OPTIMIZING AND EVALUATING THE PERFORMANCE OF A ULTRA-WIDEBAND CPW FED SLOT ANTENNA

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August 2014

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Supervisor’s name: KELLY JR

WORD COUNT

Number of Pages: 61

Number of Words: 13830

ABSTRACT

In this project, a Coplanar Wave Guide (CPW) fed hybrid slot antenna, which is combination of two antennas, for wideband applications is proposed. Two different antennas that one was taken from the literature and other one was constructed by the author were constructed and simulated to obtain ultra-wide bandwidth and then the results obtained separately. Afterward, they were nested onto one plane to obtain a combined antenna that can be used to operate over two separated ultra-wide operating bands by using microwave switches.

As the technology is progressing very quickly, the required bandwidth is increasing as well and hence wider bandwidth antennas are needed. Thus Ultra wideband antennas have drown attention of the researches since it has the most promising technological advantages for mobile systems particularly for short range systems such as PAN (Personal Area Network). Even though there are a lot of antennas operating with ultra wideband, they have some disadvantages such as unwanted big size. However, patch antennas are very popular as they offer very good features that mentioned in the introduction. Therefore, microstrip antennas became much demanded antennas. nonetheless, the slot antennas that are fed by microstrip feed transmission line are difficult to align because of the etching between both the ground plane and transmission line on the opposite sides of the substrate and microstrip line are not suitable for monolithic fabrication and hence it is not likely to integrate them with active solid-state and passive one and also they are inherently narrow band antenna. As a consequence of these problems, to widen bandwidth the coplanar waveguide transmission lines are introduced. The CPW-fed slot antennas give more advantages than patch antennas such as wider bandwidth, low radiation loss and less dispersion.

A compact CPW-fed rectangular hybrid slot antenna of operating in two frequency bands is designed. The overall dimensions of the antenna are 80x60 mm2. The antenna was fabricated and analysed to obtain its properly working properties over the ultra-wideband frequency range. The constructed antenna simulated and results of return loss, voltage standing wave ratio (VSWR) and radiation patterns were obtained. It is observed that the bandwidths stretch from 2.56 to 3.44 GHz in the lower operating frequency range and 3.9 to 4.9 GHz in the upper operating frequency range were achieved which corresponds to 29.3% and 28% fractional bandwidths, respectively. All initial constructions and simulation were done by taking advantages of CST Microwave Studio software.

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GLOSSARY

CPW	Coplanar Waveguide
PCB	Printed Circuit Board
RF	Radio Frequency
UWB	Ultra wideband
WLAN	wireless local area network
WiMax	World interoperability for microwave access
RFID	Radio Frequency Identification
Wi-Fi	Wireless Fidelity
FCC	Federal communications commission
FR4	Flame Retardant
MMIC	Monolithic microwave integrated circuits
FEC	Forward error correction
PIFA	Planar inverted-F
TEM	Transverse electro-magnetic
VSWR	Voltage standing wave ratio

INTRODUCTION

1.1 Background and Context

1.1.1 Development of CPW Transmission Lines

Even though the microstrip antennas initially were proposed in earlier 1950s, the first actual microstrip antennas came out in 1974. The first patch (microstrip) antennas were published by Artech House in 1980. On the other hand, C.P. Wen introduced coplanar waveguide transmission line for nonreciprocal microwave circuits as it was able to create elliptically polarised magnetic fields in slots in 1969 [14],[36]. Despite of the fact that it demonstrated some very good features, it was not preferred as microstrip line was already very well in use in hybrid technology. As a consequence, the coplanar lines could not draw much attention between 1970 and 1980[36]. Nevertheless, Patch antennas became very popular as they were light weight, small in size and so on. As the demand for personal and mobile communication, satellite communication, global positioning applications, RFID, interoperability for microwave access (WiMax), radar applications and for Bluetooth applications have been going up, the need for smaller and low-profile antennas has drawn much more attention to microstrip antennas [11],[37]. Nonetheless, microstrip antennas are inherently narrow band components, they can be made for ultra-wide band antennas by having larger size, but this is unwanted. Since there is a big demand for wideband radiators there have been a lot of researches done to obtain wider bandwidth antennas [39],[8]. Therefore, coplanar waveguides have been drawn a great attention because of the fact that they offer wider bandwidth, less radiation loss and so forth than microstrip transmission lines. These antennas are in general used in wireless local area networks (WLAN), Wireless Fidelity (Wi-Fi) and the worldwide interoperability for microwave access (WIMAX) technology and also used for radio frequency identification (RFID) that are used for tracking a tags attached any objects [36].

1.1.2 Development of Ultra-wideband

Ultra wideband (UWB) pulse propagation was formed by Sommerfeld in 1901 as he wanted to sort out the diffraction of time domain pulse via an excellently conducting wedge. As a matter of the fact that it might be argued that UWB started in the spark gap transmission design of Hertz and Marconi by the end of 1890s. Due to the limitations of the technology of time-being narrowband applications were preferred to UWB. UWB was mainly used for military radar applications and communication in its earlier systems. After the increasing progress since 1994, UWB picked up the momentum after the federation communications commission realised the need for UWB in 1998. After the Federal communications commission (FCC) permitted UWB communications unlicensed operating band of 3.1 GHz to 10.6 GHz, it has been caught big attention and there have been a lot

of investigations conducted for many applications such as WiFi, WiMax etc [45],[46].

1.2 Scope and Objectives

In the project the general review of the fundamental theory with regard to the operation of microwave and antenna theory were done. For instance, the antenna patterns like radiation patterns, directivity, gain, efficiency, return loss and voltage standing wave ratio (VSWR) were covered. Additionally, CST microwave studio (transient solver for time domain was used for far field) was used for constructing and doing the simulations. Two antennas that the one taken from the literature and the other built by the author for a CPW fed slot antenna were built and simulated in order to obtain the S11 (return loss), radiation patterns, efficiency, directivity and gain so that it can be seen whether the results are similar to those obtained from the literature papers. After all, the two antennas are collocated and then simulated again to achieve ultra wideband antenna of two different operation bandwidths. The obtained results are evaluated to see how well the results met the requirements.

The objective of this project is that as the current technologies are emerging, which brings new difficulties as well as gives some advantages. One issue is how to construct an antenna that covers two operating bands for covering smaller size and having a good efficiency. Thus, instead of having traditional multi band antennas which have small size and with the challenge of isolation or two separated antennas that although have simple structure, they need more space, a new novel reconfigurable antenna that consists of two ultra wideband operating frequencies and fine efficiency is produced, which has small size and better isolation than traditional multiband antenna but has the problem of complexity. The reconfigurable antenna operates in different frequency bands by incorporating with microwave switches and additional slots [25],[26]. To achieve the objective the following steps were taken:

1.2.1 Methodology

a) General literature investigation of the design of the coplanar waveguide fed wideband antennas.

b) Design two different CPW-fed hybrid rectangular slot antennas operating in different ultra-wide bandwidths for ultra wideband applications.

c) Nest the two antennas onto the same substrate and use the microwave switches to put the antennas on or off state.

d) Order the equipments required to fabricate the antennas in the lab.

e) Fabricate the antennas at the lab to do practical measurements, and validate the results, conclusions.

f) Compare the simulated results with those obtained through measurement and comment on the

any differences.

1.2.2 Equipments

The tools were used during the work on the project as follows:

a) Personal laptop

b) CST microwave studio

c) FR4 (lossy) substrate

d) SMA connector

e) PCB comical etching machinery

f) Anechoic chamber and vector network analyser.

1.3 The Working Processes

a) The CST microwave studio was studied with the tutorial in YouTube to learn how to fabricate patch antennas and evaluate the results.

b) A CPW-fed rectangular hybrid slot antenna, which is named first antenna, taken from the literature was constructed in CST microwave studio. The constructed (first antenna) was simulated and the results were compared to those obtained in the literature and it was seen that the results were quite similar, which has ultra-wide bandwidth.

c) A Reconfigurable CPW-fed rectangular slot antenna, namely second antenna, having different dimensions from the first antenna was fabricated by the author to obtain an ultra-wide bandwidth antenna.

d) after all these steps were taken successfully the first antenna and the second antenna were nested onto the same substrate in order to operate as a dual antenna by incorporating with the microwave switches by putting the first and second antenna with On-Off cases. In the case of the first antenna was on the nested antenna operates in higher operating ultra-wide bandwidth and in the case of on state for second antenna the nested antenna operates in the lower operating frequency of ultra-wide bandwidth.

1.4 Organisation of the Dissertation

The dissertation is organised as follows: in section 2 the state of the art of the topic is clarified by dividing into sub-sections of introduction 2.1, historical CPW fed slot antenna 2.2, in the section 3

there are some clarifications regarding antenna parameters, Coplanar transmission lines and Slot antennas for making the reader to better understand terms that are explained in the following sections, in the section 4 the analyses of the simulated and practical results are done to see how well it is achieved or not by comparing the results and the section 5 the conclusion of the project with giving small summery of the project, evaluation of the findings and future recommendations of the work.

2 STATE-OF-THE-ART

2.1 Introduction

Ultra wideband antenna is a non-resonant which has low Q factor and constant input impedance in wideband operating frequency range. To be non-dispersive is one of the most important characteristic of UWB antennas as it makes them avoid farther pulse compensation. Ultra wideband propagation offers high data rates because of the transmission of non-successive and so short pulses and also it is not easy to track the transmitting data which assures the data security. Furthermore, the system consumes very low transmitting power as compared to the conventional narrow band antennas. In addition, as the reflected pulses do not intervene with the original pulse it does not suffer from multipath fading [24]. Since UWB has these advantages it has become one of the most promising technology in the applications like high data rate wireless communication, high accuracy radars, and imaging systems. There was a lot of research done for UWB technology, which was mainly volumetric structure antennas, until 1990. The first UWB antenna was biconical antenna proposed by Lodge and carter between 1898 and 1939. After, the following years new UWB antennas had been proposed such as spheroidal antenna proposed by Schelkunoff (1941), coaxial horn by lindenblad (1941), large current radiator by Harmuth (1985) and so on. Non-volumetric antennas have been proposed since 1992 like microstrip, slot, and planar monopole antennas. UWB antennas initially were generally designed and deployed for military related systems in 1960s owing to the fact that the USA military tried to use pulse transmission in radar, covert imaging and stealth communications. Since the subsystem and component technology were advanced in 1990s and the technological boost paved the way for new market for Ultra wideband technology [23],[11]. After all, the Federal Communication Commission (FCC) in the USA permitted UWB operating frequency range between 3.1-10.6 GHz the academia and industry have been exited. Therefore, there have been doing a great number of researches and of course simultaneously faced a lot of technical difficulties in practice. The difficulties are topics relating to antenna in terms of theoretical and engineering. For example, from fundamental point of view how to design antennas and source pulses, model the antenna systems based on frequency/time domain and from design and applications point of view there are some challenges too such as vehicle radar systems, arrays:

compact, beam-streaming etc [43],[44]. Also the developments have suggested that conventional parameters of antennas, which are gain, polarisation linearity, and impedance matching and so on, are fine for narrow band antennas, nevertheless not sufficient for ultra wideband antennas, in which the parameters likes stability of radiation, phase linearity and so on are needed to define them for current communication systems. In spite of the fact that the recent investigations have been concentrate on omnidirectional ultra-wide band antennas as main focus is to develop wireless communication industry, generally for handsets what require omnidirectional patterns of radiation, there are interests for obtaining directional UWB antennas as well. microstrip, slot and planar antennas are being focused for current works on UWB band applications [44].

2.2 CPW Fed Slot Antennas

2.2.1 Historical overview of CPW fed slot antenna.

The first UWB patch antenna was found by Yasuto Mushika in in the 1940s that refers to so-called self-complementary antennas created by Wilhem Runge in the 1930s.Victor Rumsey introduced the first best known UWB in 1950s to express so-called frequency independent antennas and design the antenna just in terms of the angles which requires very large size. As the size of the antenna should be small researches tried to find compact antenna and the first microstrip book was written by Drs. Bahl and Bhartia. Furthermonre, since then there have been numerous texts about microstrip written in the literature like microstrip antenna design handbook written by Ramesh Garg, Prakash Bharattia, Inder Bahl and Apisak Ittipiboon in 2000. And since microstrip antennas are inherently narrow band antennas have some other drawbacks as mentioned in the introduction, the CPW feed slot antennas have more advances than microstrip antennas. As a result, there have been extensive investigations on CPW-fed aperture antennas. Practical results of loop antennas of CPW-fed and electrically narrow slot antennas have been published in terms of approximate transformation analyses. CPW-fed slots were used as primary radiators in a phase scanned antenna. The antenna impedance is reduced by a folded slot configuration [11],[12].

2.2.2 Advantages and Disadvantages of CPW-fed Slot Antennas

The slot antennas offer the advantages of lightweight, low profile, easy integration with MMICs (monolithic microwave integrated circuits) as well as radiation stability. In order to yield ultra wideband antennas different shapes of stubs implemented and/or different shapes slot antennas performed such as bow tie, rectangular, ring, E-shaped etc. When slot antenna is fed with coplanar waveguide low radiation leakage, less dispersion and low loss take place. Also the alignment issues that are generally come across in building two layer printed circuits antennas are solved by feeding the slot with CPW as the all components are on the same side of the substrate. CPW fed slot antenna can be used with fibber optics, which is a good promising application of CPW fed antenna.

Furthermore, CPW fed slot antennas can easily be integrated with active and passive devices as well as realised with series and shunt circuits on the same side of the substrate meaning that no need for vie hole integration.

On the other hand the CPW fed slot antennas struggle with parasitic modes, lower power handling capability and difficulty of confining the field as well as requirement of connection of ground at this continues [48],[28]. Moreover, one of the big problems of the CPW-fed slot antennas is the requirement for suitable transition. Lots of different slot line transitions have come out for antenna applications such as one-wavelength long offset-fed slot antenna, the half-wavelength long capacitive fed slot antenna and inductively coupled slot antenna. Also they suffer from higher attenuation and lower effective dielectric constant [49].

2.3 Ultra-wideband Theory

The traditional radio transmissions transmits the data by varying the frequency, level of power, and/or phase of the wave, which is the most crucial distinction between the ultra-wideband and the traditional radio transmissions. UWB transmitters transfer the data by producing electromagnetic energy at certain time intervals and covering a big bandwidth, therefore they enable the time modulation or pulse positioning. In addition, the data on ultra-wideband pulses can be modulated by implementing orthogonal pulses, encoding pulse polarity and/or amplitude of the pulses. In order to support positioning or time modulation UWB signals can be transmitted at relatively small signal rates, yet can also be transmitted up to the relatively small rates of the inverse of the ultra-wideband signals bandwidth. Pulse-ultra-wideband systems have been indicated at channel pulse rates more than amount of 1.3 Gpulses/s implementing seamless stream of ultra-wideband signals, more than 675 Mbps encoded data rates can be achieved by supporting FEC (forward error correction).

An important part of the UWB applications is that they are capable of determining the time of the transmission over various frequency ranges. This enables the system to deal with multipath propagation, since some of the transmitted signals have a line of sight trajectory. By the help of the cooperative symmetric two-way metering technique, the distances can be found with very high accuracy and resolution by compensating for stochastic inaccuracy and local clock drift. Another crucial property of the UWB technology is that the signals are so short, hence reflections of the pulses do not overlap the original signals, and the narrowband multipath fading does not take place. Nonetheless, multipath propagation and inter-pulse interference to fast-pulse systems takes place, which must be reduced by coding techniques [29].

2.4 Dual Band Antennas

As the technology progresses, the need for more functional electronic devices increases,

meaning that more components are required which increases the size of the devices. However, the demand for small in size equipments is very high and hence the number of components used must be kept less and small. The antennas are the key elements of the communication systems so to have small in size and work with as less antennas as possible is much more in demand nowadays. To decrease the number of antennas and simultaneously have small size, one solution is to produce an antenna that operates in different operating frequency by in cooperating with microwave switches which tunes from one operating to another. These antennas are called reconfigurable antennas, in other words reconfigurable antenna is the one that can vary it's operating parameters (e.g. frequency), in the literature. There have been a lot of conducted researches in the literature to obtain dual band antennas. U.S.Pat.No.4, 571,595 to Phillips et al. defines a dual band antenna having a sawtooth-shaped conductor element. The dual antenna can be switched between closely distanced operating bands (e.g., operating frequency centred at 915 and 960 MHz). Japanese company produced a helix antenna that can be switched between two resonant frequencies. However, this antenna has very small bandwidth. Printed monopole antennas give dual resonance with the additional parasitic strip in close proximity to the antenna. Even though this antenna gives good bandwidth, it needs the additional parasitic strip. A coil matching dual band whip antenna was made by Sweden Company Moteco AB and the antenna offers relatively sufficient bandwidth and fine performances of radiation with small size. However, as the size of the portable devices is getting smaller these antennas becomes more useless because of their size. Presently the patch antennas catch more attention as they have small size light weight and so forth. The planar inverted-F (PIFA) antenna is already in use communication systems. A meandering inverted-F antenna which is 40% small in size than traditional PIFA antenna was published more recently.

Nonetheless, since the communication devices get smaller and smaller, the antennas that are proposed still very big in size to fit upcoming future communication devices particularly handsets need more developments. Therefore, more work on developing dual-band antennas must be carried out to obtain antennas that have larger bandwidth and relatively small size with comparison to the traditional microstrip patch and PIFA antennas [31].

In order to yield the ultra-wideband dual-band antenna with small size, coplanar waveguide fed slot antenna is proposed, as CPW-fed slot antenna has more advantages than traditional microstrip antenna such as wider bandwidth, lower radiation leakage, less dispersion. It can be designed with smaller size and better radiation performance than traditional dual-band antennas.

2.4.1 Work Have Been Done with CPW-fed Slot Antennas for Dual-Band Applica-

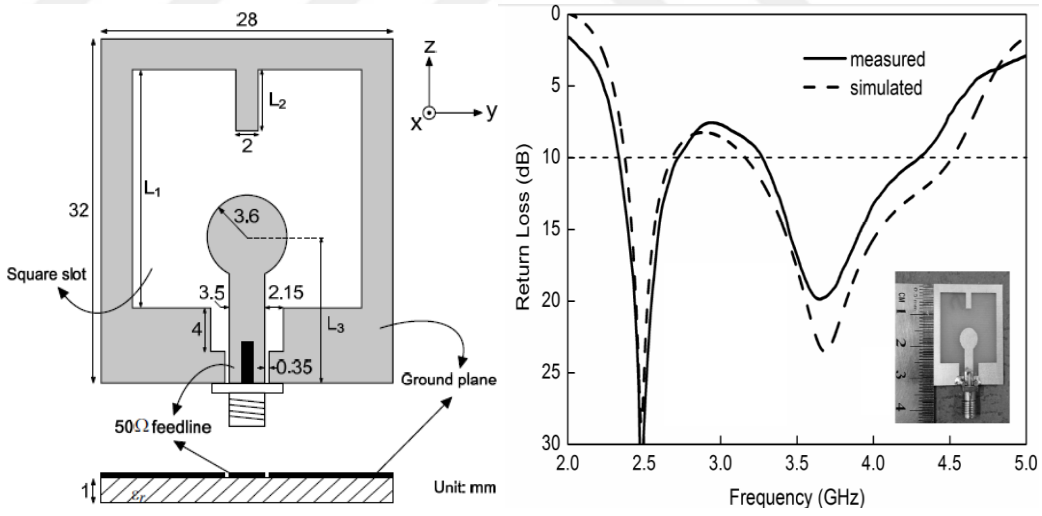
tions

There have been lots of works done regarding CPW-fed slot antennas for dual-band applications two of these are provided as follows;

2.4.1.1 Compact CPW-fed Square Slot Antenna for Dual-Band Operation

The work was conducted by W. Hu, Y.-Z. Yin, S.-T. Fan, J.-Y. Deng, and M. Zhang at National Laboratory of Antennas and Microwave Technology Xidian University, Xi'an, Shaanxi 710071, China in 2011.

A square slot antenna of compact size fed by coplanar waveguide was proposed for dual-band applications. The antenna consisted of a monopole transmitter and square slot resonator. The antenna could meet new resonance while sustaining a small size. The proposed antenna was designed to obtain an antenna of operating over separated two frequencies ranges over which WiMax and WLAN applications frequencies covered with compact antenna size. As seen the Figure: 1 (b) it was well achieved to obtain two different operating bandwidth antenna which covers the frequency ranges of stretching from 2.33 GHz and 2.73 GHz and 3.27 GHz and 4.29 GHz over which WiMax and WLAN operate, respectively. The results indicate that the objectives were achieved as WiMax and WLAN were covered with compact size antenna over Separated two bandwidths.



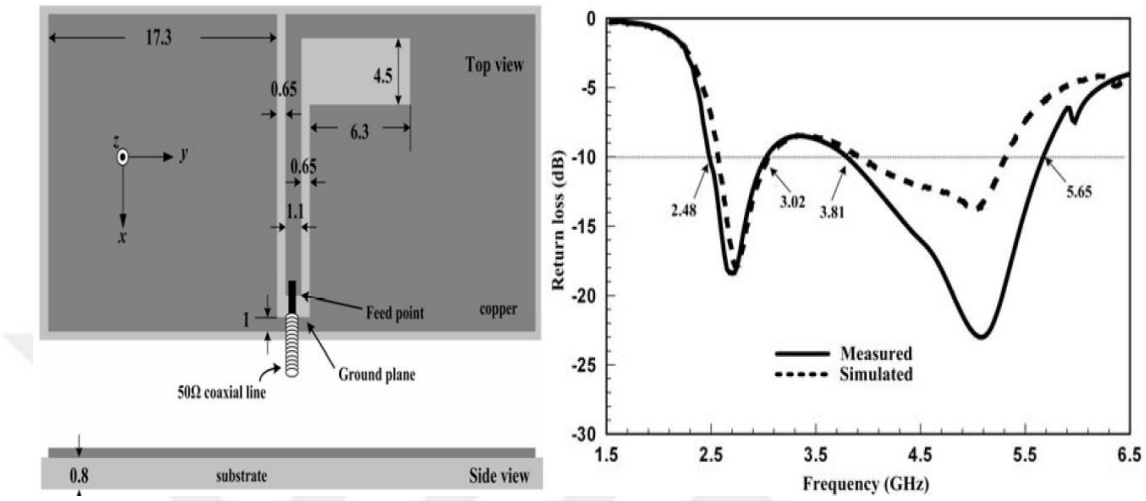
(a) (b)

Figure: 1. the geometric structure of the proposed antenna (a) and Return loss versus Frequency result of the proposed antenna (b).

2.4.1.2 Compact Printer Slot Antennas for Wireless Dual-Band and Multi-Band operations

The work was done by Y.-C. Lee and J.-S. Sun, at Institute of Computer and Communication Engineering in Taiwan, in 2008.

The proposed antenna was constructed to attain an antenna of having dual band antenna with compact size and the structure is illustrated in the Figure: 1.1 (a). The dual band antenna was intended to operate over bandwidths of covering WiMax and WLAN bands. In order to meet the desired bands, the slot antennas with slotted structure and an inverted-L slot shape for operating wireless communication operations were improved.



(a) (b)

Figure: 1.1 the geotmetric structure of the proposed antenna (a) and the return loss of the antenna versus frequency (b).

The obtained return results of measured and simulated as seen the figure (b) it was observed that the antenna has two bandwidths of spaced about 800 MHz and operating over ultra-wideband. The lower band is between 2.48 GHz and 3.02 GHz and the upper band is between 3.81 GHz and 5.65 GHz, which indicates that the antenna constructed covered the objective as it covers mobile WiMax over the lower band and WLAN over the upper band with a compact antenna size.

3 ANTAENNA PARAMETERS, COPLANAR WAVE GUIDE AND SLOT ANTENNAS

3.1 Brief explanation of Antenna Parameters

There are numerous types of antennas available but they have some common properties which are

called antenna parameters. The most fundamental parameters shown below;

3.1.1 Impedance bandwidth

Impedance bandwidth is defined as the frequency range over which the antenna can properly transmit and receive the energy. Bandwidth is measured in terms of both VSWR (voltage standing waves ratio) and return loss. To obtain these two terms the reflection coefficient (Γ) that is described as the ratio of the amplitude of the reflected voltage (V_r) normalised to the amplitude of the incident wave (V_i).

$$\Gamma = \frac{V_r}{V_i} \qquad \textbf{Eq. 3.1}$$

$$\text{Return loss} = -20\log|\Gamma| \qquad \textbf{Eq. 3.12}$$

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \textbf{Eq. 3.13}$$

The mismatch loss of 10% is acceptable, which corresponds to Γ=0.3162 reflection coefficient. In this case the return loss is below -10 dB and VSWR is below 2, meaning that 90% of the available power sent by the source is transmitted to the antenna. Also the bandwidth is mainly described as fractional bandwidth which can be worked out as follows;

$$Fractional\ Bandwidth = \frac{f_u - f_l}{f_c} x100\%$$

Where f_c is the centre frequency that is the average of f_u and f_l.

This equation is used for fractional bandwidth of less than 100%. If the fractional bandwidth is greater than 100% the fractional bandwidth is as shown below;

$$Fractional\ Bandwidth = \frac{f_u}{f_l}$$

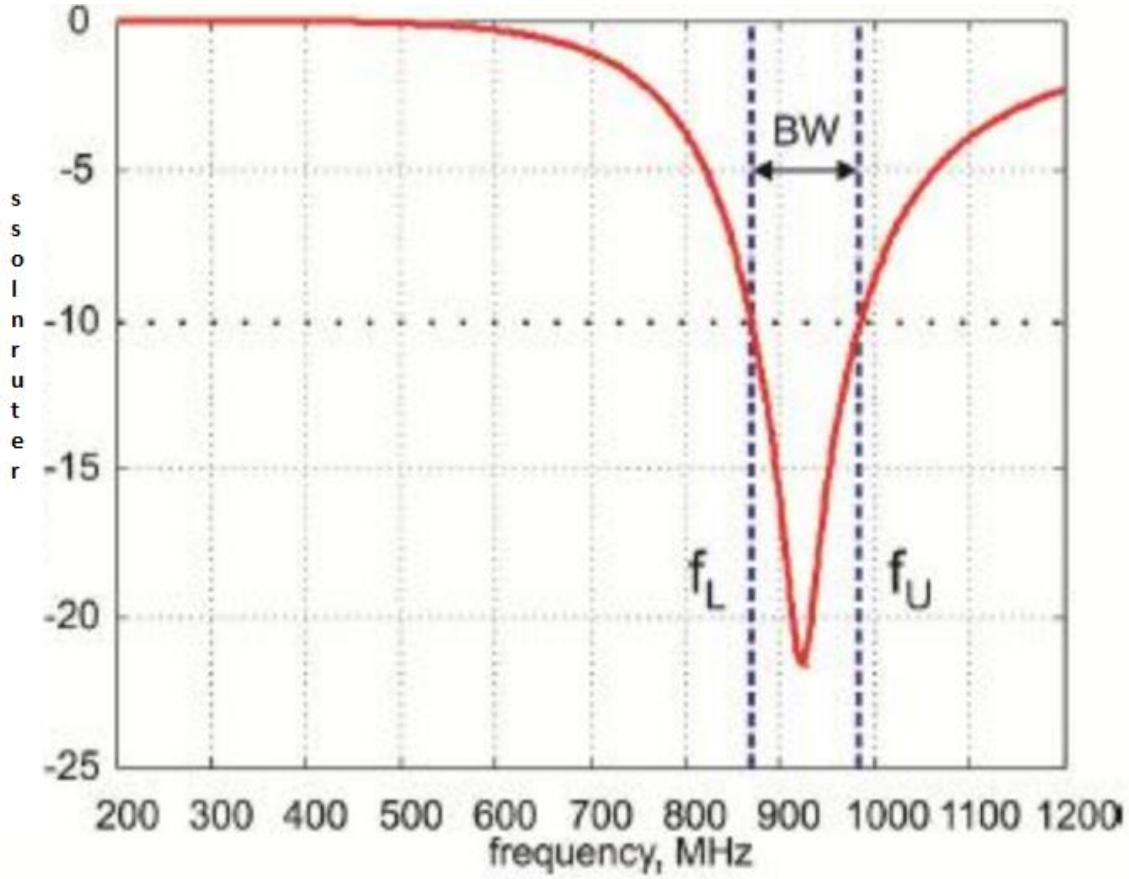


Figure: 3 return loss against frequency.

3.1.2 Radiation patterns

The radiation pattern is described as the transmitted power variation as function of direction away from the transmitter, and mainly the antenna pattern is measured in far field region that the radiation pattern remains constant in terms of their shapes. Practically there is no antenna that can radiate equally in all directions. It is measured that the antennas radiate largely in one direction wile nothing some other directions. The antenna radiation in any direction is calculated from the field strength point of view at a point distanced from the radiator antenna. The strength of the field can be deduced by working out voltages at two points on electric line of force then dividing the space between two points. The polarisation, power flux density, field strength, directivity and radiation intensity can be calculated in radiation pattern. It can be seen from the **Figure: 3.1** there is main lobe which shows that the biggest power is radiated in the direction of main lobe. On the other hand, there are side lobes which are mainly unwanted as they interfere with other radiators so they must be suppressed to minimize. Finally, the side lobe that is right opposite of the main lobe is called as back lobe.

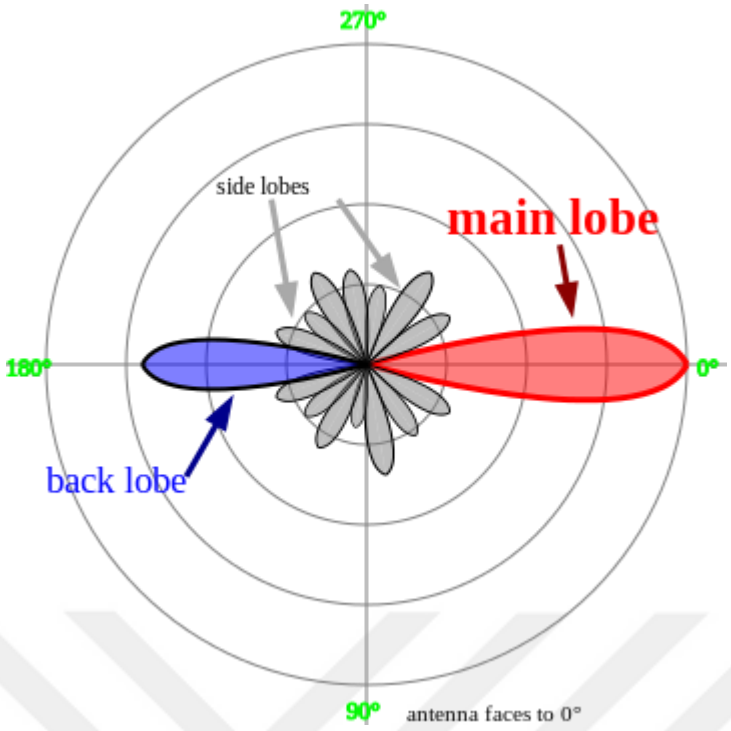


Figure: 3.1 a typical polar radiation plot

3.1.3 Directivity

An isotropic antenna is an ideal antenna that radiates in all directions uniformly, which is also known as omnidirectional antenna. As it is not possible practically to have an isotropic antenna, all antennas radiate with different filed strength in different directions. When the antennas are designed to radiate in a specific direction, it is wanted to radiate as much power as possible in desired direction from the total radiated power. This brings the term of the directivity out; the directivity is the ratio of the maximum power density to its average value, meaning that antenna transmits with larger efficiency to a particular direction in the surrounding environment than the other directions.

$$D = \frac{P(\theta, \emptyset)_{max}}{P(\theta, \emptyset)_{av}} \qquad \textbf{Eq. 1.34}$$

The directivity does not have dimension.

The smallest directivity is the directivity of the isotropic antennas and assumed to radiate uniformly to all directions with the directivity of 1.

3.1.4 *Gain*

The antenna gain is described as the ratio of the radiation intensity in a particular direction

to the radiation intensity which would be yield if the power received by the antenna were transmitted uniformly to all directions of the surrounding space. The gain is a real quantity as it consists of the ohmic losses in the antenna. In other words, gain is combination of the antenna's efficiency and the directivity.

$$G = D.e \qquad \textbf{Eq. 1.35}$$

Where

e is the efficiency of the antenna. The gain is used to measure the performances of the antenna. In particular, when it is desired to obtain directional antennas, since it can be seen how much of the total radiated power is sent to the chosen direction.

3.1.5 *Efficiency*

There are two types of efficiency that one has to focus on when evaluating antenna's performance. The first is radiation efficiency and second one is the total efficiency.

The radiation efficiency is the ratio of the power that antenna radiates as an electromagnetic wave into the free space to the power that in fed to the antennas terminal.

As all other electronic components the antenna has power losses problems as well. The efficiency is the ratio of the power radiated to the power to the input power of the antenna. It is between 1 and zero and in the literature mainly quoted as percentages. The total efficiency takes into account the reflections due to mismatch, the losses in conductors and dielectrics [34].

$$e_t = e_r.e_d.e_c \qquad \textbf{Eq. 1.36}$$

$e_t = total\ efiiciency$

$e_d = dielectric\ efficiency$

$e_c = condutor\ efficeincy$

$e_r = reflection\ (mismatch\ efficiency)$

3.1.6 *Polarization*

Polarisation is generally a crucial parameter for radio frequency antennas and radio communications. The antenna polarization is the orientation of electromagnetic fields' vectors at

a given point and its variations with time. Polarisation is described as the electric field orientation on the plane that is in the far-field as shown in **Figure: 3.1.2**. As antennas are susceptive to polarization and mainly transmit and receive one signal with a particular polarization. Assume a radiated EM field has an E field that consists of two components E_x and E_y as given in Figure: 3.1. If one assumes the components E_x and E_y are worked out;

$$E_x = a * \cos(\omega t - \beta z)$$
$$E_y = b * \cos(\omega t - \beta z + Phi)$$

Where a and b are the amplitude of E_x and E_y, respectively.

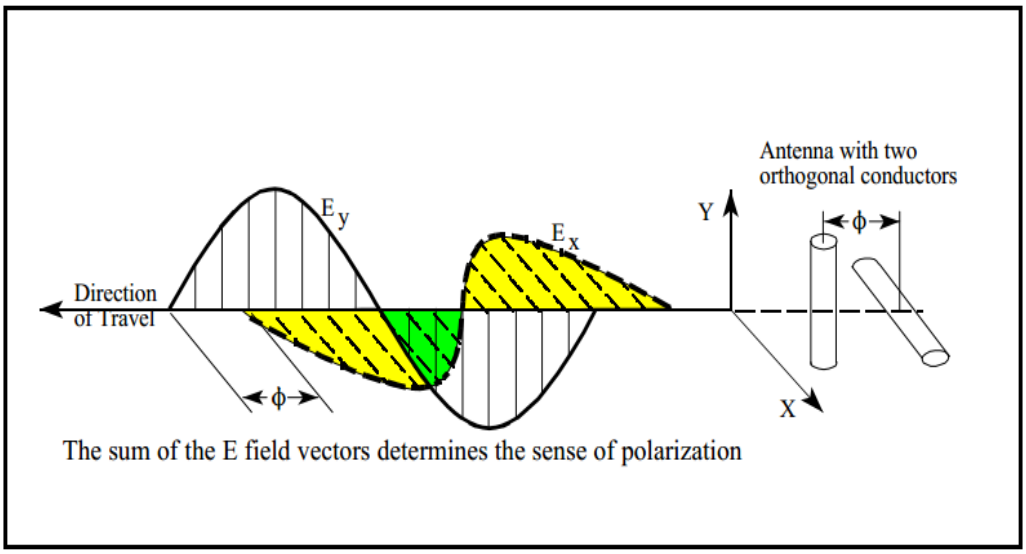


Figure: 3.1.2 polarisations coordinate

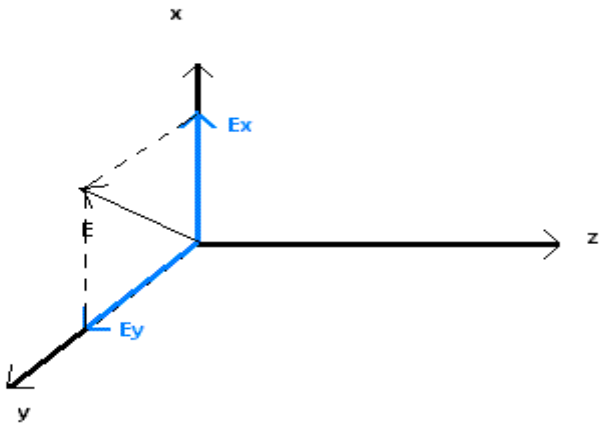
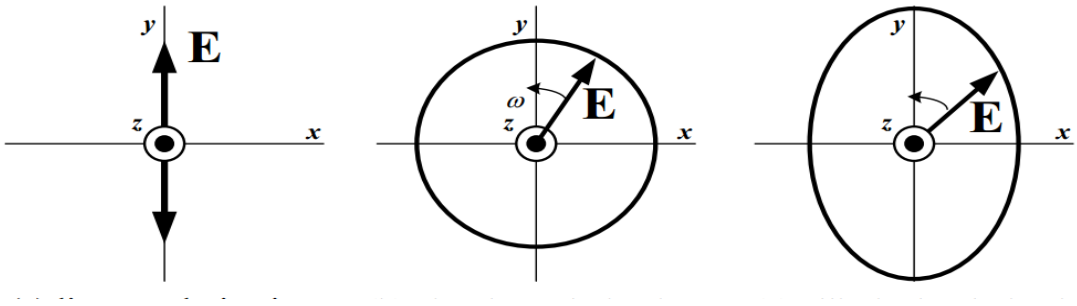


Figure: 3.1.3 E field components.



a b c

Figure: 3.1.4 linearly polarised (a) circularly polarised (b) elliptically polarised (c)

The polarization might be linearly, circularly, and elliptically polarised as indicated in **Figure: 3.1.4**[20].

If the transmitter and the receiver are not aligned or not have the same polarization, there is going to be a decrease in power transfer between the transmitter and the receiver. The decrease in the power will diminish over all system efficiency and performance. If the antennas are linearly polarised and there is a misalignment between them, there will be polarization mismatch loss.

Polarization Mismatch Loss (dB) = 20 log (cosϑ)

Where ϑ is the angle of misalignment between the receive and transmit antennas [47].

3.2 CPW Transmission Line

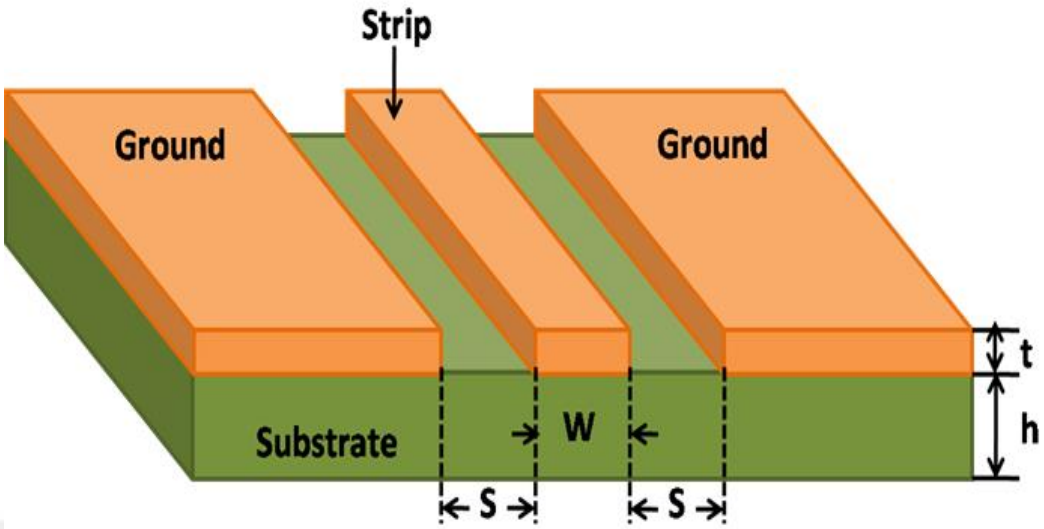


Figure: 3.2 the structure of coplanar waveguide transmission line.

The Coplanar waveguide is a sort of transmission line which is described as planar transmission line used for carrying the microwave signals which are greater than 300 MHz. It is used as an alternative to microstrip transmission lines and it has been catching so much attention as it is widely used in RF and microwave integrated circuits owing to its properties. For instance, it is not needed to use via holes for attaching circuit components to ground as active devices can be connected on top of it. Furthermore, the coplanar waveguides offer very high frequency response quick access to neighbouring power plane, low radiation leakage and dispersion loss [18],[11],[40]. In addition, they give the advantages like realizing compact balanced circuits, being integrated straightforwardly with solid state components as well as fabrication as compare to other conventional transmission lines [42]. The above structure is the perspective view of the conventional Coplanar Waveguide (CPW) transmission line. A conventional CPW is formed of substrate on which there are two ground planes and a conductor lies between as shown in the figure. The centre conductor (with width of **W**) is separated from two ground planes with the distance of **S**. It is normally desired to be infinite ground planes size and the substrate thickness (**h**) while using zero metal thickness (**t**) but adequately greater than the skin depth, as in practice the dimensions are not infinite they are just constructed large enough [16]. There are two sort of dominant propagation modes existing in CPW lines. The first one is the even mode (otherwise known as coplanar waveguide mode) which has the current flow in the same direction and equal electrical potential on the ground planes and the centre conductor current flows opposite direction of the ground planes. As can be seen from the **Figure: 3.2.2** (a) in the fields distribution of even mode the electric field lines start from the centre conductor to end at the ground planes whereas the magnetic field lines surround the centre conductor. And

the second one is the odd mode (otherwise known as slot-line mode) the current on the ground planes flow in opposite direction as shown in **Figure: 3.2.1** [15],[36]. In the odd mode the electric filed lines begin from one ground and end at other ground not all the field lines touch the centre conductor, meaning that the potential of the grounds are opposite signs. Also the magnetic field lines are longitudinal direction and therefore it causes a big dispersion [17],[7]. The even mode is the most desirable as it offers low radiation features, in other words it presents very low dispersion, and it is very suitable for application used in circuits design and very wideband applications. The odd mode is unwanted as it leads to power leakage from the wanted CPW mode, therefore must be suppressed [40]. In order to avoid the odd mode the ground planes should be either symmetric or if they are not, then air bridges can be used to keep the ground planes electrically equal potential [11],[15],[41]. As can be seen the coplanar waveguide used in the project is symmetrical hence the odd mode is not our concern.

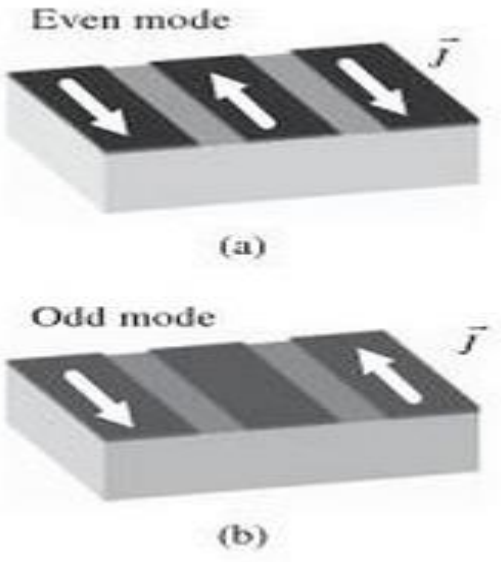


Figure: 3.2.1 even and odd mode current flow representations**.**

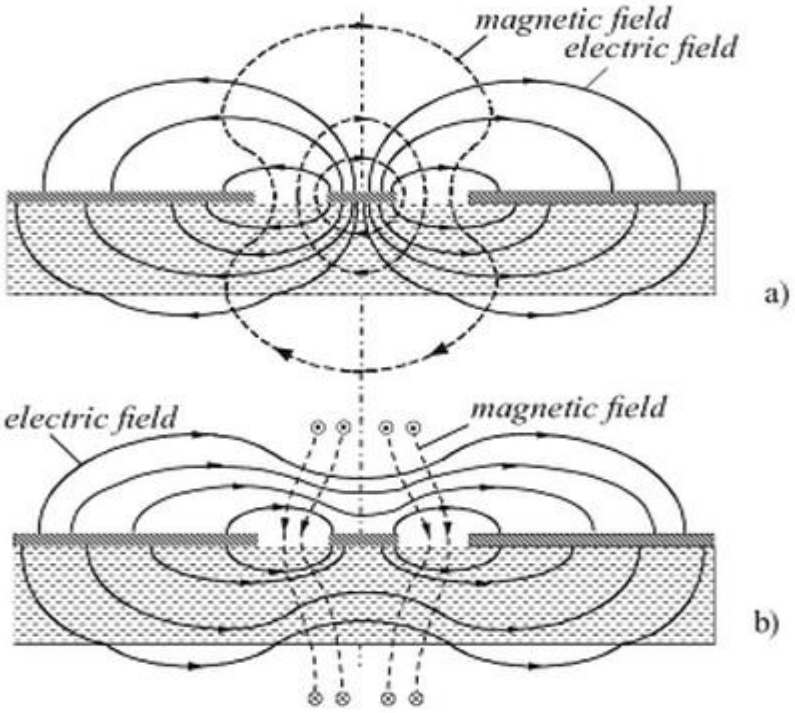


Figure: 3.2.2 Electric and magnetic field distribution of (a) the even mode and (b) the odd mode on a coplanar waveguide.

Since the coplanar wave guides consist of the substrate that has three conductors on the same side mounted in parallel it makes it easier to connect to series and shunted components. The coplanar waveguides have relatively small dimensions like width of the slots and centre conductor. As the coplanar waveguides have the conductors' width ground potential, the adjacent transmission lines decouple more efficiently. Therefore, the smaller chip and higher packaging density is attained [48].

As the Coplanar waveguides are not homogeneity of the dielectric interface between substrate and air interface they do not have TEM propagation. When the operating frequencies are low the loss and dispersion are not high and it is defined as quasi-TEM as a matter of the fact that it has similar propagation properties to Tem mode. Nonetheless, when the operating frequencies are high the surface waves interact with the even mode and therefore the loss and dispersion get utterly important problems [16],[29]. Also if the substrate is not thick enough the field lines get out of the substrate from the bottom as seen from the **Figure: 3.2.2**. This is not wanted as the coplanar circuit might be connected to on top of conductive components this can cause changes in electrical properties of the transmission line. In order not to get affected by the dielectric constant in terms of

thickness high permittivity dielectric substrate is used [16]. It is clear that the substrate thickness affects the dispersion properties of the transmission line. If the space from one ground plane to other one is close to one-half wavelength some problems might take place in radiation, which will restrict the dielectric permittivity of the substrate used at the operating frequency [48].

Characteristic impedance of the coplanar can be obtained by means of conformal mapping:

$$Z_0 = \frac{30*\pi}{\sqrt{\varepsilon_{eff}}} \frac{K'(k)}{K(k)} \ \Omega \qquad \textbf{Eq.3.1}$$

Where K (k) and K' (k) represent the complete elliptic integral of the first kind and its complement, and they associated with each other via the formula of K (k) =K (k').

Where k' is the complementary modulus and k'=$\sqrt{1-k^2}$. The argument of the integrals is associated with CPW parameters. As seen from the structure of **Figure: 3.2**.

K=s/(s+2*w). Even though K and K' are separately more or less tricky, the ratio of K/K' can be calculated effectively by means of the formula provided below:

$$\frac{K}{K'} = \frac{\pi}{ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)} \quad \text{If } 0 \leq k \leq 1/\sqrt{2} \qquad \textbf{Eq.3.11}$$

$$\frac{K}{K'} = \frac{ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right)}{\pi} \quad \text{If } 1/\sqrt{2} \leq k \leq 1 \qquad \textbf{Eq.3.12}$$

The effective dielectric constant can be derived by applying curve fitting procedure to field-theoretical results and the equation shown below can be obtained:

$$\varepsilon_{eff} = \frac{\varepsilon_r+2}{2}\left\{tanh\left[1.875\, log\left(\frac{h}{w}\right)+1.75\right]+\frac{k*w}{h}[0.04-0.7* k+0.01*(1-0.1*\varepsilon_r)*(0.25+k)]\right\}$$

[19],[48]. **Eq.3.13**

3.2.1 **QUASI-STATIC ANALYSIS BY CONFORMAL MAPPINGS**

Coplanar waveguide is a proper transmission line and able to produce elliptical polarised magnetic fields of the both modes so-called non-TEM and quasi-TEM for CPW. By the use of conformal mappings method that is the very simple and often used quasi-static method contains complete elliptic integral that are very hard to compute even by computers the CPW can be quasi-statically analysed. Therefore, approximate equations are proposed so as to work out the elliptic integral via conformal mapping which is used to modify the structure of the PCB into another con-

formation, whose properties make the calculations easier [18],[11].

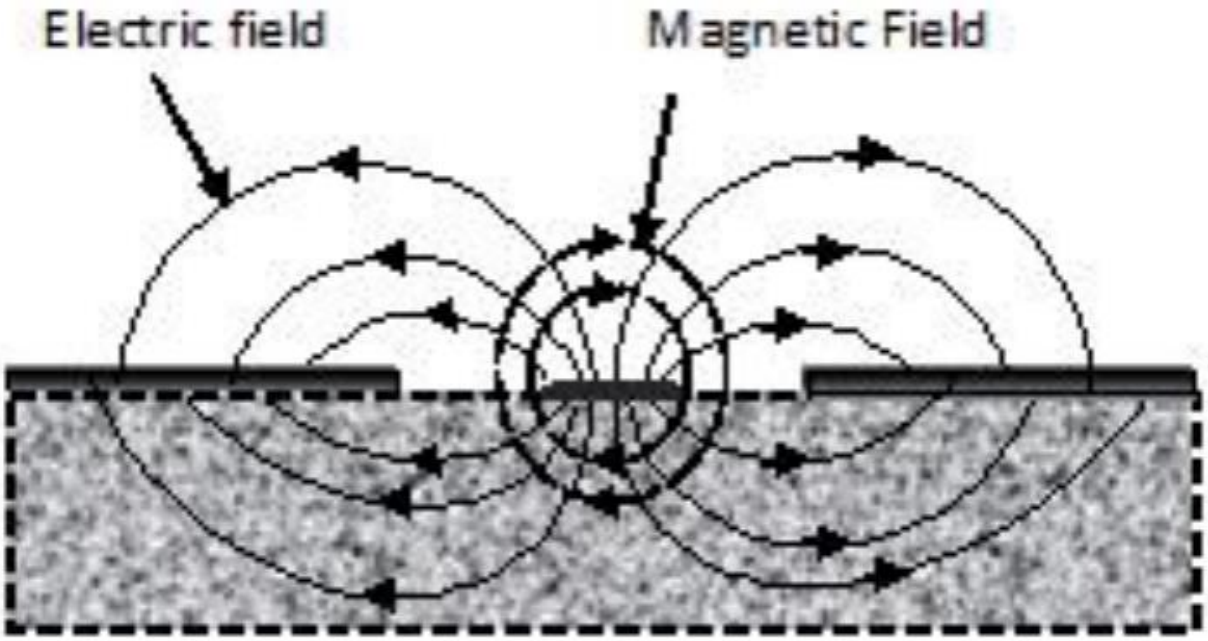


Figure: 3.2.3 Electric and magnetic fields of the even mode.

Practically the is constructed with a finite thickness of **h**, for going on with the analysis of the conformation, a preliminary conformal mapping modifies the finite thickness dielectric to an infinite thickness one. Just effective dielectric constant is changed and it becomes:

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2} * \frac{K(k_2)}{K'(k_2)} * \frac{K'(k_1)}{K(k_1)} \qquad \textbf{Eq.3.14}$$

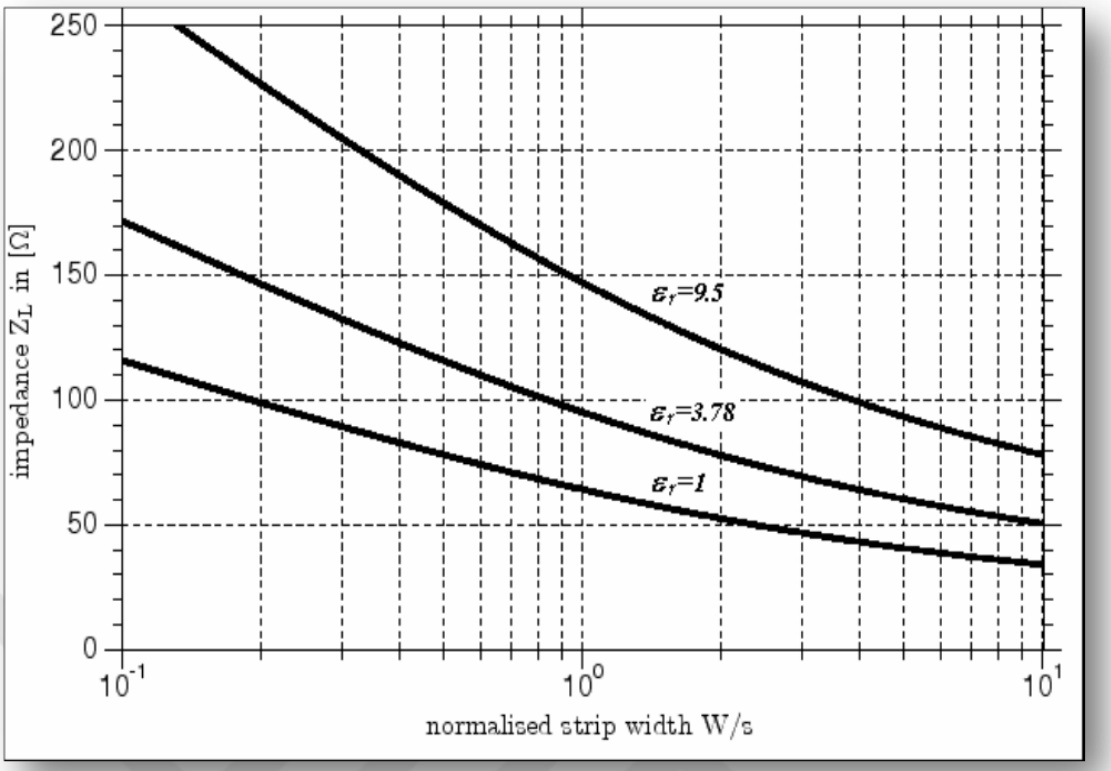


FIGURE: 3.2.4 Characteristic impedance as approximated by Eq.1 for ε_r=1(air), ε_r=3.78 (quartz), ε_r=9.5 (alumina).

Where $$k_2 = \frac{\sin\left(\frac{\pi * w}{4 * h}\right)}{\sin\left(\frac{\pi * (w+2*s)}{4 * h}\right)}$$ **Eq.3.15** [48]

3.2.2 Effect of Dispersion

The dispersion owing to interaction with surface waves parallel-plates modes in the substrate are dependent very much on the total distance (w+2*s) between the ground planes. To obtain the minimum dispersion and radiation losses the total distance between the ground planes should be small as comparison with substrate thickness and dielectric wavelength. Short distance between parallel grounds as compare to substrate thickness is needed not to have the excitation of the micrstrip mode and to yield the least deviation of the CPW mode form the odd mode of the ideal line. Nevertheless, if the total distance between grounds becomes too short the conductor losses will take place, hence this limits the reduction of the total distance and the centre conductor. On the other hand, if the thickness of the substrate is very big with respect to (w+2*s) the operation of the CPW will inevitably not be less than the cut off frequency of surface wave modes. Nonetheless, if the total

distance between ground planes is short as comparison to the dielectric wavelength, the interaction of the CPW mode with surface wave modes is not important for integrated circuit applications. The dispersion affects the CPW similar to those in microstrip lines, although the impact on the impedance is not somewhat similar. A closed form expression to calculate $\varepsilon_{eff}(f)$ from its quasi-static value:

$$\sqrt{\varepsilon_{eff}(f)} = \sqrt{\varepsilon_{eff}(0)} + \frac{\sqrt{\varepsilon_r} - \sqrt{\varepsilon_{eff}(0)}}{1 + G * (\frac{f}{f_{TE}})^{\wedge}(-1.8)} \quad \textbf{Eq.3.16}$$

Where

$$G = e^{u} * \ln(\frac{w}{s}) + v \quad \textbf{Eq.3.17}$$

$$u = 0.54 - 0.64p + 0.015p^2 \quad \textbf{Eq.3.18}$$

$$v = 0.43 - 0.83p + 0.54p^2 \quad \textbf{Eq.3.19}$$

$$p = \ln(\frac{w}{h}) \quad \textbf{Eq.3.2}$$

f_{TE} is the cut-off frequency of the TE_0 mode, referred as:

$$f_{TE} = \frac{c}{4h * \sqrt{\varepsilon_r - 1}} \quad \textbf{Eq.3.20}$$

The accuracy of the this formulas is believed to be better than 5% for $0.1 \leq \frac{w}{h} \leq 5$, $0.1 \leq \frac{w}{sh} \leq 5$, $1.5 \leq \varepsilon_r \leq 50$ and $0 \leq \frac{f}{f_{TE}} \leq 10$ [17, *sample*, 16].

3.2.3 Effect of Metallization Thickness

In spite of the fact that the thickness of the strip is very thin in most of the practical works, the thickness cannot be totally ignored. A first order correction to take into consideration the non-zero thickness of the conductor is given by:

$$s_e = s - \Delta \quad \textbf{Eq.3.21}$$

And

$$w_e = w + \Delta \quad \textbf{Eq.3.22}$$

Where

$$\Delta = \frac{1.25t}{\pi}\left\{1 + \ln\left(\frac{4\pi w}{t}\right)\right\} \qquad \textbf{Eq.3.23}$$

The k_1 and the effective dielectric permittivity are influenced when the impedance is being calculated, thus k_1 have to be substituted bye an effective modulus k_e where

$$k_e = \frac{w_e}{w_e + 2s_e} \approx k_1 + (1 - {k_1}^2)\frac{\Delta}{2s} \qquad \textbf{Eq.3.24}$$

And

$$\varepsilon_{eff}{}^t = \varepsilon_{eff} - \frac{0.7(\varepsilon_{eff} - 1)\frac{t}{s}}{\frac{K(k_1)}{K'(k_1)} + 0.7.\frac{t}{s}} \qquad \textbf{Eq.3.25}$$

[48].

3.3 Slot Antenna

Slot antenna is a sort of antenna which consists of similar characteristics to the complementary dipole antenna and comprises a radiator that is formed of a tiny slot in a big metal sheet as seen from the **figure**: **3.3**. The length of the slot is half wavelength and the width of the slot is a small fraction of wavelength at the desired frequency. At low frequencies the transmission lines and at high frequencies waveguide can be used to feed the slot antenna. The slot antennas are popular as they are easy to but cut on metal sheet wherever on the surface they are needed to be connected as well as giving almost omnidirectional radiation patterns (as is seen in a wire dipole antenna)[21]. In many applications the slot antennas are very commonly used, in particular when the low-profile or flush mountings are needed such as for high-speed aircraft [20].

3.3.1 Slot Antenna and Its Complementary Dipole

The slot antenna is mainly associated with the conventional half wavelength dipole antenna. According to booker, the radiation patterns characteristics of the slot antenna is the same as those of the complementary half wavelength dipole having an excellently conducting flat strips that has the width of w and excited as seen in the **Figure:3.3.** If the flat strip dipole antenna placed into the slot of the infinite metal sheet it fits the slot in the metal sheeet, which is called to be complementary.

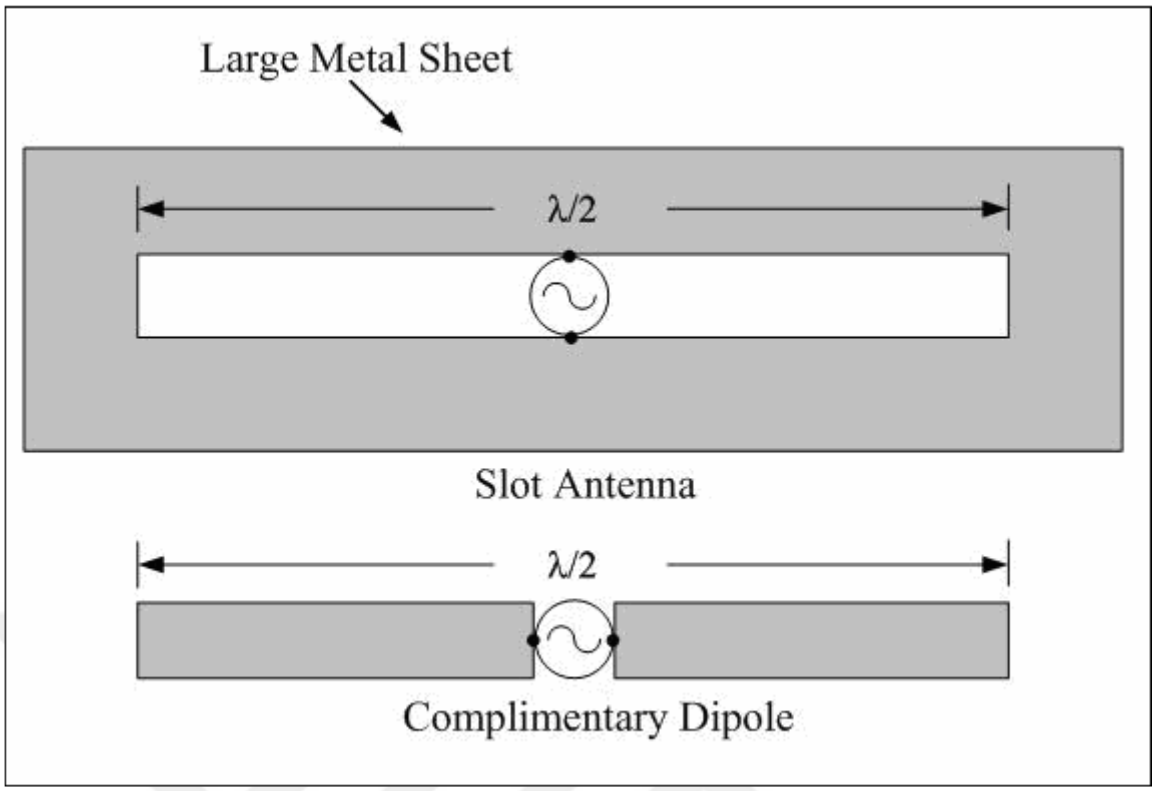
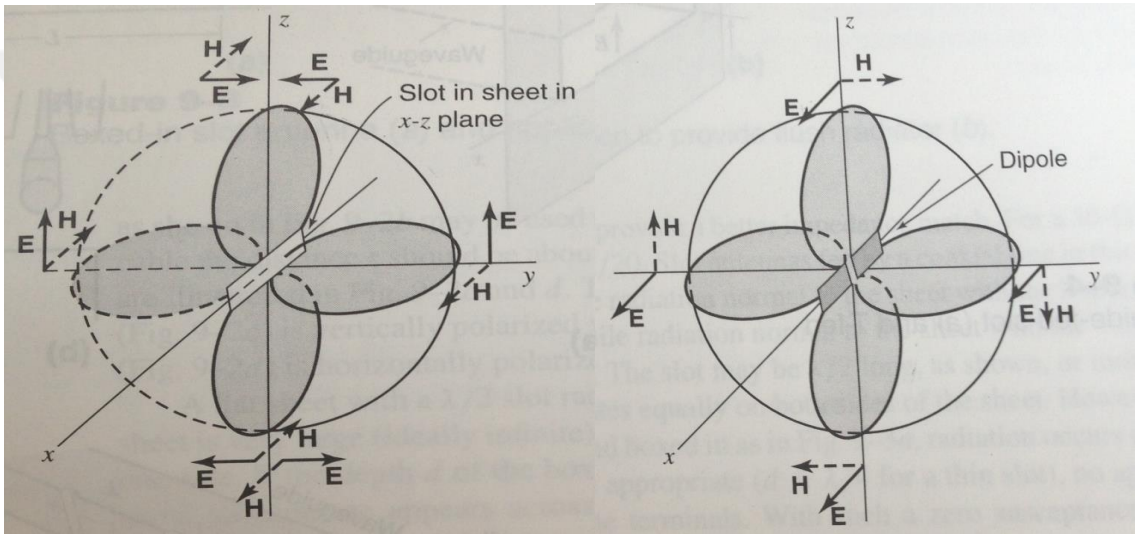


Figure: 3.3 the structure of the slot antenna and of the complementary dipole, respectively.

3.3.2 Radiation Patterns of Slot antenna

Imagine a slot antenna with λ/2 length and width of small fraction of λ in excellently conducting flat sheet of large size (ideally infinite) as illustrated in **Figure: 3.3.2 (a)**. When the slot is excited at the centre, the radiation patterns of the slot is the same as the those that obtained from the complementary horizontal dipole which has excellently conducting flat strips of the same dimensions as slot antenna and excited at the center as illustrated in **Figure: 3.3.2 (b)**. However**,** there are some differences between the both slot and its complementary dipole. The first difference is that, if take the horizontal slot and dipole antennas, for the slot antenna the magnetic and electric fields are interchanged as shown in the **Figure: 3.3.1 (a)** and the magnetic field lines radiate horizontally while electric fields having vertical radiation lines, for the dipole, nonetheless, the electric field lines are horizontal whereas the magnetic field lines make loops through the vertical plane as indicated in **Figure: 3.3.1 (b)**. In the slot antenna the electric field lines are constructed around the tiny dimensions of the slot. Therefore, a horizontal slot radiates vertically on the contrast vertical slot antenna radiates horizontally. The second difference is the electric field's components that are perpendicular to the metal sheet are discontinuous from one surface of the metal sheet to another one, similarly

the tangential component of the magnetic field is discontinues inevitably, meaning that the magnetic and electric fields have sudden reverse direction on the opposite side of the metal sheet. Nevertheless, dipole antenna creates electric field lines which have the same direction and magnetic field lines of continuous closed loops [22],[20]. When the slot is excited the currents going through the conductive metal sheet are not only restricted to the edge of the slot but they flow all over the sheet surface and thus, both side of the slot radiate as seen in **Figure: 3.3.2 (a).** On the other hand, the currents flow over the complementary dipole antenna is more restricted to the edge of the stubs as shown in **Figure: 3.3.2 (b),** hence much bigger amount of currents are required to generate a desired power output using the dipole, which means that slot antenna is very much more efficient than its complementary dipole [20].



(**a**) (**b**)

Figure: 3.3.1. Radiation patterns of the slot in an infinite Sheet (a) and of complementary dipole antenna (b).

Assume that z axis is vertical and x-y is horizontal in an infinite sheet, then the horizontal slot radiates vertically in x-y plane as illustrated in **Figure: 3.3.1 (a**). On the contrary, when the slot is coincident with the z axis then the vertical slot radiates horizontally all over the x-y plane and hence**,** there is only E_ϕ component as depicted in **Figure: 3.3.3 (a).** If the width if the slot is very small (w<<λ) and the length is equal to $\lambda/2$, E_ϕ varies as a function of θ as follows;

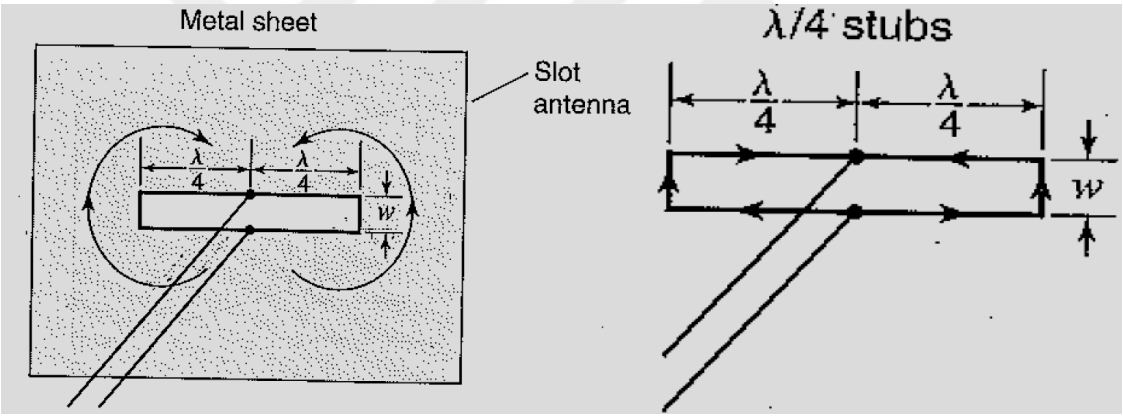
$$E_\phi(\theta) = \frac{\cos\left[(\pi/2)\cos\theta\right]}{\sin\theta}$$

Eq. 3.26

However if the sheet is a very good conductor and infinitely large, then the magnitude of $E_{\emptyset}$ stays constant as a function of ϕ for any value of θ. Therefore,

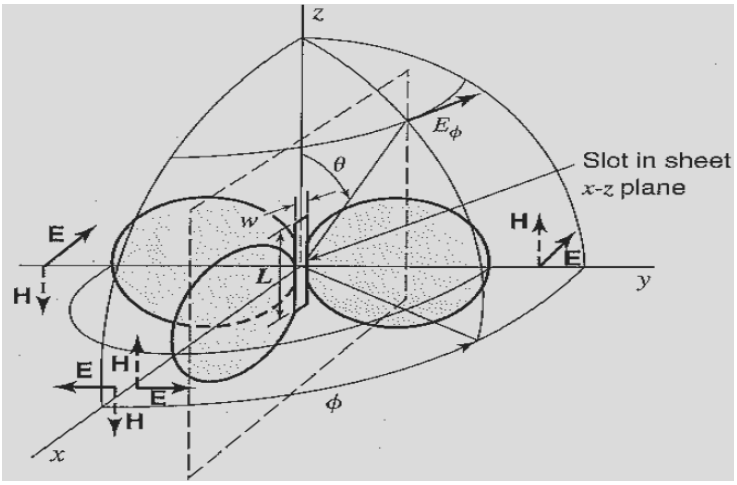
$$E_{\phi}(\phi) = constant \qquad \textbf{Eq. 3.27}$$

If one considers a slot in a finite sheet, the $E_{\phi}(\theta)$ is not so different from the infinite sheet, whereas there is a noticeable change in the $E_{\phi}(\phi)$ pattern as the sheet radiates equally in magnitude on both sides but out of phase in x direction so they cancel out each other and as a result null occurs in all directions in the sheet plane as illustrated in **Figure: 3.3.3 (a) and (b)** with the solid curves and dashed curves represent the $E_{\phi}(\phi)$ of infinite sheet.

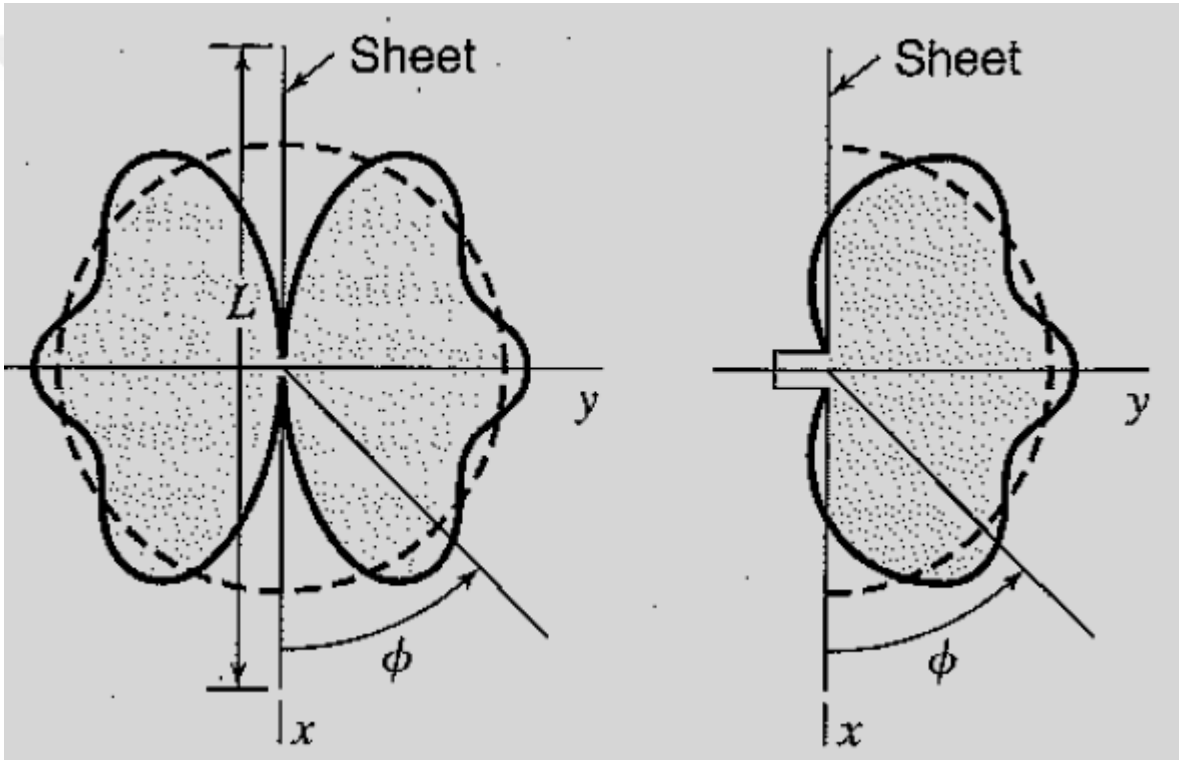


(a) **(b)**

Figure: 3.3.2 good efficient slot antenna (a) poor efficient stubs (b).



(a)



(b) (c)

Figure: 3.3.3 radiation pattern of vertical slot (a) solid curves indicate patterns in x-y plane in (a) slot is open on both side in (b) and closed on left side in (c). The dashed lines indicate pattern for infinite sheet [20].

4 ANALYSIS

.

4.1 Antennas Descriptions

a) **The Figure: 4.2.1** indicates the geometry of the first proposed antenna that is fed by a CPW transmission line and has two rectangular-shaped slots. The antenna is printed onto an FR4 substrate thickness of 1.58 mm and relative permittivity of 4.3.The CPW transmission line, which is 50 ohms in the resonant frequency, is printed as centre line and separated from the symmetric ground planes with the small gap of 0.25 mm. The substrate has the rectangular shape of 80x60 mm^2 (LhxWh), so does the ground plane. In the **table: 4.2.1** the dimensions of the antenna are given. The return loss, total efficiency radiation patterns of each slot antenna fed by CPW is simulated and computed by use of CST microwave studio software.

b) The second antenna which is shown in **figure: 4.2.4** has the same substrate and ground plane characteristics as the first antenna but it has got different dimensions as shown in the **table: 4.2.2.**

c) The upper and lower operating band antennas are illustrated in **figure: 4.3.1 and 4.3.5**, respectively, as well as the total dimensions in the **table: 4.2.1 and 4.2.2.** As seen the two structures that there are additional slots and gaps available as the two antennas nested onto the same substrate.

In the following sections 4.2 the first antenna and the second antenna were discussed and in the section 4.3 the upper and lower operating antennas were evaluated.

4.2 The First and Second Antennas Evaluations

4.2.1 CPW-fed rectangular hybrid slot antenna (first antenna)

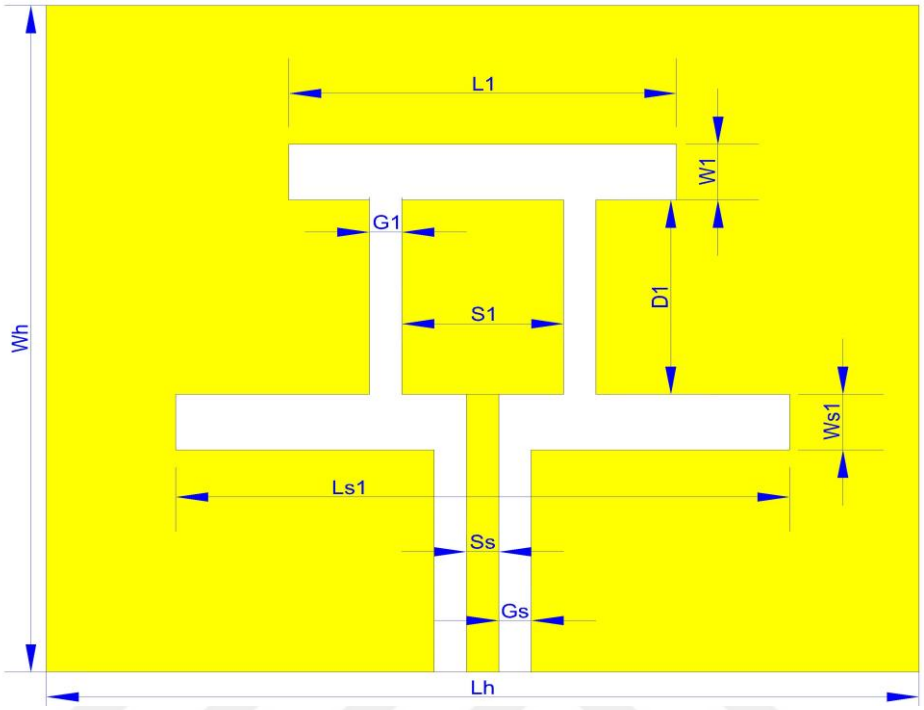


Figure: 4.2.1 the geometric structure of the CPW-fed rectangular hybrid slot antenna (first antenna).

As it can be seen from the **Figure: 4.2.2 and 4.2.3** which represent the return loss of constructed antenna and antenna taken from the literature, respectively, the antenna constructed in the CST microwave has similar return loss to the antenna taken from the literature, which was desired to get the similar results to those obtained in the original antenna. The first antenna has the bandwidth of 1.66 GHz (between the cut-off frequencies of 3.64 and 5.3 GHz) which represents the fractional bandwidth 38% that is an ultra-wideband as the fractional bandwidth greater than 20% is called ultra-wideband. It also gives 86% radiation efficiency and 78% total efficiency, which is good antenna efficiency, since good antenna radiation efficiency is mainly assumed to be greater than 50%.

ε_r=4.3	h=1.58 mm
S1=11 mm	Ss=1.26 mm
G1=0.5 mm	Gs=0.25 mm
L1=21.8 mm	Ls=40.3 mm
W1=6.7 mm	Ws=4.3 mm
D1=16.5 mm	
Wh=60 mm	Lh=80 mm

Table: 4.2.1 the dimensions of the first antenna.

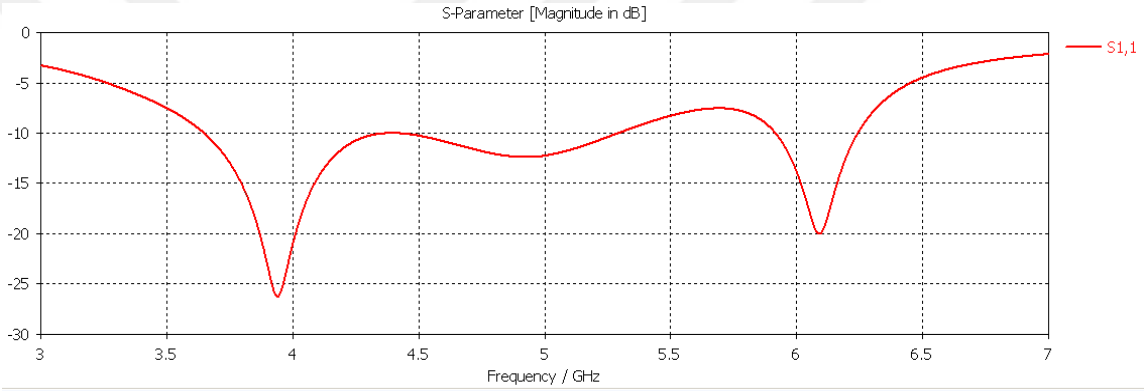


Figure: 4.2.2 the first antenna (constructed in CST microwave) taken from the literature return loss against frequency.

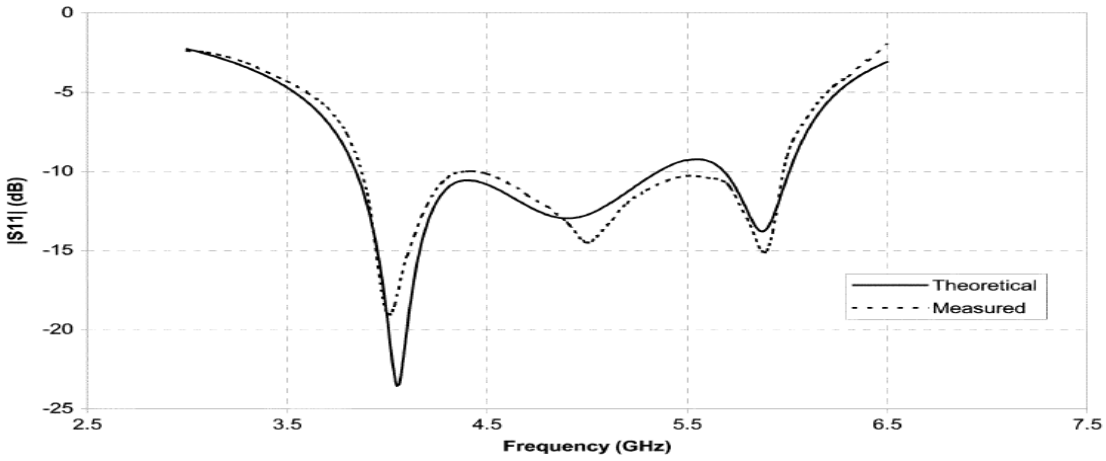


Figure: 4.2.3 first antenna return loss, taken from the literature, against the frequency.

4.2.2 CPW-fed Ractangular Hybrid Slot Sntenna (second antenna)

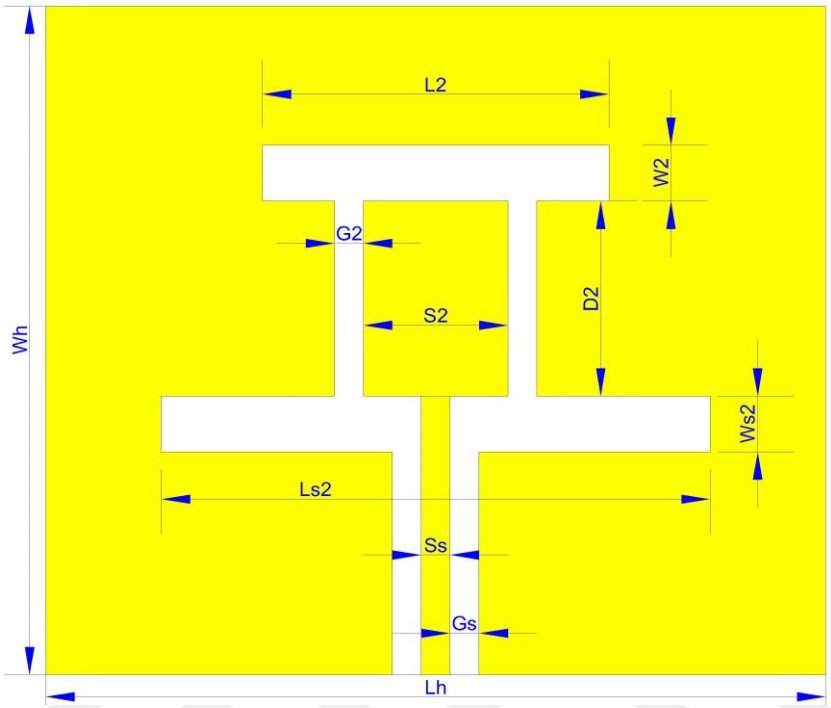


Figure: 4.2.4 the geometric structure of the CPW-fed rectangular hybrid slot antenna (second antenna).

S2=22	Ss=1.26
G2=0.6	Gs=0.25
L2=40.3	Ls2=67
W2=6	Ws=4.3
D2=34	

Table: 4.2.2 the dimensions of the second antenna.

The second antenna was taken from the literature but only Ls2, L2, and S2 dimensions were known. Also the S11 (return loss) result of the antenna was given. The purpose was to find the other dimensions to obtain similar S11 (return loss) results to that of the paper by reconfiguring the antennas' unknown dimensions. The different dimensions were tried and simulated and hence very similar results were yielded. After, it was attempted to achieve better bandwidth then that of the given by trying to change the values of the found dimensions such as D2, Ws2, and W2. As a consequence, a better antenna bandwidth, which extends from 2.285 to 3.314 GHz (1.0284 GHz) as shown in **figure: 4.2.5** with comparison to **Figure: 4.2.6**, was achieved and be used for nested antenna. Also it was observed that the antenna has radiation efficiency of 68.74 % which is good. In

spite of the fact that a good bandwidth and radiation efficiency were achieved, it was monitored that the total efficiency of 33% was obtained, which should be utilised as it means that 33 % of the total power applied to the antenna reaches to the antenna terminal so the rest of the total power is reflected due to mismatch and being absorbed by the conductors and dielectric material, which might lead to heat up so much the antenna and therefore burn it down depending upon the amount of power being supplied. Furthermore, the antenna has the gain of 6.26 dBi and directivity of 7.604 dB.

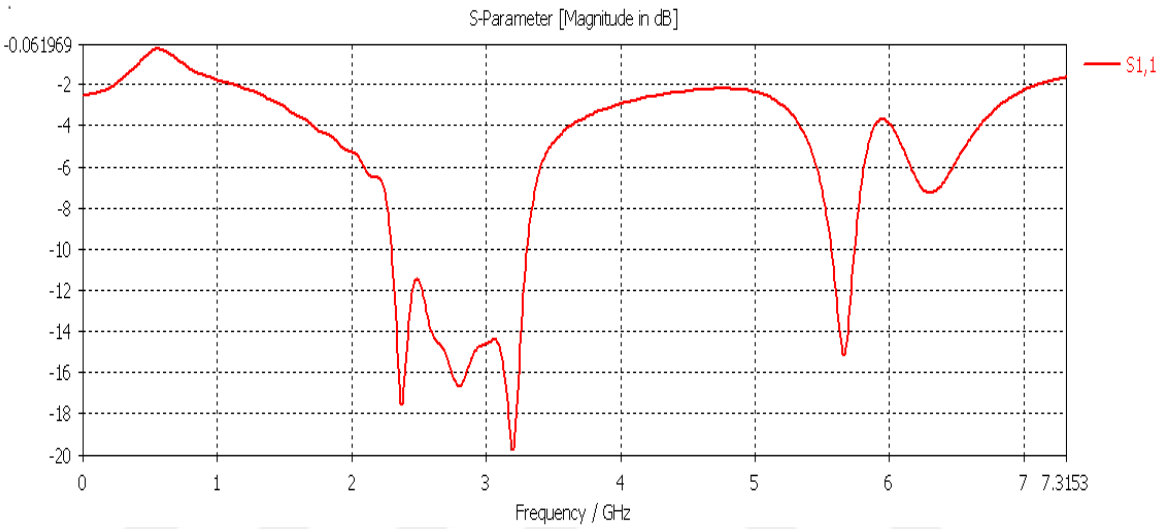


Figure: 4.2.5 the CPW-fed rectangular slot antenna (second antenna) return loss against frequency.

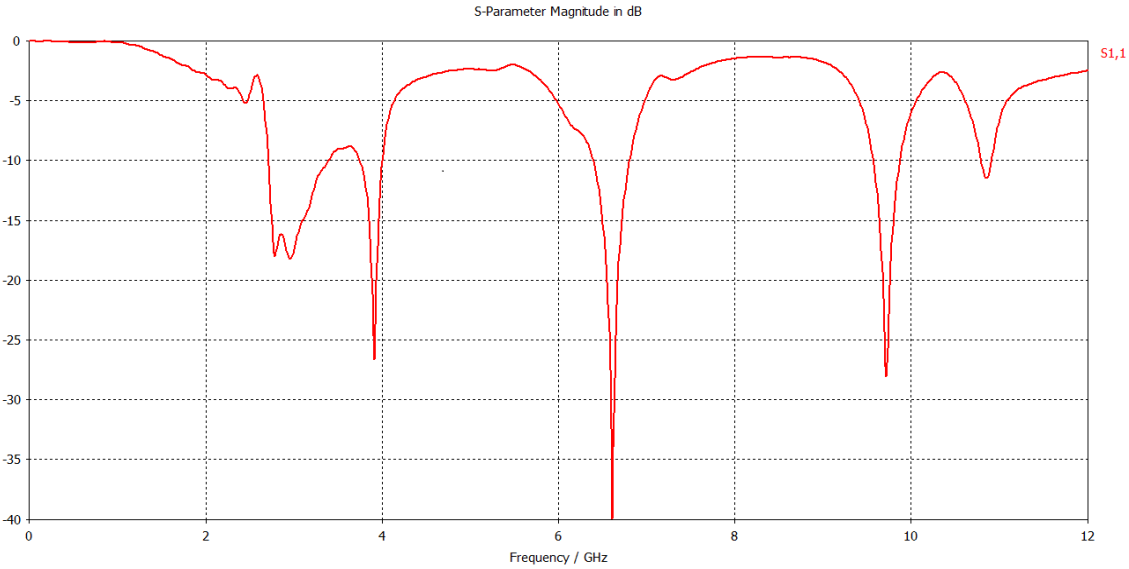


Figure: 4.2.6 the return loss of the second antenna from the literature against frequency.

4.3 The Nested Dual Antenna

4.3.1 Upper Operating Band Antenna

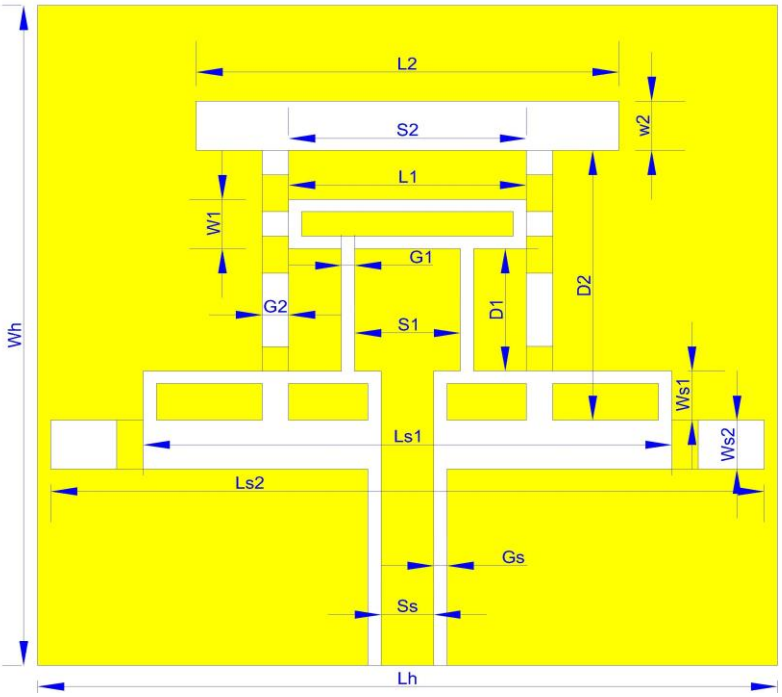
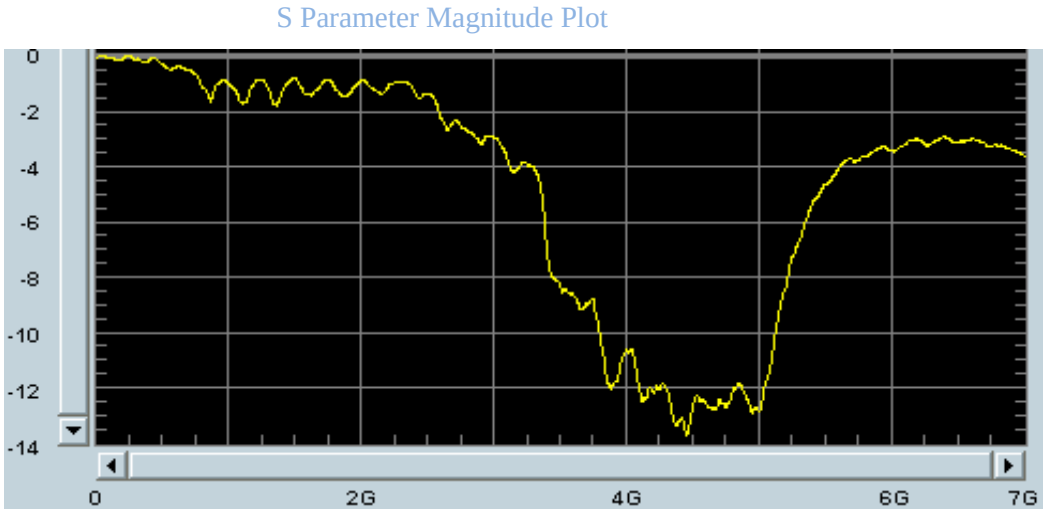


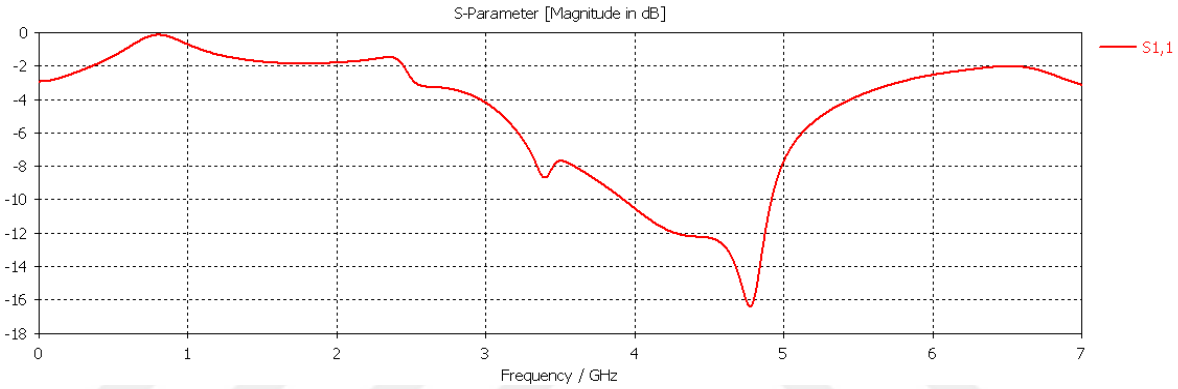
Figure: 4.3.1 the geometric structure of the upper band antenna fed by CPW.

After managing to meet all the desired results of the first and second antennas they were combined together on the same substrate which has the same size as those used for the first and second antennas as shown in **Figure: 4.3.1** and **4.1.9** namely upper operating band and lower operating band antennas, respectively. If it is had a look at the **figure: 4.3.1**, it can be seen that the slot which has the dimensions of second antenna is cancelled by means of the switches used in the gaps G2 and the slot that has Ls2 and Ws2 dimensions. As these switches were used, there is no potential difference around Gs2 and slot of Ls2×Ws2, since they have the same potential as the ground planes and hence it cannot act like antenna to radiate electromagnetic energy into the space or vice versa . Nonetheless, the first antenna is active and the return loss results are given below in **Figure: 4.3.2** (a) and (b). As can be monitored that the return loss of the measured in the lab (a) is very similar to that of obtained with the software in terms of the bandwidth (b). The antenna measured has the bandwidth stretches from 3.85 GHz (lower cut- off) to 5.1 GHz (upper cut-off) (1.3 GHz) and the simulated bandwidth stretches from 3.87 GHz to 4.91 GHz (1.04 GHz). As can be noticed that there is a slight shift down on the higher frequency limit as much as 20 MHz, which means the

measurement result has 20 MHz wider than simulated one. The shift might be because of the cable that connected to the antenna; the materials close to the antenna while was under test or not have good calibration settings and also might be due to the FR4 substrate as it is very cheap and not very good quality material it might not have the same dielectric constant as given properties in the form or might have changed in value so much while under test. But in any case the results are mainly in a good agreement. The fractional bandwidth of the antenna is almost equivalent to 28% which is greater than 20% meaning that the antenna is an ultra-wideband antenna. In the result of measured the S11 becomes zero after below 1 GHz which is very much desired as it means the antenna will not radiate or receive strongly at these frequencies and therefore will not get interfered with other antennas that operate in these frequencies but the simulated results are not as good as in these frequencies. The higher frequencies above upper cut-off frequency they are similar to each other with slight differences. Also it is clear that in the lower or higher frequencies the simulated results are smoother than measured results because the measured S11 line oscillates so much, ideally it is desired to have smooth S11 parameters since there would not be big difference between adjacent frequencies results, meaning that the gain at adjacent frequencies would not be so different. In spite of the fact that the measured results over the operating band frequencies (below 10 dB) oscillates more than the simulated result it is relatively flatter than simulated result. Additionally, the measured antenna resonates around 4.5 GHz while simulated antenna resonance frequency is around 4.8 GHz.

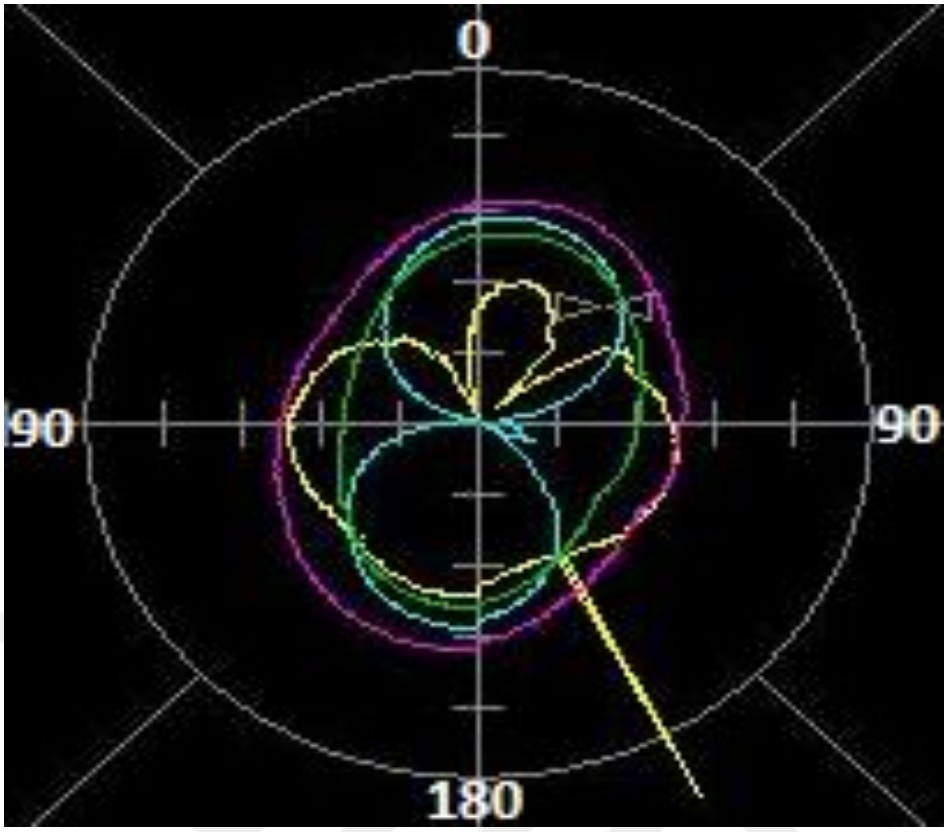


(a)

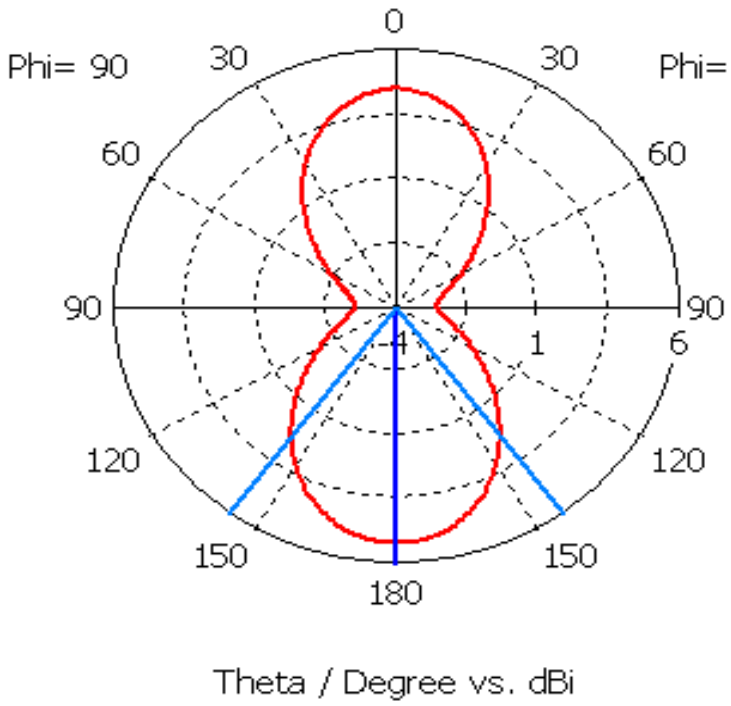


(b)

Figure: 4.3.2 the return loss (S11) of the upper band antenna measured result (a) and simulated result (b).



(a)



(b)

Figure: 4.3.3 the radiation patterns of the upper band antenna measured in the lab 3GHZ (yellow), 2.7 GHz (green), 4.5 GHz (turquoise), and 5 GHz (pink) (a) and the simulated at the frequency of GHz (b)

In the **Figure: 4.3.3** the radiation patterns of the antenna measured and simulated results are il-

lustrated, respectively. It is observed that the result from the simulated pattern at the frequency 4.5 GHz and at the same frequency in the measurement, which is represented in turquoise colour, have some discrepancies. First of all, it can be noticed that the simulated antenna has a very smooth bidirectional E-field radiation patterns of having bore sights of towards 0° and 180°. However, even though the measured result at the same frequency has almost smooth E-field radiation pattern and bidirectional as well, the measured radiation pattern has slightly shifted towards 10° and 170° which might be because of the factors that given below;

1) Misalignment between the receiver and transmitter which is most likely.
2) As the anechoic chamber is not 100% ideal, propagation loss might take place.
3) The transmit antenna might have been tilted, while the turn table was turning. As a result polarisation miss match loss might have taken place.
4) As the software mainly does not have connector to feed the antenna, it does not have any effect on the radiation pattern but in the measurement the connector affects the patterns particularly when the antenna is small in size.

Other difference is that there is a side very small side lobe, which is undesired, in the measured patterns whereas the simulated pattern does not have any side lobes. Furthermore, the simulated antenna looks more directive than the measured one as the measured patterns look like circles.

On the other hand in order to see the stability of the E-field at different frequencies of at 3 GH, 2.7 GHz, and 5 GHz were measured and the measured results at these frequencies are shown in the **Figure: 4.3.3** (a) with different colours. When it is taken a very close look at the results, it can be realized that the antenna has mainly different radiation patterns for different frequencies which indicates that the antenna has unstable radiation patterns in general. As the 4.5 GHz and 5 GH within the operating band frequency range, they are much more important to be paid attention. As it is seen the pattern results are utterly different which means the antenna radiates unstably, meaning that radiation patterns vary with frequency variation. On the other hand, there is an error observed at 3 GHz (yellow), which seems very directive like sward shaped pattern, because of the analyzer software error.

It can be observed from the **figure: 4.3.4** that the total radiation efficiency increases starting from lower cut-off frequency from the lower and reaches the pick point somewhere between 4.5 GHz and 4.7 GHz and then goes down till reaches the upper cut-off frequency. It is also monitored that the radiation efficiency is much higher than the total efficiency and the total efficiency is much sensitive to frequency variations than radiation efficiency as it change faster than radiation efficiency against the frequency alterations. The antenna has its lowest efficiencies at 5 GHz. if the efficiencies is calculated will be observed that the antenna has total efficiency of greater than 0.80

(80%) , radiation efficiency of greater than 0.87 (87%),which means more than 80% of the total power propagated to the antenna by the source reaches to antenna terminal and more than 87% of the total power reached the terminal is radiated by the antenna at the peak point.

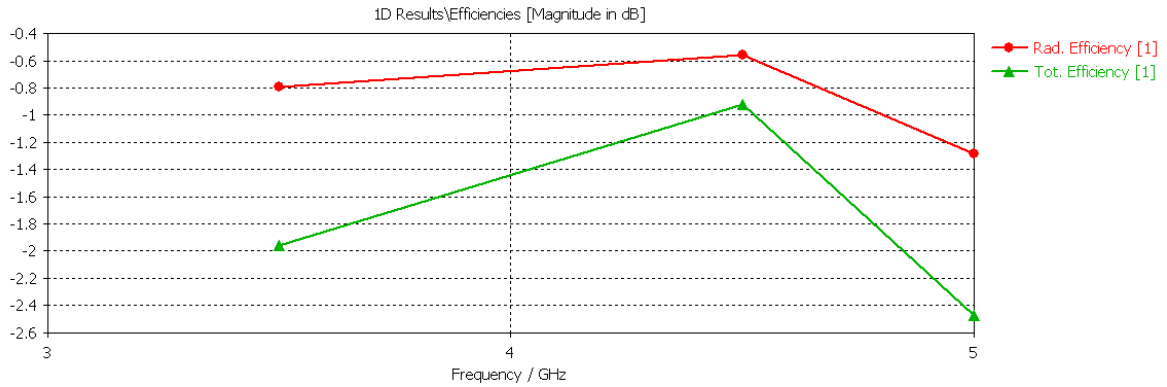


Figure: 4.3.4 the total and radiation efficiency of the upper operating band against frequency.

4.3.2 Lower Operating Band Antenna

When the combined antenna works in the upper band antenna for a while then it starts to work in lower band antenna by means of the switches that is used to turn upper band antenna off or vice versa in the same principle as explained in the upper operating band antenna text. As it is seen in the **Figure: 4.3.6** the return losses (S11) of the measured (a) and simulated (b) have similar curves with some slight differences.

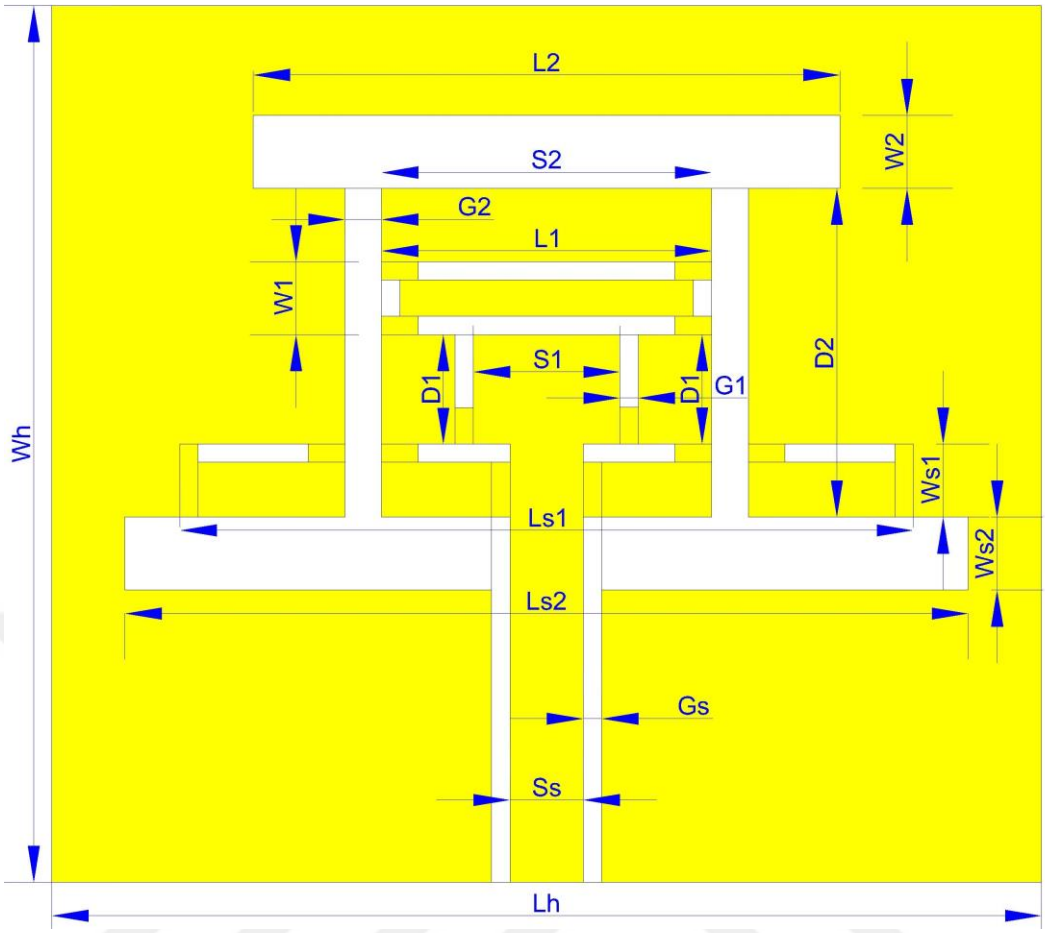
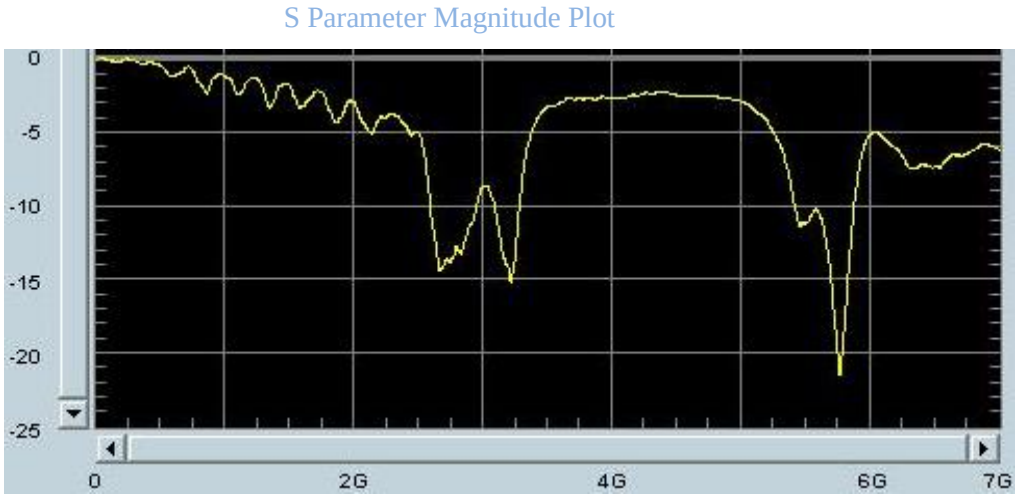
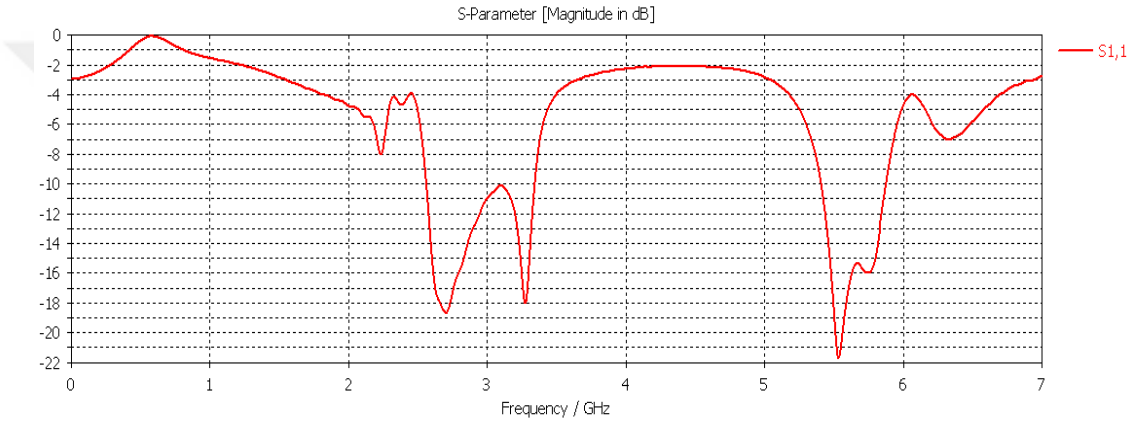


Figure: 4.3.5 the geometric structure of the lower band antenna fed by CPW.

If it is closely looked at the return losses, it will be spotted that the simulated antenna demonstrates better performance than measured one since it has all its component of over the desired frequency range below -10 dB. The simulation result and measured antenna have different result even if they have the same properties and it might be because of the fabrication problems, or the connected cable calibration mistakes and/or other materials that close to the antenna while it was under test. As the CST microwave studio gave very good result in terms of other antennas' return losses, it is very small possibility to be a mistake due to the software. For the lower frequencies the measured results approach zero with the line of oscillations and once reaches zero remains almost zero for afterward, which is wanted as the antenna would not radiate or receive very strongly over these frequencies but it is better to approach zero with non-oscillated line as the simulated result.



(a)



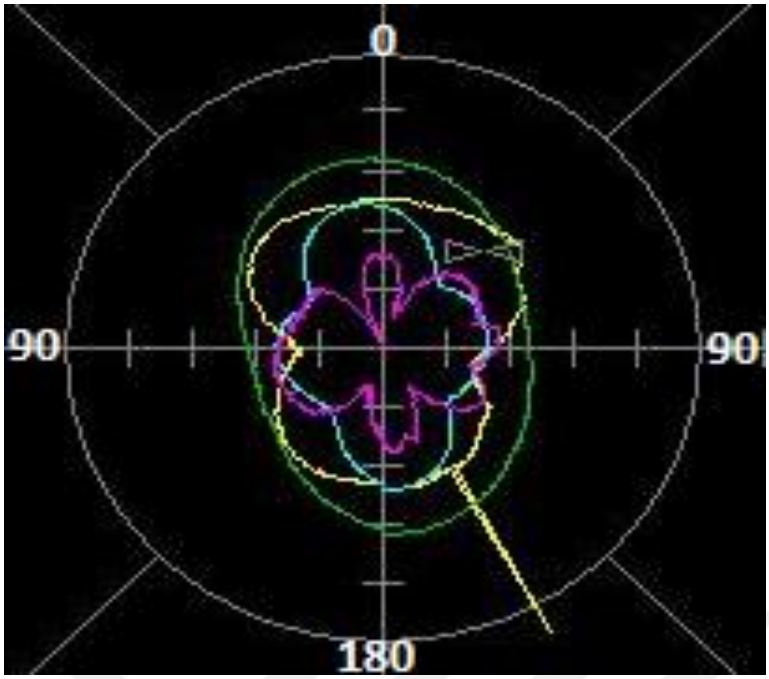
(b)

Figure: 4.3.6 the return losses (s11) of the lower band antenna measured at the lab (a) and simulated (b).

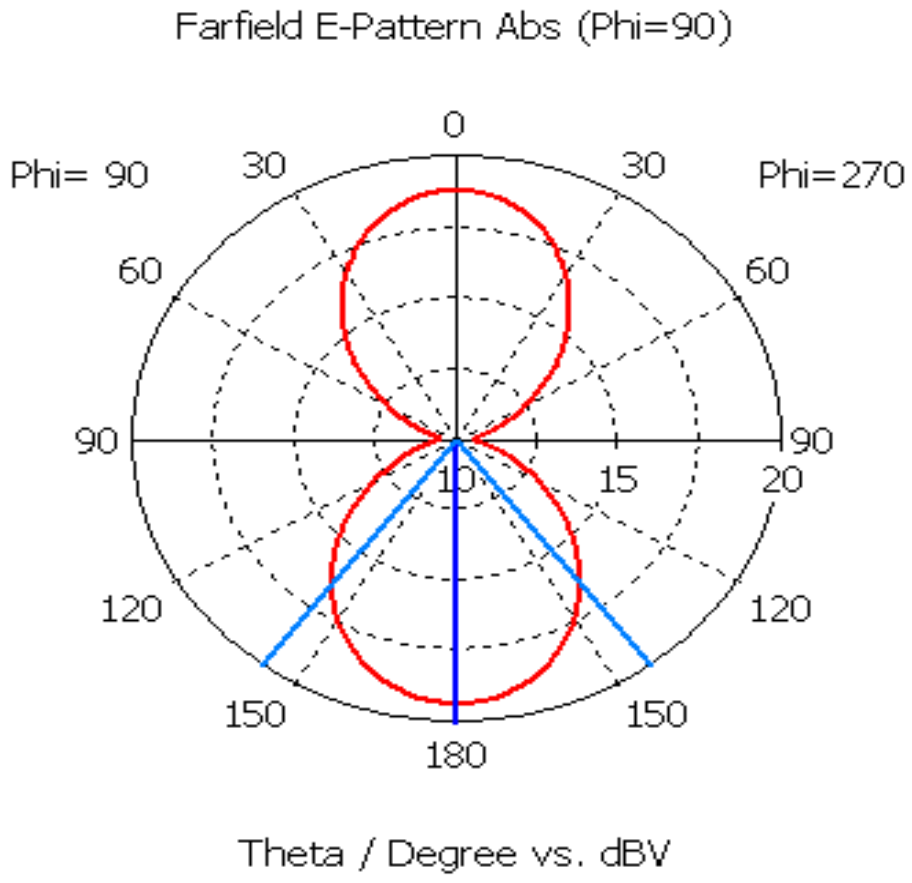
However, even though in the simulated S11 line for lower frequencies (lower than 2.56 GHz) it approaches zero too, it returns towards minus dB values again. For the frequencies higher than 3.44 GHz the results of the two are almost the same some small differences.

If it is assumed that the antenna operates as the simulated result then antenna has the bandwidth of stretching from 2.56 GHz to 3.44 GHz (0.88 GHz), which equals to fractional bandwidth of 29.3%, meaning that the antenna is an ultra-wideband since the fractional bandwidth is greater than 20 %.

In the **Figure: 4.3.7,** if we a glance at the E-field radiation patterns at 3 GHz for the measured (yellow colour (a)) and simulated (b), then we can spot that the patterns are not matched as good as the upper band antennas' pattern results from similarity point of view.



(a)



(b)

Figure: 4.3.7 the radiation patterns of the lower band antenna measured at the lab 2.7 GHz (green), 3GHZ (yellow), 4.5 GHz (turquoise), and 5 GHz (pink) (a) and the simulated at the frequency of 3 GHz (b).

The simulated antenna has two maximum gain of towards opposite directions of 0° and 180° with almost good smooth shape whereas the measured antennas' radiation patterns of towards 60°'s and 180° as can be observed from the provided figures (a) and (b). The simulated patterns are more directive than measured one. The measured and simulated result react similarly in terms of having different shapes in the directions of 0° and 180°'s but the measured result has more of its power radiated in the region between 0° and 90°s. One more difference can be monitored is that towards 0° the measured pattern are almost flat but simulated one is very directive. The reason of having these discrepancies might be the same reasons mentioned in the upper band antenna part. Finally as seen in the figure (a) there is a similar error to in the upper band simulation at 3 GHz observed due to analyser software errors.

To observe the stability of the antenna from E-field radiation patterns point of view in the lower operating band, the antenna E-field was measured at different frequencies of 2.7 GHz, 4.5 GHz, and 5 GHz too. The E-field radiation patterns at these different frequencies are completely different from one another whether in the operating band or out of the band. It demonstrates that the antenna is unstable in the lower operating frequencies as well, meaning that the E-field radiation patterns vary as the frequency varies.

Finally as seen from the **figure: 4.3.8** the total efficiency of the antenna has its peak value at 2.5 GHz and decreases linearly to its lowest value at 3.5 GHz over the operating frequency, meaning that the undesired losses between antenna's terminal and the feeding source get worse as the frequency increases. On the contrast, even though the radiation efficiency has its lowest at 2.5 GHz, as the frequency increases the radiation efficiency goes up and reaches its peak value at 3.5 GHz, which means the antenna gets better with higher frequency in term of radiation efficiency. Also the total efficiency is more sensitive to frequency variations than radiation efficiency since it changes more in value than radiation efficiency over the same frequency variations. The antenna has the total efficiency of 0.44.7 (44.7%) , radiation efficiency of 0.8 (80%) at 3.5 GHz, while the total efficiency has its peak value of 66%radiato and the radiation efficiency has its lowest value of 70%. It is clear that the lower operating band antenna works relatively better over lower frequencies, meaning that the applications work in the lower frequencies of the lower band antenna will work better than the applications used over the upper frequency ranges.

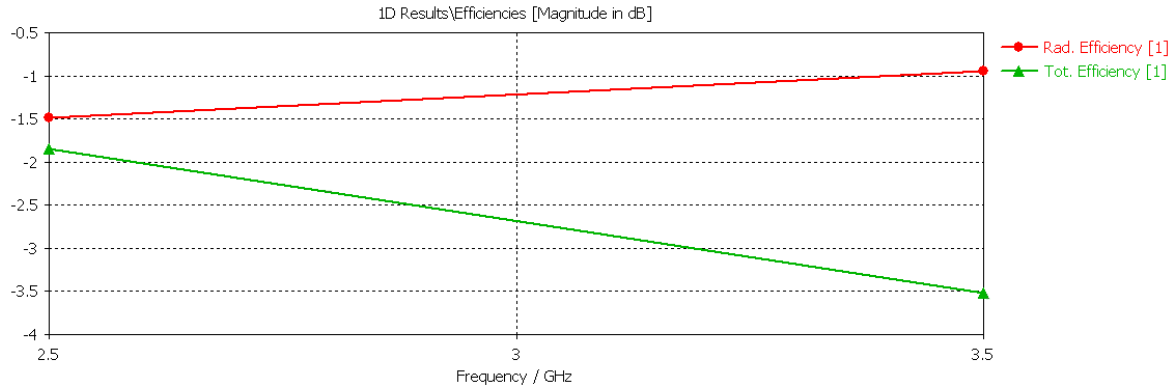


Figure: 4.3.8 the total efficiency and radiation efficiency of lower operating band against frequency.

5 CONCLUSION

5.1 Summary

The very rapid developments of the communication systems increase the need for high data rate and speed. Moreover, besides the need for high data rate and speed, smaller size components are more in demand as the new communication devices are getting smaller and smaller in size. The antennas are essential elements of communication systems as they transmit and receive the signals of the communications systems. In order for increasing the demanded data rate and speed of the system ultra-wideband antennas are required, since the wider the bandwidth the higher data rate and faster speed can be yielded. Also ultra-wideband antennas are safer than the traditional antennas and they are used for precise positioning in radar applications and identifying and tracking applications (RFID).

Coplanar fed slot antennas are used to obtain ultra-wideband as they have very attractive properties such as low profile, low cost, low radiation leakage, less dispersion and so forth. Also they perform very high bandwidth with small antenna size which is very much needed. For further having smaller antennas size instead of having two separated antennas of operating in different frequencies ranges in order to serve different applications, the antennas can be collocated to operate with the same frequency ranges, which they do when separated, by incorporating with the microwave switches by which one antenna can be turned on while other one is off or vice versa, which might decrease the total space the antennas were required almost by 50%.

5.2 Evaluation

The initial purpose was to learn how to use the CST microwave studio and to perform some tutorial fabrications achievements. The work was done and the software successfully learned. After, one antenna taken from the literature, which is a CPW fed hybrid slot antenna, was built, simulated and the scattering parameters compared with the scattering parameters result of the paper and it was observed that results were very well agreed. The next step, a different CPW fed slot antenna taken with mostly unknown dimensions for trying to work out to obtain similar results to the original results. The antenna was built with different dimensions and similar results to S11 in **Figure: 4.1.5** obtained. As the antenna was not an ultra-wideband, the next step was to attempt to utilize the antenna for yielding ultra-wideband antenna and it was achieved as shown in **Figure: 4.1.4**. After all, it was intended to collocate onto the same substrate and by in cooperating with microwave switches antenna will operate in two different operation bandwidths. The antenna was built and simulated in the software and then it was observed the antennas operate with ultra-wideband as provided in Figures: 4.1.7 (b) and 4.2 (b). Afterward, the antennas were fabricated in the lab and the scattering parameters and E-filed radiation patterns were measured. It was achieved to meet the following objectives;

a) Two antennas of operating in two different bandwidths.

b) The antennas were nested onto the same substrate, hence smaller size was achieved.

c) As there is the lower band antenna upper frequency and the upper band antenna lower frequency is 3.44 GHz and 3.85 GHz, there is 410 MHz difference between the two antennas, which means antennas are well isolated from each other.

d) Good antenna efficiency was achieved in the upper operating band antenna. Unfortunately, in the lower band antenna it was not managed to obtain an antenna of good efficiency.

5.3 Future Work

Explain any limitations in the results and how things might be improved. Discuss how this work might be developed further.

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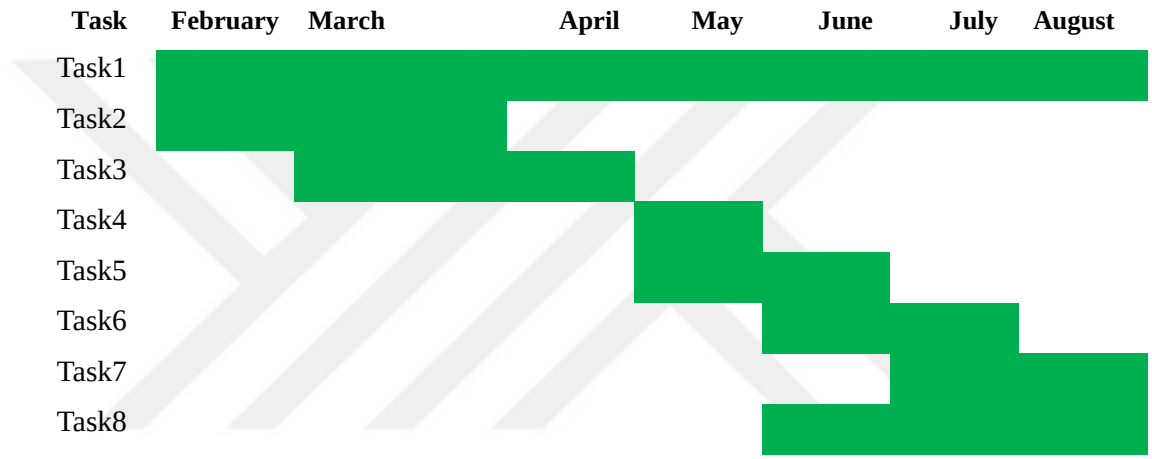
APPENDIX 1- Work plan



Task1	Literature Review ,Get Familiar with CST software
Task2	Try building the first antenna and compare results.
Task3	Try understanding and evaluating the initial findings.
Task4	Try constructing second antenna and obtain ultra-wideband.
Task5	Exam brake.
Task6	Try doing nested antenna and finishing the introduction part.
Task7	Doing the fabrication and obtaining the measurement results in the lab.
Task8	Finishing state of the art, technical part and resit exam brake.
Task9	Finalising report.