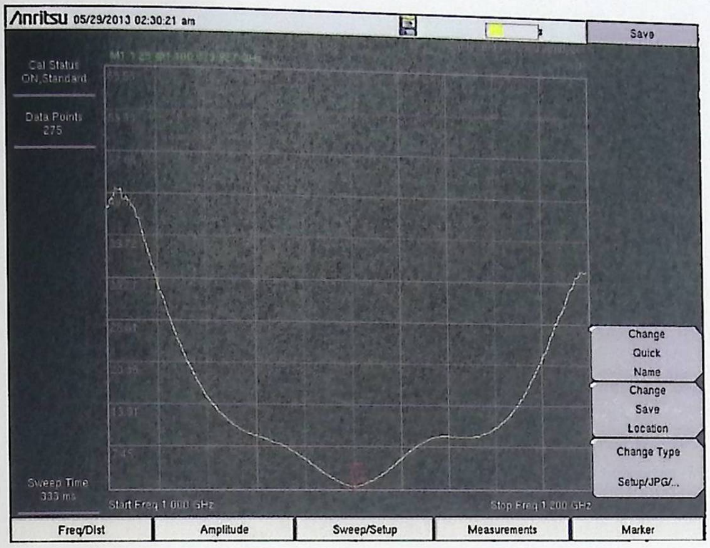


Fig 8.19: Measured VSWR of the circularly polarized E- shaped antenna

Chapter 9

Results , Conclusion and Challenges

9.1 Overview

This chapter presents verification for the designed E- shaped microstrip antenna using Ansoft and HFSS designer softwares and measured prototype. It also discusses the simulated and measured results of the antennas in terms of return loss and radiation patterns. It also presents a comparison between single layer and multilayer antenna using different dielectric substrates with different thickness , and for two types of polarization (linear & circular) , using coaxial feeding for all designs .

Also ,we examined the challenges that we faced during the design using the softwares fabrication and measurements of the prototypes.

9.2 Results and Conclusion

Through our design and analysis of microstrip antenna with a transmission line feed and a dipole antenna with a differential feed , we find out the effect of many parameters of the antenna as follows :

- As the output impedance of the antenna increased , the width and length of the antenna will be decreased .
- As the dielectric constant of the substrate increased , the width and length of the antenna will be decreased .
- As the thickness of the substrate increased , the width of the antenna will be decreased , while the antenna length will not affected .

Also , we designed and analyzed an E-shaped microstrip antenna, we get different results of return loss by changing the width of the quarter wave length matching line at the same frequency (1.8GHz) and the same length (L=30.826mm) in order to get proper value of return loss (less than -10 dB) which means good matching and low loss , but we have high losses at 2.21GHz because our resonant frequency is 1.8 GHz and at higher frequencies higher losses happened .

After that , we designed an E-shaped microstrip antenna using different substrates with different thickness for Linear & circular polarization using HFSS software ,we obtained the following results:

1. The dielectric material forms a cavity that stores energy, hence would reduce the antenna's bandwidth .
2. The patch is printed on a finite rectangular substrate of dimensions in order to avoid the excitation of surface waves, and the antenna is directly fed by a 50-Ω SMA connector.
3. The wideband characteristic is due to large separation between the radiating patch and the ground plane and due to the use of low permittivity substrate with the proposed design , since as substrate dielectric constant ($\mathcal{E}_r$) increases the bandwidth will be decreases, so the bandwidth of the E-shaped microstrip antenna will be increased using air substrate ($\mathcal{E}_r$=1)
4. The effect of the slots, most importantly, the amplitudes of currents around the slots are different at low resonant frequencies and high resonant frequencies. So , by decreasing slot length the whole return loss curve shifts towards the higher resonance frequency and vise versa.
5. We changed the slot width (Ws) in two ways , first we increased it from the middle slot of the E- shaped antenna , we note that the curve shifts toward the lower resonance frequency.

   Then , we increased Ws , by changing the upper & lower slots of an E-shaped antenna we note that the curve shifts toward the higher resonance frequency and the antenna resonating enhanced specially at the lower resonance frequency.
6. Patch length (Lp) affects the S_{11} – parameter curve , when it decreased the curve shifts toward the higher resonance frequency and vice versa .
7. The patch width (Wp) affects the resonance frequency of the lower mode more than the higher mode .By decreasing Wp , the whole return loss curve shifts towards the higher resonance frequency and vise versa .
8. To preserve matching ,we must scale feed position (X_f) , since unmatching cause :
   - Frequency shift .
   - Asymmetrical bandwidth at the two resonance frequencies , one narrow and other wide .

9. We scaled up the dimensions of the design to be radiated at GSM frequency 900 MHz , and L_2 - band GPS frequency 1200 MHz that can be measured using lab volt devices that available in our university's lab which operates at limited range of frequencies from (750 – 1200) MHz.

10. We designed a multilayer E-shaped microstrip antenna to get better resonance at the two desired resonance frequencies (900 & 1200) MHz . We found that we had physical restrictions of duroid material and we couldn't fabricate it . Also the resonance curve magnitudes were close to -10 dB .

11. Thin materials provides sharper resonance which means less bandwidth .

9.3 Challenges

During perform our design we face many problems :

1- In the introduction of the graduation project , we used Ansoft designer sv. software , and fed the antenna by microstrip line feeding instead of coaxial feeding due to software limitation of our student version.

2- Since there is no standard formula to determine the input impedance of the E-shaped microstrip antenna , we used 50Ω half wavelength transmission line connected to a quarter wavelength matching line.
We also did many trials to optimize the impedance of the quarter wave line until it become matched by noting the best return loss ,

3- Getting the HFSS software cracking , and learning how to use to be familiar with it , and learning how to design the E-shaped microstrip antenna since it different from the Ansoft designer that we used in the introduction of the graduation project.

4- Getting appropriate tutorial for designing an E-shaped microstrip antenna using coax feeding , we first started with the design of a patch antenna and then apply it on our E- shaped antenna .

5- Lack of researches and papers about the E- shaped microstrip antenna , since it is a new and hot topic in antennas , we faced many problems during the design to get good matching (appropriate return loss $S_{11} < -10dB$) and bandwidth at the two desired resonant frequencies , and we perform a parametric studies to analyze the E-shaped antenna and see the effect of each parameter on the resonance and bandwidth at the desired frequencies.

6- Lack of the materials that used to implement the design ,although we communicated with many companies , we get only one offer from Int. - Engineers company which provides the desired materials from Britain.

7- Limitation in the range of operation frequencies of the measurement devices (650 MHz – 1400 MHz) , since we fabricated and measured the designed E-shaped microstrip antenna using lab volt range system that is available in our university's lab.

8- In order to get broadband frequency , we faced up to a new challenge aided by our supervisor of added a bar and designed a circularly polarized microstrip antenna , also we changed several parameters such as feed position (X_f) to get a good matching and bandwidth .

Appendices

Appendix (A)

```
%
% Tutorials / simple patch antenna
%
% Describtion at:
% http://openems.de/index.php/Tutorial:_Simple_Patch_Antenna
%
% Tested with
%  - Matlab 2011a / Octave 3.4.3
%  - openEMS v0.0.27
%
% (C) 2010-2012 Thorsten Liebig <thorsten.liebig@uni-due.de>

close all
clear
clc

%% setup the simulation
physical_constants;
unit = 1e-3; % all length in mm

% patch width in x-direction
patch.width  = 30; % resonant length
% patch length in y-direction
patch.length = 40;

%substrate setup
substrate.epsR   = 3.38;
substrate.kappa  = 1e-3 * 2*pi*2.45e9 * EPS0*substrate.epsR;
substrate.width  = 60;
substrate.length = 60;
substrate.thickness = 1.524;
substrate.cells = 4;


%setup feeding
feed.pos = -6; %feeding position in x-direction
feed.width = 2;  %feeding port width
feed.R = 50;     %feed resistance

% size of the simulation box
SimBox = [200 200 150];

%% setup FDTD parameter & excitation function
f0 = 2e9; % center frequency
fc = 1e9; % 20 dB corner frequency
FDTD = InitFDTD( 30000 );
FDTD = SetGaussExcite( FDTD, f0, fc );
BC = {'MUR' 'MUR' 'MUR' 'MUR' 'MUR' 'MUR'}; % boundary conditions
FDTD = SetBoundaryCond( FDTD, BC );

%% setup CSXCAD geometry & mesh
```

```
CSX = InitCSX();

%initialize the mesh with the "air-box" dimensions
mesh.x = [-SimBox(1)/2 SimBox(1)/2];
mesh.y = [-SimBox(2)/2 SimBox(2)/2];
mesh.z = [-SimBox(3)/3 SimBox(3)*2/3];

%% create patch
CSX = AddMetal( CSX, 'patch' ); % create a perfect electric conductor (PEC)
start = [-patch.width/2 -patch.length/2 substrate.thickness];
stop = [ patch.width/2  patch.length/2 substrate.thickness];
CSX = AddBox(CSX,'patch',10,start,stop); % add a box-primitive to the metal
property 'patch'

%% create substrate
CSX = AddMaterial( CSX, 'substrate' );
CSX = SetMaterialProperty( CSX, 'substrate', 'Epsilon', substrate.epsR,
'Kappa', substrate.kappa );
start = [-substrate.width/2 -substrate.length/2 0];
stop  = [ substrate.width/2  substrate.length/2 substrate.thickness];
CSX = AddBox( CSX, 'substrate', 0, start, stop );

% add extra cells to discretize the substrate thickness
mesh.z = [linspace(0,substrate.thickness,substrate.cells+1) mesh.z];

%% create ground (same size as substrate)
CSX = AddMetal( CSX, 'gnd' ); % create a perfect electric conductor (PEC)
start(3)=0;
stop(3) =0;
CSX = AddBox(CSX,'gnd',10,start,stop);

%% apply the excitation & resist as a current source
start = [feed.pos-feed.width/2 -feed.width/2 0];
stop  = [feed.pos+feed.width/2 +feed.width/2 substrate.thickness];
[CSX port] = AddLumpedPort(CSX, 5 ,1 ,feed.R, start, stop, [0 0 1], true);

%% finalize the mesh
% generate a smooth mesh with max. cell size: lambda_min / 20
mesh = DetectEdges(CSX, mesh);
mesh = SmoothMesh(mesh, c0 / (f0+fc) / unit / 20);
CSX = DefineRectGrid(CSX, unit, mesh);

%% add a nf2ff calc box; size is 3 cells away from MUR boundary condition
start = [mesh.x(4)     mesh.y(4)     mesh.z(4)];
stop  = [mesh.x(end-3) mesh.y(end-3) mesh.z(end-3)];
[CSX nf2ff] = CreateNF2FFBox(CSX, 'nf2ff', start, stop);


%% prepare simulation folder
```

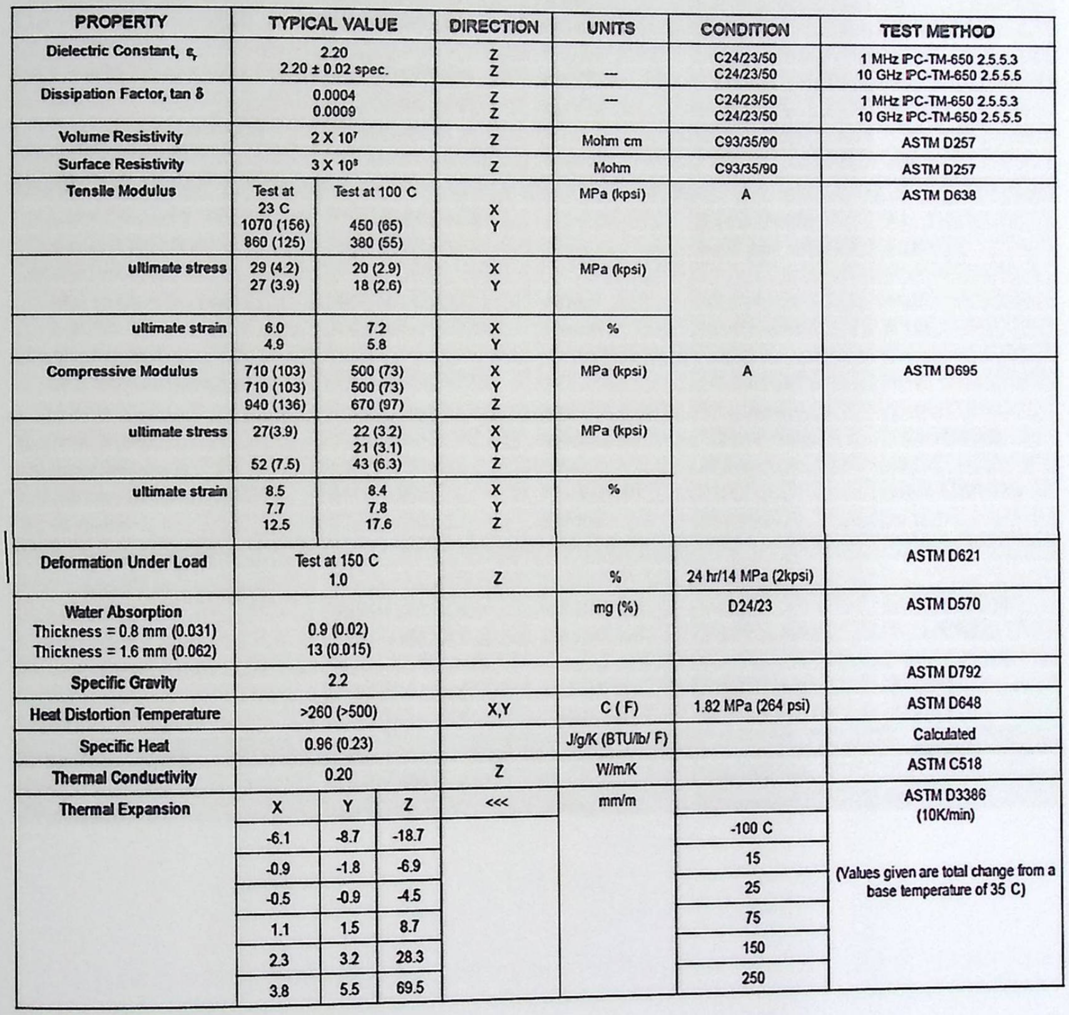
```
Sim_Path = 'tmp_Patch_Ant';
Sim_CSX = 'patch_ant.xml';

[status, message, messageid] = rmdir( Sim_Path, 's' ); % clear previous
directory
[status, message, messageid] = mkdir( Sim_Path ); % create empty simulation
folder

%% write openEMS compatible xml-file
WriteOpenEMS( [Sim_Path '/' Sim_CSX], FDTD, CSX );

%% show the structure
CSXGeomPlot( [Sim_Path '/' Sim_CSX] );

%% run openEMS
RunOpenEMS( Sim_Path, Sim_CSX);

%% postprocessing & do the plots
freq = linspace( max([1e9,f0-fc]), f0+fc, 501 );
port = calcPort(port, Sim_Path, freq);

Zin = port.uf.tot ./ port.if.tot;
s11 = port.uf.ref ./ port.uf.inc;
P_in = 0.5 * port.uf.inc .* conj( port.if.inc ); % antenna feed power


% plot feed point impedance
figure
plot( freq/1e6, real(Zin), 'k-', 'Linewidth', 2 );
hold on
grid on
plot( freq/1e6, imag(Zin), 'r--', 'Linewidth', 2 );
title( 'feed point impedance' );
xlabel( 'frequency f / MHz' );
ylabel( 'impedance Z_{in} / Ohm' );
legend( 'real', 'imag' );


% plot reflection coefficient S11
figure
plot( freq/1e6, 20*log10(abs(s11)), 'k-', 'Linewidth', 2 );
grid on
title( 'reflection coefficient S_{11}' );
xlabel( 'frequency f / MHz' );
ylabel( 'reflection coefficient |S_{11}|' );

drawnow

%% NFFF contour plots %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%find resonance frequncy from s11
f_res_ind = find(s11==min(s11));
f_res = freq(f_res_ind);


% calculate the far field at phi=0 degrees and at phi=90 degrees
```

```
disp( 'calculating far field at phi=[0 90] deg...' );

nf2ff = CalcNF2FF(nf2ff, Sim_Path, f_res, [-180:2:180]*pi/180, [0
90]*pi/180);

% display power and directivity
disp( ['radiated power: Prad = ' num2str(nf2ff.Prad) ' Watt']);
disp( ['directivity: Dmax = ' num2str(nf2ff.Dmax) ' ('
num2str(10*log10(nf2ff.Dmax)) ' dBi)'] );
disp( ['efficiency: nu_rad = ' num2str(100*nf2ff.Prad./real(P_in(f_res_ind)))
' %']);


% normalized directivity
D_log = 20*log10(nf2ff.E_norm{1}/max(max(nf2ff.E_norm{1})));
% directivity
D_log = D_log + 10*log10(nf2ff.Dmax);


%% display polar plot
figure
plot( nf2ff.theta, D_log(:,1) ,'k-' );
xlabel( 'theta (deg)' );
ylabel( 'directivity (dBi)');
grid on;
hold on;
plot( nf2ff.theta, D_log(:,2) ,'r-' );
legend('phi=0','phi=90')


%%
disp( 'calculating 3D far field pattern and dumping to vtk (use Paraview to
visualize)...' );
thetaRange = (0:2:180);
phiRange = (0:2:360) - 180;
nf2ff = CalcNF2FF(nf2ff, Sim_Path, f_res, thetaRange*pi/180,
phiRange*pi/180,'Verbose',1,'Outfile','3D_Pattern.h5');


E_far_normalized = nf2ff.E_norm{1} / max(nf2ff.E_norm{1}(:)) * nf2ff.Dmax;
DumpFF2VTK([Sim_Path
'/3D_Pattern.vtk'],E_far_normalized,thetaRange,phiRange,1e-3);
```

Appendix (B)

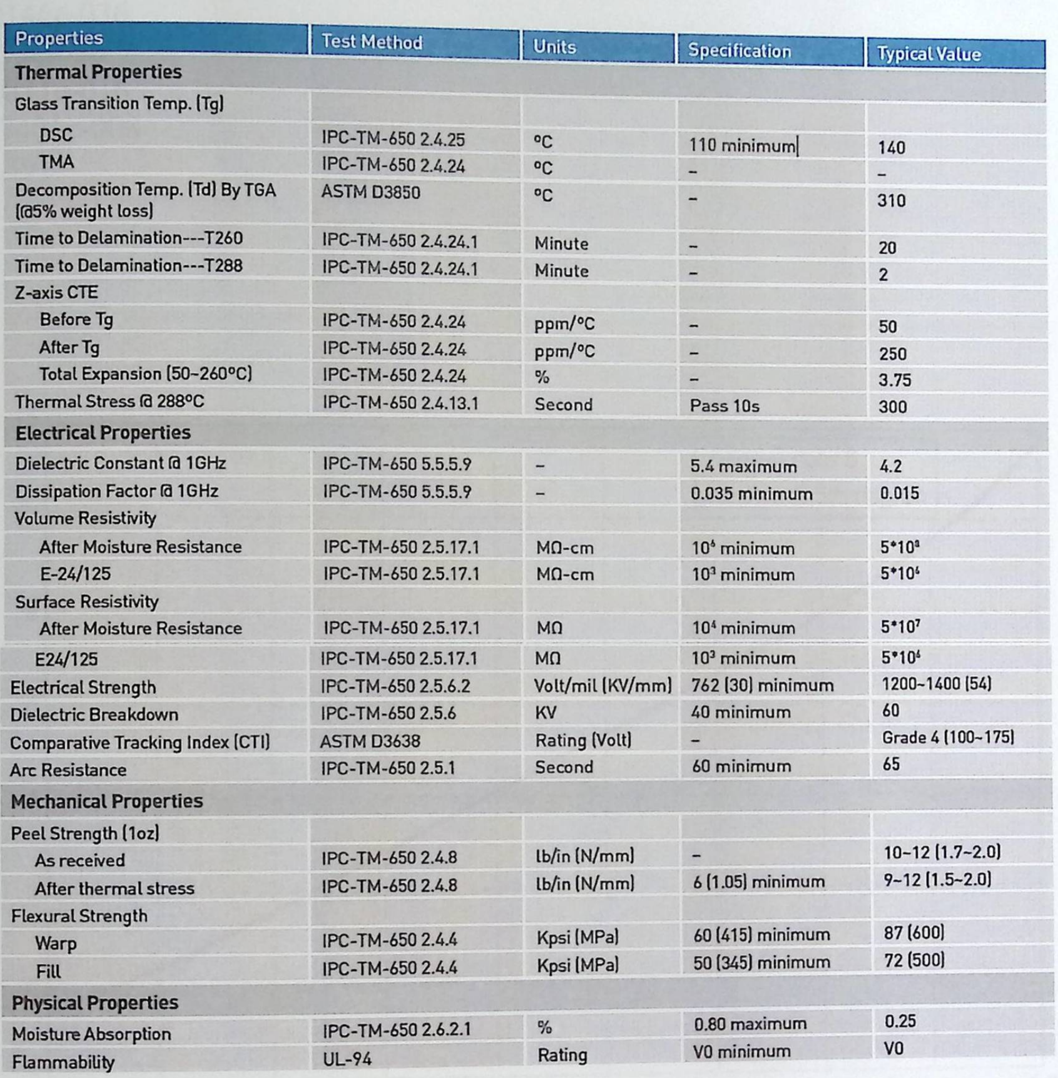
Data sheet of the used materials ; RT/Duroid 5880 and FR4.

Table B.1: Properties of RT/Duroid 5880



PROPERTY	TYPICAL VALUE			DIRECTION	UNITS	CONDITION	TEST METHOD
Dielectric Constant, ε_r	2.20 2.20 ± 0.02 spec.			Z Z	---	C24/23/50 C24/23/50	1 MHz IPC-TM-650 2.5.5.3 10 GHz IPC-TM-650 2.5.5.5
Dissipation Factor, tan δ	0.0004 0.0009			Z Z	---	C24/23/50 C24/23/50	1 MHz IPC-TM-650 2.5.5.3 10 GHz IPC-TM-650 2.5.5.5
Volume Resistivity	2 X 10^7			Z	Mohm cm	C93/35/90	ASTM D257
Surface Resistivity	3 X 10^8			Z	Mohm	C93/35/90	ASTM D257
Tensile Modulus	Test at 23 C 1070 (156) 860 (125)	Test at 100 C 450 (65) 380 (55)		X Y	MPa (kpsi)	A	ASTM D638
ultimate stress	29 (4.2) 27 (3.9)	20 (2.9) 18 (2.6)		X Y	MPa (kpsi)		
ultimate strain	6.0 4.9	7.2 5.8		X Y	%		
Compressive Modulus	710 (103) 710 (103) 940 (136)	500 (73) 500 (73) 670 (97)		X Y Z	MPa (kpsi)	A	ASTM D695
ultimate stress	27(3.9) 52 (7.5)	22 (3.2) 21 (3.1) 43 (6.3)		X Y Z	MPa (kpsi)		
ultimate strain	8.5 7.7 12.5	8.4 7.8 17.6		X Y Z	%		
Deformation Under Load	Test at 150 C 1.0			Z	%	24 hr/14 MPa (2kpsi)	ASTM D621
Water Absorption Thickness = 0.8 mm (0.031) Thickness = 1.6 mm (0.062)	0.9 (0.02) 13 (0.015)				mg (%)	D24/23	ASTM D570
Specific Gravity	2.2						ASTM D792
Heat Distortion Temperature	>260 (>500)			X,Y	C (F)	1.82 MPa (264 psi)	ASTM D648
Specific Heat	0.96 (0.23)				J/g/K (BTU/lb/ F)		Calculated
Thermal Conductivity	0.20			Z	W/m/K		ASTM C518
Thermal Expansion	X	Y	Z	<<<	mm/m		ASTM D3386 (10K/min)
	-6.1	-8.7	-18.7			-100 C	(Values given are total change from a base temperature of 35 C)
	-0.9	-1.8	-6.9			15	
	-0.5	-0.9	-4.5			25	
	1.1	1.5	8.7			75	
	2.3	3.2	28.3			150	
	3.8	5.5	69.5			250	

Table B.2: Properties of FR4



Properties	Test Method	Units	Specification	Typical Value
Thermal Properties				
Glass Transition Temp. (Tg)				
DSC	IPC-TM-650 2.4.25	°C	110 minimum	140
TMA	IPC-TM-650 2.4.24	°C	–	–
Decomposition Temp. (Td) By TGA (@5% weight loss)	ASTM D3850	°C	–	310
Time to Delamination---T260	IPC-TM-650 2.4.24.1	Minute	–	20
Time to Delamination---T288	IPC-TM-650 2.4.24.1	Minute	–	2
Z-axis CTE				
Before Tg	IPC-TM-650 2.4.24	ppm/°C	–	50
After Tg	IPC-TM-650 2.4.24	ppm/°C	–	250
Total Expansion (50~260°C)	IPC-TM-650 2.4.24	%	–	3.75
Thermal Stress @ 288°C	IPC-TM-650 2.4.13.1	Second	Pass 10s	300
Electrical Properties				
Dielectric Constant @ 1GHz	IPC-TM-650 5.5.5.9	–	5.4 maximum	4.2
Dissipation Factor @ 1GHz	IPC-TM-650 5.5.5.9	–	0.035 minimum	0.015
Volume Resistivity				
After Moisture Resistance	IPC-TM-650 2.5.17.1	MΩ-cm	10^6 minimum	$5*10^8$
E-24/125	IPC-TM-650 2.5.17.1	MΩ-cm	10^3 minimum	$5*10^6$
Surface Resistivity				
After Moisture Resistance	IPC-TM-650 2.5.17.1	MΩ	10^4 minimum	$5*10^7$
E24/125	IPC-TM-650 2.5.17.1	MΩ	10^3 minimum	$5*10^6$
Electrical Strength	IPC-TM-650 2.5.6.2	Volt/mil (KV/mm)	762 (30) minimum	1200~1400 (54)
Dielectric Breakdown	IPC-TM-650 2.5.6	KV	40 minimum	60
Comparative Tracking Index (CTI)	ASTM D3638	Rating (Volt)	–	Grade 4 (100~175)
Arc Resistance	IPC-TM-650 2.5.1	Second	60 minimum	65
Mechanical Properties				
Peel Strength (1oz)				
As received	IPC-TM-650 2.4.8	lb/in (N/mm)	–	10~12 (1.7~2.0)
After thermal stress	IPC-TM-650 2.4.8	lb/in (N/mm)	6 (1.05) minimum	9~12 (1.5~2.0)
Flexural Strength				
Warp	IPC-TM-650 2.4.4	Kpsi (MPa)	60 (415) minimum	87 (600)
Fill	IPC-TM-650 2.4.4	Kpsi (MPa)	50 (345) minimum	72 (500)
Physical Properties				
Moisture Absorption	IPC-TM-650 2.6.2.1	%	0.80 maximum	0.25
Flammability	UL-94	Rating	V0 minimum	V0

Appendix (C)

$$z = p1*x^5 + p2*x^4 + p3*x^3 + p4*x^2 + p5*x + p6 \qquad (C.1)$$

p1 = 4.8979e-045
p2 = 1.2146e-036
p3 = -5.53e-026
p4 = 1.0831e-016
p5 = -6.7401e-008
p6 = 12.391

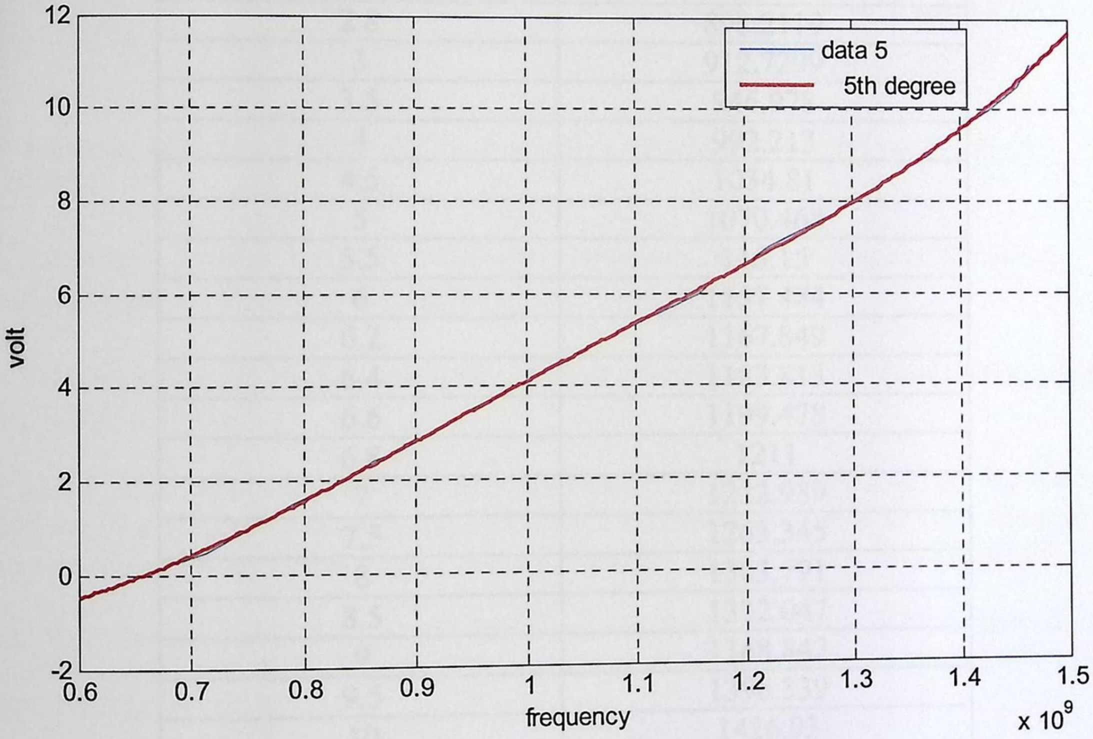


Fig C.1: Relationship between frequency and voltage on the LabVolt Antenna Range

Table C.1 : Values of measured frequency with respect to voltage

Voltage (volt)	**Frequency (MHz)**
0	652.95
0.5	713.208
1	754.658
1.5	790.453
2	834.692
2.2	849.564
2.4	862.328
2.6	883.6119
2.8	898.2119
3	912.7299
3.5	946.978
4	992.213
4.5	1034.81
5	1070.468
5.5	115.15
6	1157.484
6.2	1167.849
6.4	1183.813
6.6	1199.478
6.8	1211
7	1222.989
7.5	1263.345
8	1303.791
8.5	1332.047
9	1368.842
9.5	1396.339
10	1426.93
10.5	1452.407
11	1464.849

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