REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL ELECTRONICS ENGINEERING

MICROSTRIP PATCH ANTENNA DESIGN FOR ULTRA-WIDEBAND COMMUNICATIONS

ERKAN AYDIN

MASTER OF SCIENCE

ADANA 2019

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21/06/2019

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]
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ABSTRACT

MICROSTRIP PATCH ANTENNA DESIGN FOR ULTRA-WIDEBAND COMMUNICATIONS

AYDIN Erkan

Master's Degree of Electrical Electronic Engineering

Supervisor: Asst. Prof. Dr. Şule ÇOLAK

06 / 2019, 93 Pages

In this thesis, different configurations of microstrip patch antennas are designed for Ultra-Wideband (UWB) communication systems. The parameters of the antenna are examined between 3.1 GHz - 10.6 GHz such as Return Loss, Voltage Standing Wave Ratio and Radiation Pattern. In the study, materials and dimensional parameters are changed on the designed antennas for improving antenna behaviors within the specified frequency range. The generally, referenced methods are to vary the size, shape and types of materials used in the substrate, ground plane and patch. Antennas are designed and simulated by using CST Microwave Studio computer program.

Key Words: microstrip patch antenna, radiation pattern, Return Loss, Ultra-Wideband

ÖZET

ULTRA-GENİŞ BANT HABERLEŞMELERDE MİKROŞERİT YAMA ANTEN TASARIMI

AYDIN Erkan
Yüksek Lisans, Elektrik Elektronik Mühendisliği
Danışman: Dr. Öğr. Üyesi Şule ÇOLAK
06 / 2019, 93 Sayfa

Bu tez çalışmasında, Ultra Geniş Bant (UWB) haberleşme sistemleri için farklı tipte mikro şerit yama antenler tasarlanmıştır. Geri Dönüş Kaybı, Voltaj Duran Dalga Oranı ve Işıma Örüntüsü gibi anten parametreleri 3.1 GHz - 10.6 GHz UWB frekans aralığında incelenmiştir. Çalışmada, anten özelliklerini istenen frekans aralığında iyileştirmek için tasarlanan antenler üzerinde malzemeler ve boyutsal parametreler değiştirilmiştir. Yaygın olarak başvurulan yöntemler alt tabaka, zemin düzlemi ve yama olarak kullanılan malzemelerin boyut, şekil ve türlerinin değiştirilmesidir. Antenler, CST Microwave Studio bilgisayar programı kullanılarak tasarlanmış ve simüle edilmiştir.

Anahtar Kelimeler: mikroşerit yama antenler, ultra geniş bant, geri dönüş kaybı, ışıma örüntüsü

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Finaly, I must determine my gratitude to my family to support me forever.

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NOMENCLATURE

UWB	Ultra-wideband
FCC	Federal Communications Commission
GHz	Gigahertz
RF	Radio Frequency
MHz	Megahertz
mm	Milimeter
f_h	Highest Frequency
f_l	Lowest Frequency
f_c	Center Frequency
B_f	Fractional Bandwidth
dB	Decibel
C	Maximum Channel Capacity
BW	Bandwidth
SNR	Signal-to-Noise Ratio.
WPAN	Wireless Personal Area Networks
P_r	Received Power
P_t	Transmitted Power
G_r	Receiver Antenna Gain
G_t	Transmitter Antenna Gain
c	Speed of Light
f	Frequency
d	Distance
R_r	Radiation Resistance
R_L	Conduction and Dielectric Losses
X_A	Imaginary Part of the Antenna
Z_A	Antenna Impedance
R	Distance from Antenna Surface
ʎ	Wavelenght
D	Directivity

U	Radiation Intensity
U_0	Radiation Intensity of Isotropic Source
P_{rad}	Radiated Power
e_0	Total Efficiency
e_r	Reflection Efficiency
e_c	Conduction Efficiency
e_d	Dielectric Efficiency
VSWR	Voltage Standing Wave Ratio
Γ	Reflection Coefficient
Z_{in}	Input Empedance
Z_0	Characteristic Impedance
G	Gain
t	Thickness
h	Height
GPS	Global Positioning System
$\mathcal{E}_{reff}$	Effective Dielectric Constant
L_{eff}	Effective Lenght
f_r	Resonant Frequency
q	Fringing Factor
L_g	Ground Plane Lenght
W_g	Ground Plane Width
Y	Admidttance
G	Conductance
B	Susceptance
Y_{in}	Input Admittance
R_{in}	Input Resistance
E	Electric Field
H	Magnetic Field
ϑ_0	Speed
J_0	Bassel function
V_0	Voltage
Z_c	Characteristic Impedance

W_0	Microstrip Line Width
R_{in}	Input Resistance
a	Radious
a_e	Effective Radious
CST	Computer simulation Technology
MWS	Microwave Studio
W_s	Substrate Width
L_s	Substrate Lenght
W_p	Patch Width
L_p	Patch Lenght
W_f	Feed Line Width
L_y	Feed Line Lenght
h_s	Substrate Thickness
h_g	Ground Thichness
h_p	Patch Thickness
ε_r	Relative Permitivity
f_c	Center Frequency
T	Period
dBi	Decibel Isotopic
PEC	Perfect Electric Conductor

1. INTRODUCTION

Ultra-wideband (UWB) communication is an enormous wideband system that uses pulse signals to transfer data from the transmitting side to the receiving side. The pulses have very short-duration and these pulses generate extremely large bandwidth. UWB communication has its origins in the 19th century with the first experiment carried out by Hertz about spark-gap transmitters (Nekoogar, 2005**;** Molisch, 2009)**.** After Hertz's studies, a more extensive research was performed by Guglielmo Marconi in 1901 who used UWB system to transmit Morse codes.

During 1960-1990, this technology was limited by Military Department of Defense to be used only for covert communications. However, United States Federal Communications Commission (FCC) allowed unlicensed use of UWB systems in February 2002 (FCC, 2002). According to FCC regulations, a bandwidth of 7.5 GHz, which extends from 3.1 GHz to 10.6 GHz in the spectrum, is allocated for UWB applications. Since then, this area has become a popular and quite promising technology due to its many advantages over the other traditional narrow band systems. Some of these advantages are high data speed, low power spectral density and ultra-wide band width. The technology uses the spectrum together with other communication systems without any interference problem. Additionally, the system is perceived as white noise by other radio frequency devices (Çolak et al., 2007).

At the beginning of studies on antennas, Joseph Henry began to observe the deviation of magnetism in an experiment in 1842. With this experiment, the remote sensing phenomenon was noticed by Henry and improving his experiment, electrical signal was detected from several kilometers away due to lightning (R. Smirnov and Rueda, 2005). In the next years, the electric arc during the opening and closing of a switch in an electric circuit was perceived by Edison. Enhancing his work, a charged and grounded antenna in vertical position was developed in 1875 (Ian Wills, 2006). Hertz, who made his first studies on the concept of polarization, worked on the radiation phenomenon in 1887 (D. J. Cichon and W. Wiesbeck, 1995).

In 1901, Marconi, who made communication between the United Kingdom and the United States via the Atlantic with monopole antenna between 1916 and 1920, performed electromagnetic radiation by using an antenna in the direction of a conductive parabolic reflector. He determined that the radiation diagram calculated by the measured radiation diagram is in harmony with each other (John S. Belrose, 1995).

In our daily life, the wireless system is an indispensable part of human life. Great numbers of technologic devices use the wireless system. Antenna is one of the fundamental components of a wireless system. It is a kind of device that radiates or receives radio waves. Antennas convert not only electrical power to the electromagnetic wave and transmit electromagnetic waves into the space but also intercept these electromagnetic waves and again turn them back into electrical power (Balanis, 2005).

With developing technology, small antennas have begun to be needed in commercial and public applications including mobile phone, wireless communications and large dimensional applications like aircraft, space shuttle, satellite and guided missile. These needs have started to be met with microstrip antennas. Microstrip antennas were first designed in 1953 and patented in 1955. Many studies have been made on microstrip antennas. Because these antennas have small profile, they are easy to install on surfaces, robust in construction, low cost in manufacturing with printed circuit techology (G.A. Deschamps,1953; Gutton et al., 1955).

Antenna design is a critical factor affecting the performance of UWB communication due to broadband nature of the system. Design stage is a big challenge since the designed antenna must work efficiently over the whole UWB frequency interval. Most of the traditional antennas are narrowband and they should be adapted to work well over that frequency range. In this study, micro strip patch antennas are designed and analysed for UWB applications. Antenna parameters as Return Loss, Voltage Standing Wave Ratio (VSWR) and Radiation Pattern are examined in the UWB frequency range.

2. ULTRA-WIDEBAND

2.1. ULTRA-WIDEBAND SIGNALS AND BANDWIDTHS

Continuous waveform radio frequency (RF) signals are regulated by a exclusive carrier frequency for transmitting or receiving information in a classical narrow band communication system. The narrow band signal in time domain is shown in Figure 2.1 (a) while the signal in frequency domain is shown in Figure 2.1 (b).

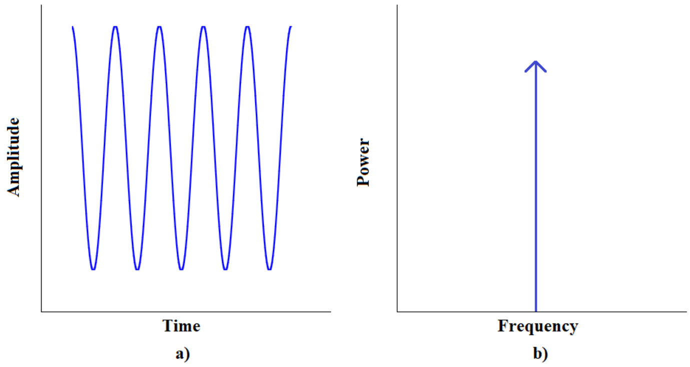


Figure 2.1: a) Narrow band signal in time domain **b)** Narrow band signal in frequency domain

UWB signal is usually described as a signal that has a large relative bandwidth, or, in other words, a large absolute bandwidth (Win et al., 2009; Rahayu 2008). The system uses short-duration pulses which have very low duty cycle to transmit or receive data without carriers. The duty cycle is defined as the ratio of the duration in which a pulse is not zero to the total transmission time. This is explained in Figure 2.2 and its formula is given as,

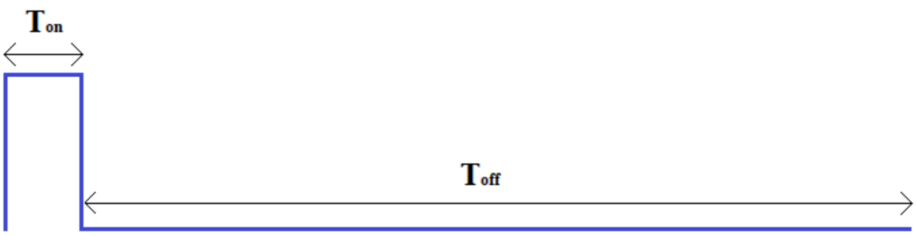


Figure 2.2: This is a low pulse duty cycle when the pulse appears in T_{on} and the pulse disappears in T_{off}

$$\text{Duty Cycle} = \frac{T_{on}}{T_{on}+T_{off}} \tag{2.1}$$

A considerably low average transmission power is presented in an Ultrawideband communication system when duty cycle is low. UWB pulse in both time and frequency domains are illustrated in Figures 2.3 (a) and 2.3 (b), respectively.

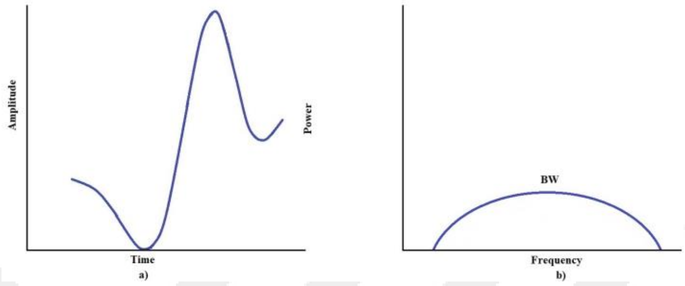


Figure 2.3: UWB pulse in **(a)** time domain **(b)** frequency domain

UWB signals and their bandwidths must be greater than 500 MHz or the fractional bandwidth should be 20% greater than the total transmitted (Molisch, 2009). The fractional bandwidth is a kind of factor to classify signals as a narrow band, large band and ultra-wide band. It is equal to the ratio of -10 dB bandwidth to center frequency.

$$B_f = \frac{BW}{f_c} \times \%100 = \frac{(f_h - f_l)}{(f_h + f_l)/2} \times \%100 = \frac{2(f_h - f_l)}{(f_h + f_l)} \times \%100 \tag{2.2}$$

where, the higher cutoff frequency is f_h, the lower frequency is f_l, center frequency is f_c and B_f is the fractional bandwidth. A UWB signal might be represented by any broadband signal such as Gaussian signal. In the 2 GHz center frequency, a large bandwidth is obtained by a 500 picoseconds pulse. The Gaussian signal with duration of 500 picoseconds is shown in Figure 2.4.

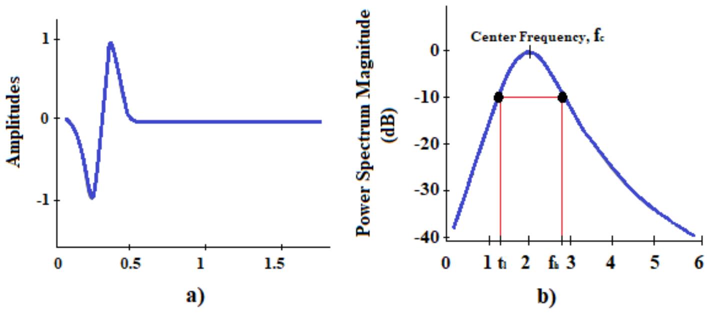


Figure 2.4: The Gaussian monocycle signal **a)** time domain **b)** frequency domain

The center frequency is calculated as,

$$f_c = \frac{1}{T} = \frac{1}{500 \times 10^{-12}} = 2 \times 10^9 \text{ Hz} = 2 \text{ Ghz} \tag{2.3}$$

The lower cutoff frequency is approximately 1.2 GHz and the higher cutoff frequency is aproximately 2.8 GHz at –10 dB. It causes a fractional bandwidth of % 80 and this value is much larger than the minimum value of the fractional bandwidth which is specified by the FCC.

$$B_f = 2 \times \frac{(2.8-1.2)}{(2.8+1.2)} \times 100\% = 80\ \% \tag{2.4}$$

The classification of the signals according to B_f;

Narrowband	$B_f < 1\%$
Wideband	$1\% < B_f < 20\%$
Ultra-Wideband	$20\% < B_f$

2.2. ULTRA-WIDEBAND ADVANTAGES

UWB technology has many advantages over narrow band communication systems. Its improved channel capacity and very low power are the most important advantages.

2.2.1. Frequency Spectrum Sharing

The transferred power in UWB system is only 75 nanowats/MHz in accordance with FCC rules (Nekoogar, 2005). These systems are able to operate without interference with other systems due to power restrictions. It is minimally affected by other narrow band systems because UWB system is below the noise floor. Thus, these systems can operate on a common frequency spectrum. The UWB signal is indicated in RF spectrum as shown in Figure 2.5 below.

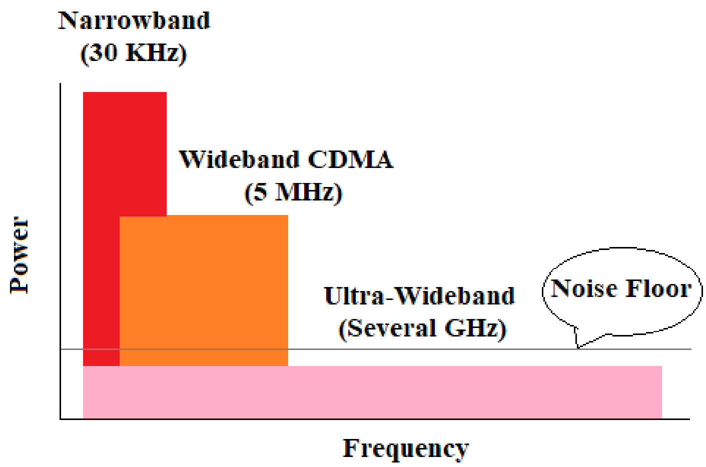


Figure 2.5: The UWB signals in RF spectrum

2.2.2. Large Channel Capacity

The channel capacity is described as the maximum quantity of information that can be transmitted in seconds for communications systems. It is shown in the following formula as,

$$C = BW \log_2(1 + SNR) \tag{2.5}$$

where, the maximum channel capacity is C, bandwidth is BW, and the signal-to-noise power ratio is SNR. This formula denotes that the maximum channel capacity increases linearly with increasing bandwidth. Thus, a very large bandwidth can be used at the gigahertz levels for UWB signals and a data rate of gigabits per second can be obtained. This high data rate can be utilized solely for short ranges of maximum 10 meters, because of FCC's restriction on power for UWB communications. In this situation, UWB technology is the best solution for short range and high data rate wireless applications such as wireless personal area networks (WPANs).

2.2.3. Low Signal to Noise Ratio

According to the maximum channel capacity formula, the relation between channel capacity and signal to noise ratio means that large bandwidth yields large channel capacity. On the other hand, channel capacity depends on the logaritmic function of SNR. Considering that the bandwidth is too high, and it increases faster than a logarithmic function of the SNR, UWB systems can operate with very low SNR values.

2.2.4. Low Intercept and Detection

Detection and interception is not always possible because UWB sytems have a low average power. The listener must be nearby about 1 meter to the transmitter to uncover data.

2.2.5. Good Operate in Multipath Channels

Multipath effects can result serious disturbances for the narrowband signals. Conversely, UWB pulses are less responsive under the multipath channel effects because duration of the UWB pulse is too short.

2.2.6. High Penetration Properties

UWB systems can operate in different materials as distinct from narrow band systems. The low frequencies in the UWB frequency spectrum have long wavelengths and these frequencies provide to pass through in different materials. This characteristic helps to use UWB between wall communication and radar technology.

2.2.7. Simple Architecture

Carrier frequencies are not used in UWB systems, in other words, there is no modulation to carry data as in narrow bands systems. In this manner, architecture of the UWB technology is simple because of carrierless transmission.

2.3. ULTRA-WIDEBAND DISADVANTAGES

There are several disadvantages of the UWB technology besides the advantages. Some of these challenges are explained in below.

2.3.1. Pulse Distortions

This signal is not the same as narrow band signals all along the transmission line. It is very difficult to analyze UWB signals due to their weak character and low power. This condition causes UWB signals to be distorted along the transmission line.

The pulse distortion in the communication channel is expressed by the following formula:

$$P_r = P_t G_t G_r \left(\frac{c}{4\pi df}\right)^2 \tag{2.6}$$

where, the meaning of the parameters in formula is that received power P_r, transmitted power is P_t, gain of the the receiving antenna is G_r, gain of the transmitting antenna is G_t, the speed of light c, signal frequency f and distance between receiver and transmitter antenna is d. This formula indicates that frequency and received power are inversely proportional. The received power is very low under high frequency and it is the reason of distortions in the receiver during the transmission line.

2.3.2. Channel Estimation

Channel estimation is a basic problem for UWB communication systems since it is not always feasible to quantify wireless channel. In this way, it is important to be able to define parameters of the channel with test sequences. The received signals and predefined signals are associated to each other by UWB receivers but received signals can be distorted and as a result the channel estimation in the system is difficult.

2.3.3. High-Frequency Synchronization

One of the basic problems in the UWB system is high frequency synchronization. The sampling and synchronization operations should be done at nanosecond level and synchronization is not easy in that level. So, UWB system requires fast analog-to-digital converters and pulse-position modulation receivers.

2.3.4. Multiple-Access Parasite

Each user can send information to the same region simultaneously and independently from each other. It is anticipated that information is identified and separated in a multiple UWB receiver, but it is extremely difficult for UWB systems due to their low power capacities.

3. FUNDAMENTALS OF THE ANTENNAS

3.1. ANTENNAS

The task of the antenna can simply be defined as transmitting or receiving radio waves. It acts as a transition between the free space and guiding device. The coaxial line or a hollow pipe can be used for transmission line and electromagnetic energy is conveyed by transmission line (Balanis, 2005). The basic antenna circuit is given in Figure 3.1.

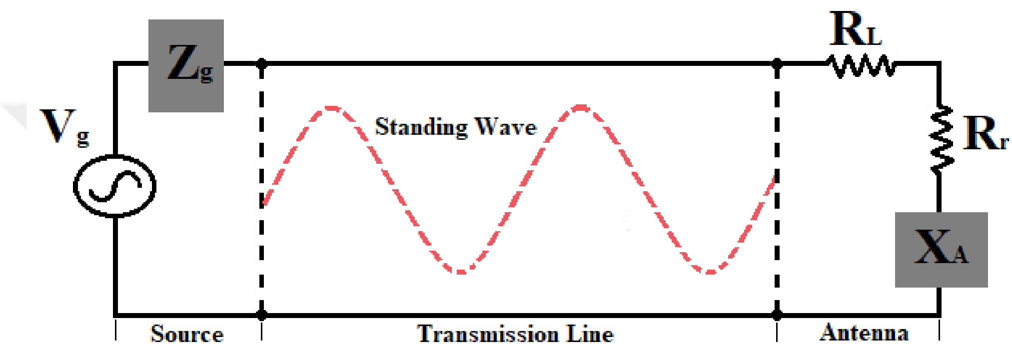


Figure 3.1: The equivalent circuit of the antenna

where, in accordance with this antenna equivelent circuit, R_r is radiation resistance, R_L denotes conduction and dielectric losses and X_A is the imaginary part of the radiation of the antenna. The impedance calculation of antenna is denoted,

$$Z_A = [(R_r + R_L) + jX_A] \tag{3.1}$$

The energy is produced by the source and this energy is given to the radiation resistance for antenna radiation. There can be interface incompatibility between transmission line and antenna besides dielectric losses. In this way, all of the source energy is not transferred to the antenna and reflection occurs. Mismatch loss is a big problem for antenna radiation. The maximum power can be transferred under the condition of conjugate matching and all antenna losses are neglected. Conjugate matching is crucial for antenna design because all energy will not radiate as long as load and transmission line impedance are not equal. Some of the energy is reflected back. Transmitted signal and reflected signal encounter and there occur a standing wave. If the antenna is not planned correctly, the transmission line behaves as energy storing device.

For that reason, an antenna does not efficiently radiate. All losses in an antenna are unwanted situations. These losses can be reduced by making some changes. For Instance, transmission line losses can be eliminated by using less lossy lines and losses due to antenna, its loss resistance R_L can be reduce. The load impedance of the antenna and impedance of the transmission line might be matched in order to diminish standing wave. In addition, storage capacity of the transmission line can also be reduced.

3.2. BASIC PARAMETERS OF ANTENNAS

Antenna parameters are used to understand whether the antennas are operating in the optimum conditions and at the desired level. Each of antenna types has different parameters such as radiation pattern, efficiency, return loss, gain and polarization. These parameters are related to each other and they are used to investigate characteristics of the antenna.

3.2.1. Radiation Pattern

Radiation pattern is described as a function that shows the magnitude of the radiating electric field components at elevation and azimuth planes in space coordinates. The antenna pattern demonstrates how the power is distributed in the space. It is printed as a logarithmic function and decibel (dB) forms because the pattern has small parts and values. Logarithmic functions make it easier to examine radiation pattern of the antennas. The coordinate system of the antenna is illustrated in Figure 3.2.

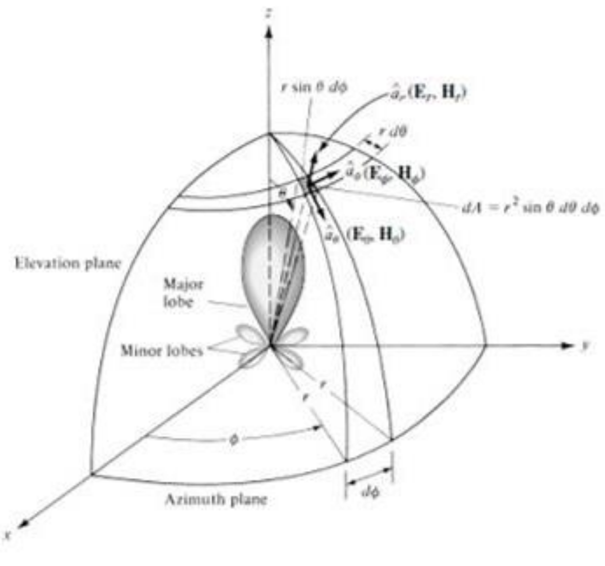


Figure 3.2: Coordinate System for Antenna Analysis (Constantine A. Balanis, 2005)

The angular space parameters of the magnitude of the electric or magnetic field indicate field pattern. The square of the electric or magnetic field defines power pattern and decibel form of this parameter shows power pattern in dB. Half power points are -3dB and these points are calculated as 0.707 times the maximum value for the field pattern and 0.5 times the maximum value for the power pattern. The power pattern in dB form is calculated -3 dB value. These calculations are based on maximum values. The field and power pattern of the antenna are illustrated in Figure 3.3.

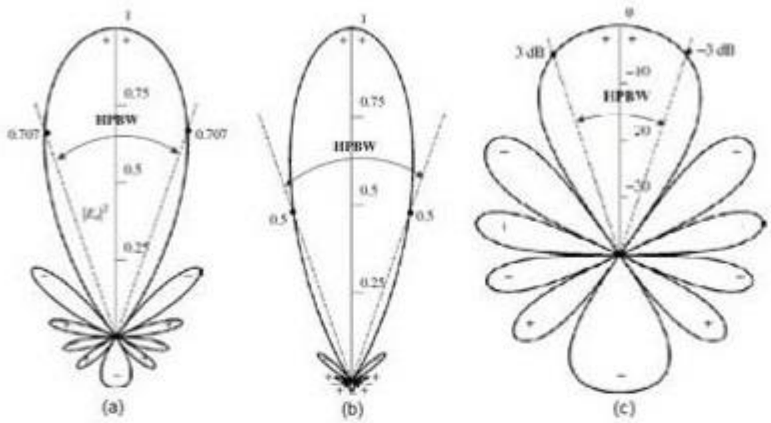


Figure 3.3: **(a)** Field pattern **(b)** Power pattern in dB (Constantine A. Balanis,2005)

3.2.2. Isotropic Patterns

An isotropic antenna has uniformly radiation in all directions without losses. These losses are a kind of conjecture because all antennas are lossy. This conjecture helps to take a reference antenna to analysis antenna parameters and radiation character. Wireless antenna has an isotropic antenna.

3.2.3. Directional Patterns

A directional antenna is defined as the antenna with strong radiation in a certain direction. Yagi-Uda, Horn and log-periodic antennas have directional patterns.

3.2.4. Omnidirectional Patterns

Omnidirectional antennas have two planes perpendicular to each other. These antennas have nondirectional pattern in azimuth plane while they have directional pattern in elevation plane. The antennas, name is dipole and slot, have omnidirectional pattern.

3.2.5. Investigation of the Antenna Field Regions

In general, antennas are examined in three regions. These regions are reactive near field, radiating near-field (Fresnel) and far-field (Fraunhofer). These areas are shown in Figure 3.4.

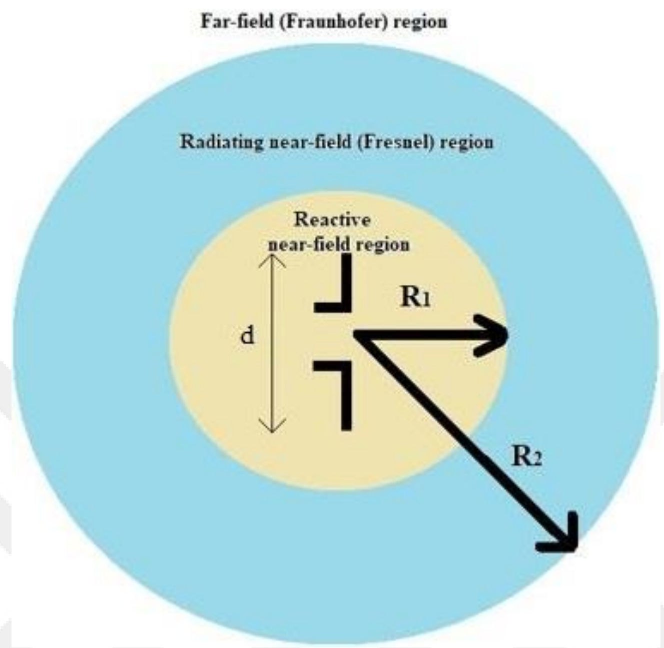


Figure 3.4: Field zones of the antenna according to the radiating characteristics.

3.2.5.1. Reactive near field region

This region is the closest to the antenna and it shows capacitive character and the reactive field is so effective in this region. Boundrry of this region is calculated by this formula,

$$R < 0.62\sqrt{d^3/\lambda} \tag{3.2}$$

where, R is a range from antenna surface, wavelenght is λ, the largest size of the antenna is d.

3.2.5.2. Radiating near field region (Fresnel)

This region is between reactive field region and far field region. The radiation characteristic of the antenna is more effective than reactive near field region. This zone can not ocur if the maximum size of the antenna is not greater than wavelenght.

Internal limit of radiating near field area is calculated by,

$$R \geq 0.62\sqrt{d^3/\lambda} \tag{3.3}$$

and outer limit of radiating near field area is calculated by,

$$R < 2\,d^2/\lambda \tag{3.4}$$

3.2.5.3. Far field region (Fraunhofer)

In this area, radiation character does not change with distance. In general, far field region is calculated by this formula,

$$R > 2\,d^2/\lambda \tag{3.5}$$

It is very far from the antenna, so its size or shape are unimportant. It can be imagined like a point source**.**

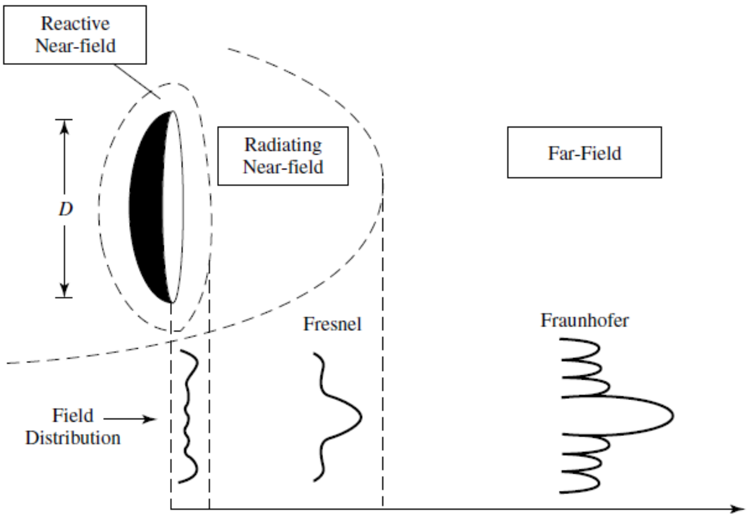


Figure 3.5: Radiation character of antenna in field zones (Constantine A. Balanis, 2005)

Radiation pattern of the antenna is changing from to near field to far field. At the begining of the radiation, there aren't any lobes for near field region. Lobes start to be formed towards radiating near field region, and finaly, there are a few minor lobes and a main lobe in the far field region (Johnson, 1993; Balanis, 2005). It is presented above in Figure 3.5.

3.2.6. Directivity

Directivity of the antenna explains that how far the antenna can spread in a certain direction. Directivity of the antenna is 1, if the equal radiation intensity every direction. The simplest way to explain the directivity is to compare the maximum radiation intensity to the average radiation intensity. The formulation form of the directivity is shown below.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{3.6}$$

where, directivity is D and dimensionless, radiation intensity is U and it is also dimensionless. U_0 is radiation intensity of isotropic source and P_{rad} is total radiated power.

3.2.7. Efficiency

For maximum radiation, the transmission line and antenna must match. If not, there is reflection and this reflection makes antenna efficiency reduced. Therefore, mismatch losses are important for antenna design. The other significant antenna losses are copper losses due to conduction and dielectric losses. The efficieny of the antenna is calculated by,

$$e_0 = e_r e_c e_d \tag{3.7}$$

where, the total efficiency is e_o, reflection efficiency is e_r, conduction efficiency is e_c, and dielectric efficiency is e_d.

3.2.8. Standing Wave Ratio

Standing wave ratio is also referred as voltage standing wave ratio (VSWR). It describes the measure of reflected power from the antenna. Its reason is difference between impedance of transmission line and load impedance of the antenna. Energy is produced by source and it is transferred in transmission line. All energy is not radiated by the antenna if the impedance does not match between the transmission line and the load. The energy that cannot be radiated by the antenna returns back to the source on the transmission line. In this time, transmitted and reflected signals meet on the transmission line and produce standing wave.

The energy is not effectively used, and efficiency of the antenna is low due to VSWR.

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{3.8}$$

Γ is the reflection coefficient of the input terminal of the antenna, Z_{in} is an input impedance and Z_0 is characteristic impedance of the transmission line. VSWR is calculated by,

$$\mathrm{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{3.9}$$

3.2.9. Gain

Antenna Gain depends on antenna efficiency and directivity. Hence efficiency is important for antenna gain. The power gain is expressed by,

$$G = e_0 D \tag{3.10}$$

4. THEORY OF THE MICROSTRIP PATCH ANTENNA

4.1. ANALYSIS OF THE MICROSTRIP PATCH ANTENNA

The first studies on microstrip antennas were started by Deschamps in 1953 and its patent was taken by Gutton and Baissinot in 1955, but its popularity increased in the 1970s (Kavas and Karagoz, 2014). These antennas, which have widespread use today, continue to be developed. These antennas have a wide range of applications including mobile satellite communications and global positioning systems. Additionally, biomedical systems, radars, broadcast systems and remote sensing are some other areas which utilize microstrip patch antennas for their applications. (Neyestanak, 2008).

Generally, a microstrip antenna consist of radiating patch on top of the structure and ground plane at the bottom. There is a dielectric substrate between patch and plane. The conductor patch which is on the dielectric substrate acts like a radiating component. The ground plane is a conductive layer and it is to be located under the substrate. All layers are shown in Figure 4.1. The thickness of the patch is smaller than wavelenght, $t \ll \lambda_o$ and height of the patch is also smaller than wavelenght, $h \ll \lambda_o$. In general, height can have values as $0,003\lambda_o \leq h \leq 0,05\lambda_o$. The microstrip antenna has a substrate and its dielectric constant takes values as $2.2 \leq \varepsilon_r \leq 12$. To obtain the best performance with the antenna, the dielectric constant must be low. Radiation is performed on the patch. The patch can have any shape such as square, rectangular, circular, elliptical, and triangular. The square, rectangular and circular patchs are so popular because of their easy analysis and production (Balanis, 2005).

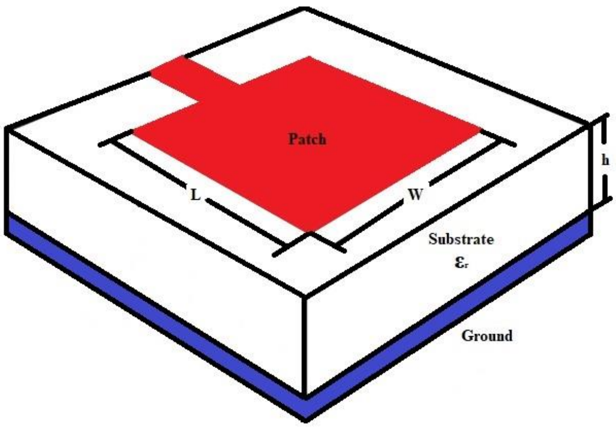


Figure 4.1: Microstrip Patch Antenna

Microstrip Antennas are operating in a small frequency range. It is very useful for narrow band applications such as government security systems (Balanis, 2005). There are many methods to increase bandwidth range. The two most common methods are circuit analysis and structural analysis. The circuit analysis is used for providing equal characteristic impedance between transmission line and antenna. Otherwise, there will be standing wave because of mismatching and it decreases the performance of the antenna. In this way, circuit analysis is using for conjugate matching. The structural analysis is mostly done by changing the substrate of the antenna, such as changing the height or dielectric constant. Bandwidth of the antenna can be increased by increasing substrate height, but it will also give rise to surface waves and loss of the power.

4.2. FEEDING METHODS

Some feeding technigues may be used such as line feeding, coaxial probe feeding, proximity coupled and aperture coupled feeding (Singh and Tripathi, 2011). Each of these methods has its own positive or negative sides.

4.2.1. Line Feeding Method

Production of microstrip line feed is easy. The feed line has a smaller width as compared to the patch. The negative side of this method is that surface wave and spurious feed radiation increases with increasing substrate thickness. The line feeding method for microstrip antenna is given Figure 4.2.

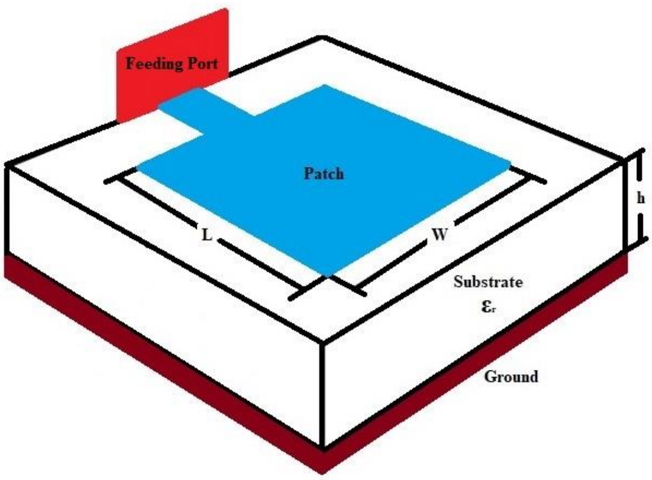


Figure 4.2: The line feeding for microstrip Patch antenna

4.2.2. Coaxial Feeding Method

This method is one of the most popular techniques in feeding. The radiation patch is joined together with inner conductor of the coaxial cable and ground plane is connected with outer conductor. Even though coaxial feeding method has easy modelling and low spurious radiation, it is narrow bandwidth. For this reason, modelling is very difficult for thick substrate (Singh and Tripathi, 2011). The coaxial feeding method is illustrated in Figure 4.3.

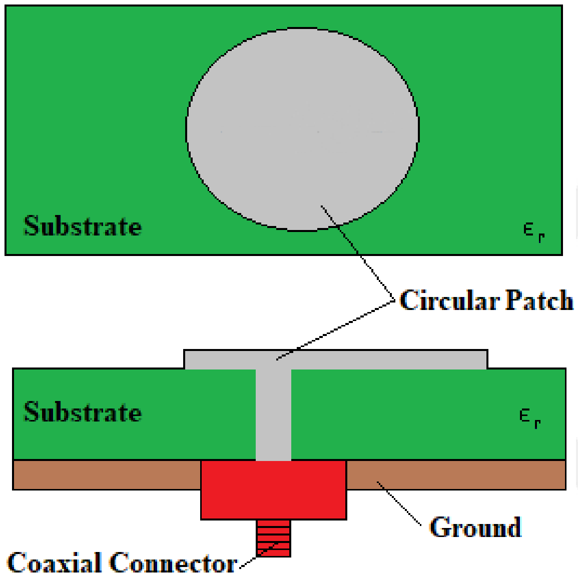


Figure 4.3: Coaxial feeding for Microstrip antenna

4.2.3. Aperture Coupled Feeding Method

It is the most difficult to fabricate in all and the bandwidth is narrow. On the other hand, design is easier and spurious radiation is acceptable. This method consists of two different substrates seperated by a ground plane (Singh and Tripathi, 2011). The connection is provided with a slot or an aperture in the ground plane between feed line and patch (Raheel et al., 2012). The aperture coupled feeding method is shown in Figure 4.4.

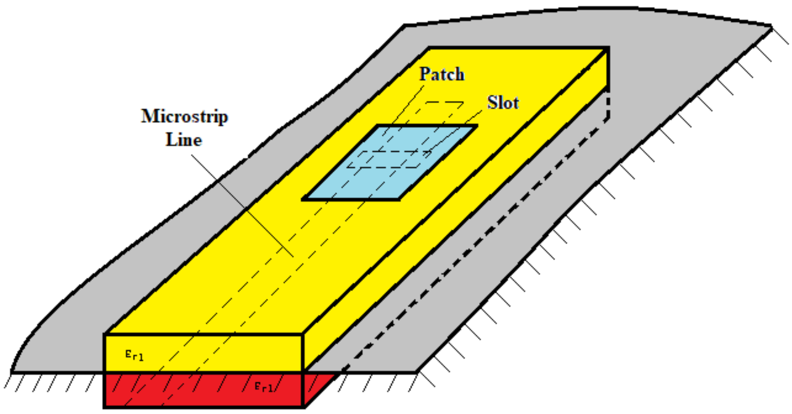


Figure 4.4: Aperture coupled feeding for Microstrip antenna

4.2.4. Proximity Coupled Feeding Method

Another name of this technique is electromagnetic coupling feeding. This method consist of two substrates and feed line is between these two substrates. The location of the radiating patch is on the upper substrate (Raheel et al., 2012. Its production is difficult because two layers must have proper alignment. The proximity feding method is shown in Figure 4.5.

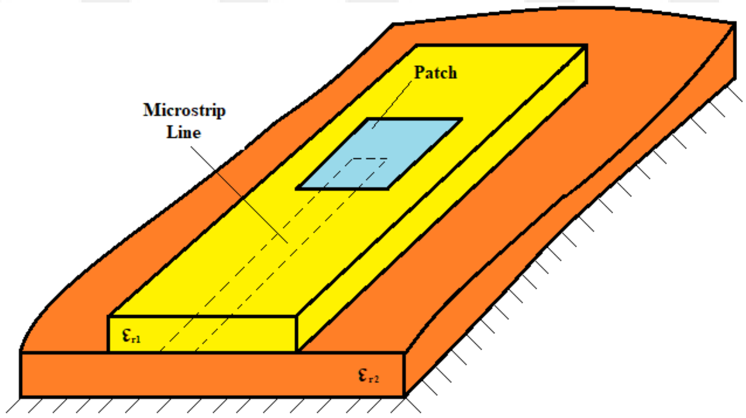


Figure 4.5: Proximity coupled feeding for Microstrip antenna

4.3. ADVANTAGES AND DRAWBACKS OF THE MICROSTRIP ANTENNA

Microstrip antennas are very famous because they are low profile and easy to montage. Some of the important advantages of the microstrip antennas are given below (Balanis, 2005; Singh and Tripathi, 2011; Yazgan, 1987; Breed, 2009).

- Lightness, small volume, low production cost.
- Useful because of its planar shape.

- They can be designed very thin and be coherent with the aerodynamic effect of the wind.
- These antennas may be assembled on guided missiles, rockets and satellites and settled easily.
- Scattering cross section.
- According to the feeding method, their radiating characteristics can have linear and circularly polarized radiation.
- They are convenient to consist of compound systems.

Microstrip antennas have also a number of drawbacks as the other antennas. The negative sides of this antennas are given below (Balanis, 2005; Singh and Tripathi, 2011; Yazgan, 1987; Breed, 2009).

- These antennas have narrow bandwidth and also low gain due to antenna losses.
- There are some difficulties to obtain the highest gain of 20 dB.
- Poor insulation between the feeder and the radiating element.
- Low power capacity and having unwanted feed radiation.
- High quality factor and high dielectric and conductor losses.
- These antennas have cross polarization and their polarization efficiency is poor.
- They can be easily affected from environment factors such as temperature and humidity.

4.4. APPLICATION AREAS OF THE MICROSTRIP ANTENNAS

Microstrip antennas are used in many applications due to their advantages. These antennas are the mostly preferred in defense industry such as rocket, aircraft, missiles but their application areas are increasing day by day. In consequence, it is expected that microstrip antennas will take the place of many conventional antennas in the future. Some application areas for these types of antennas are given below.

4.4.1. Mobile and Satellite Application

Microstrip antennas are used in mobile and satellite communication applications. Because they are low profile, they have small size and low cost. In satellite communication applications, the antenna must have circular polarization. For this reason, microstrip antennas are required thereby using two feed points and different design methods (Singh and Tripathi, 2011).

4.4.2. Global Positioning Systems

At the beginning, Global Positioning Systems (GPS) are used in military area but nowadays they are also used in commerciall area. GPS enable to follow location of the vehicles such as plane, ship, and car.

4.4.3. Radar Application

The Radar is used to comprehend moving targets as people or vehicles. This system involves low profile and lightweight antennas so, microstrip antennas are suitable for radar applications (Singh and Tripathi, 2011).

4.4.4. Medical Application

Microstrip antennas are used in order to treat malignant tumors. Because, the most effective way to induce hyperthermia is to use microwave energy (Singh and Tripathi, 2011). The microwave energy radiator should be mounted to the treated surface. It is provided by microstrip antennas.

5. RECTANGULAR AND CIRCULAR MICROSTRIP PATCH ANTENNAS

5.1. RECTANGULAR MICROSTRIP PATCH ANTENNA

The most commonly used type of microstrip antenna is rectangular patch antenna. This patch may be used for simple or complicated applications because of the fact that its analysis is simple. The best analysis technique is the transmission line and cavity models for rectangular patch antennas.

5.2. TRANSMISSION LINE MODEL

This method is easier than other methods, but the accuracy and the diversity of the results are extremely low. The rectangular patch antenna is made up of two radiating slots. The distance between each radiating slot is equal to the length and, their width is W and height is h (Balanis, 2005).

5.2.1. Fringing Effects

The patch is discontinuous along lenght and width so there occur fringings. The intense of the fringing effects depend on dimension of the patch and height of the substrate. The fringing effect is a function of $\mathrm{L/h}$ and the dielectric constant of substrate ε_r. The fringing effect is decreasing because $\mathrm{L/h} \gg 1$ in microstrip antenna.

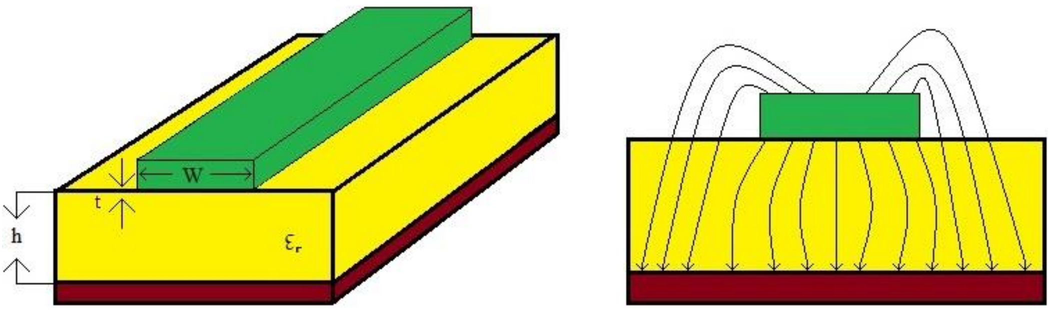


Figure 5.1: The microstrip line and electric field line

In Figure 5.1, most of electric field lines are located in the substrate and some the lines are located in the air. Most of the electric field lines occur in the substrate as long as $\mathrm{W/h} \gg 1$ and $\varepsilon_r \gg 1.5$.

In order to determine fringing effect and wave propogation in the line caused by moving electric waves in the substrate and air, effective dielectric constant ε_{reff} should be calculated.

The interval of the effective dielectric constant is $1 < \varepsilon_{reff} < \varepsilon_r$ and also value of $\mathcal{E}_{reff}$ will be closer to actual dielectric constant of the substrate when the electric constant of the substrate is $\varepsilon_r \gg 1$. The e_{reff} for $W/h > 1$ is given,

$$e_{reff} = \frac{e_r+1}{2} + \frac{e_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{5.1}$$

5.2.2. Fringing Effect on the Lenght

Microstrip patch seems to be bigger than its actual size because of fringing effect. It is illustrated in Figure 5.2. Both sizes of the patch are elongated as ΔL and these depend on ε_{reff} and W/h.

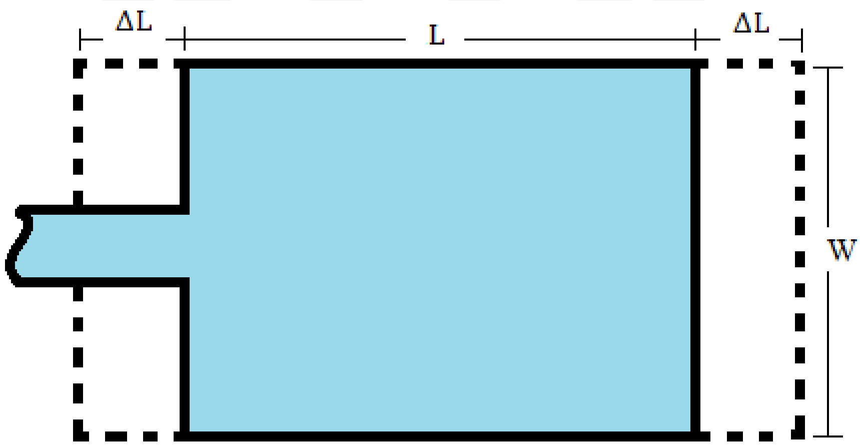


Figure 5.2: Actual size and effective lenght of the patch

$$\frac{\Delta l}{h} = 0.412\frac{(e_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(e_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{5.2}$$

The lenght of the patch is equal to $\lambda/2$ without fringing effects and dominant mode TM_{010} but lenght is changing with fringing effect. Effective length is introduced as

$$L_{eff} = L + 2\Delta L \tag{5.3}$$

The resonant frequency and lenght of the microstrip patch antenna are related to each other in dominant mode TM_{010} as,

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{c}{2L\sqrt{\varepsilon_r}} \tag{5.4}$$

where, the speed of the light is c and the fringing factor is q. This formula should be rearranged with fringing effect.

$$(f_{rc})_{010} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = \frac{1}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} \tag{5.5}$$

$$= q\frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = q\frac{c}{2L\sqrt{\varepsilon_r}} \tag{5.6}$$

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \tag{5.7}$$

5.2.3. Design of the Rectangular Microstrip Patch Antenna

The resonant frequency and dielectric constant should be determined before designing microstrip patch antenna. After that antenna parameters can be calculated easily by the formulas. These unknown antenna parameters are listed below respectively.

- **Width**

This parameter is calculated by the following equation (Afridi, 2015).

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{5.8}$$

where, width of the patch is W, speed of the light is c and the electric constant of the substrate is ε_r.

- **Lenght**

The lenght of the microstrip patch is inscreasing approximately by an amount ΔL because of the fringing effect. Thus, the actual lenght is figured out by using the formula below (Al-Sajee and Hamad, 2011).

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{5.9}$$

where, h is height for substrate. For calculating the lenght of the patch, the formula is given below (Afridi, 2015; Kumari and Sridevi, 2016).

$$L = L_{eff} - 2\Delta L \tag{5.10}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{5.11}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}\, L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{5.12}$$

- **Effective Dielectric Constant**

Some of the electrical wave is moving in air and some is moving in substrate because of fringing effects. The effective dielectric constant must be calculated because of having a different dielectric constant air and the substrate. Its interval is $1 < \varepsilon_{reff} < \varepsilon_r$ and formula is described below (Afridi, 2015; Nikordeh et al., 2015).

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\,\frac{h}{W}\right]^{-1/2} \quad , \quad \frac{W}{h} > 1 \tag{5.13}$$

- **Width and Lenght of the Ground Plane**

Up to now, all unknown parameters and their calculation are shown. Width and lenght of the ground plane are found using the following formulas (Afridi, 2015; Al-Sajee and Hamad, 2011; Sandeep and Kashyap, 2012).

$$L_g = 6h + L \tag{5.14}$$

$$W_g = 6h + L \tag{5.15}$$

where, L_g is the lenght of the ground plane and W_g is the width of the ground plane.

5.2.4. Conductance of the Microstrip Patch Antenna

The Conductance can be determined by using transmission line model for microstrip patch antenna. Radiation patches are parallel to each other and equivalent admittance is denoted as Y. The conductance is G and susceptance is represented by B. Their formulas are described below (Balanis, 2005).

$$Y = G + jB \tag{5.16}$$

$$G = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right], \qquad \frac{h}{\lambda_0} < \frac{1}{10} \tag{5.17}$$

$$B = \frac{W}{120\lambda_0}[1 - 0.636\ln(k_0 h)], \qquad \frac{h}{\lambda_0} < \frac{1}{10} \tag{5.18}$$

Usually, conductance is indicated as,

$$G = \frac{2P_{rad}}{|V_0|^2} \tag{5.19}$$

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_0}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 (\sin\theta)^3 d\theta \tag{5.20}$$

$$G = \frac{2\left[\frac{|V_0|^2}{2\pi\eta_0}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 (\sin\theta)^3 d\theta\right]}{|c|^2} = \frac{1}{120\pi^2} \tag{5.21}$$

$$I = \int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 (\sin\theta)^3 d\theta \tag{5.22}$$

$$= -2 + \cos(x) + xS_i(x) + \frac{\sin(x)}{x} \qquad \text{and} \qquad x = k_0 W \tag{5.23}$$

$$G = \frac{1}{90}\left(\frac{W}{\lambda_0}\right), \qquad W \ll \lambda_0 \tag{5.24}$$

$$G = \frac{1}{120}\left(\frac{W}{\lambda_0}\right), \qquad W \gg \lambda_0 \tag{5.25}$$

5.2.5. Input Resistance of the Microstrip Antenna

The slot, which is located on the patch is explained by parallel equivalent admittance circuit. For impedance matching, imaginary parts of two slots have equal magnitude and opposite sign. They cancel each other when calculating equivalent admittance. As a result of that total admittance and impedance are expressed as (Balanis, 2005),

$$Y_2 = G_2 + jB_2 = G_1 - jB_1 \tag{5.26}$$

or

$$G_2 = G_1 \tag{5.27}$$

$$B_2 = -B_1 \tag{5.28}$$

$$Y_{in} = Y_1 + Y_2 = 2G_1 \tag{5.29}$$

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \tag{5.30}$$

When the mutual effect between the slots are considered, input resistance is regulated as,

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \tag{5.31}$$

where the plus sign is valid for resonance single voltage distribution modes and also negative sign is valid for double resonance voltage distribution modes. The mutual conductance for far field region is described as,

$$G_{12} = \frac{1}{|v_0|^2} \mathrm{Re} \iint E_1 \times H_2^*. ds \tag{5.32}$$

$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2} \cos\theta\right)}{\cos\theta} \right]^2 J_0(k_0 L \sin\theta)(\sin\theta)^3 d\theta \tag{5.33}$$

where, E_1 is the electric field, which is radiated by slot 1, H_2 is the magnetic field, which is radiated by slot 2, V_0 is the voltage between slots and J_0 is a Bessel function. The height of the substrate is not critical patameter for input resistance. If $k_0 h \ll 1$, input resistance is independent of the substrate height. Otherwise, input resistance can be reduced by increasing width of the patch. The characteristic impedance for the microstrip line is shown as,

$$Z_c = \frac{60}{\sqrt{\varepsilon_{reff}}} \ln\left[\frac{8h}{W_0} + \frac{W_0}{4h}\right], \quad \frac{W_0}{h} \leq 1 \tag{5.34}$$

$$Z_c = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{W_0}{h} + 1.393 + 0.667\ln\left(\frac{W_0}{h} + 1.444\right)\right]} \quad , \quad \frac{W_0}{h} > 1 \tag{5.35}$$

where, width is W_0 for the microstrip line. The input resistance is determined as,

$$R_{in}(y = y_0) = \frac{1}{2(G_1 \pm G_2)}\left[\cos^2\left(\frac{\pi}{L} y_0\right) + \frac{{G_1}^2 + {B_1}^2}{{Y_c}^2} \sin^2\left(\frac{\pi}{L} y_0\right) - \frac{B_1}{Y_c} \sin\left(\frac{2\pi}{L} y_0\right)\right] \tag{5.36}$$

where $Y_c = 1/Z_c$. In general, microstirp line is $G_1/Y_c \ll 1$ and $B_1/Y_c = 1$. Thus, the input resistance is modified as,

$$R_{in}(y = y_0) = \frac{1}{2(G_1 \pm G_2)} \cos^2\left(\frac{\pi}{L} y_0\right) \tag{5.37}$$

$$= R_{in}(y = 0) \cos^2\left(\frac{\pi}{L} y_0\right) \tag{5.38}$$

5.3. CAVITY MODEL

Cavity model analysis is better than the transmission line analysis and also it is more complicated in nature. It is supposed that the ratio of the height of substrate and width of the patch is quite small in this model. Hereunder, charge density under the patch is much more effective than the top of the patch. When the ratio of the height of substrate and width of the patch is reduced, current desity is practically zero. In this case, there is not magnetic field around of the patch edge. It means that the electric and magnetic field, under the patch, are not destroyed (Markad et al., 2015)

5.4. CIRCULAR MICROSTRIP ANTENNA

Circular patch antenna is another most commonly used micro strip antenna. To improve microstrip patch antenna performance, the lenght and width of the patch is changed but for circular patch antenna, its radius is modified to obtain best antenna performance (Balanis, 2005). The circular antenna is given in Figure 5.1.

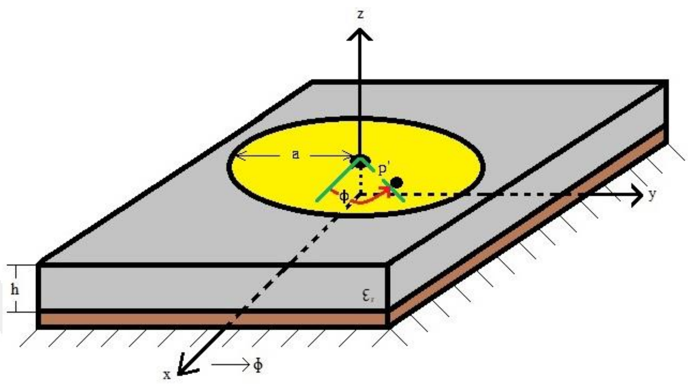


Figure 5.3: Circular Microstrip Patch Antenna

The operation of the circular patch antenna can be investigated by applying cavity model. Its real radius is given as (Pandey and Markam, 2016),

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \tag{5.40}$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \tag{5.41}$$

There is also fringing effect on the circular patch, like the rectangular patch. As a result of this effect, the effective radius is calculated as (Pandey and Markam, 2016),

$$a_e = a\left\{1+\frac{2h}{\pi a\varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2} \tag{5.42}$$

where, ε_r is the dielectric constant of the substrate, h is the height of the substrate and its unit should be centimeter, f_r is the resonant frequency, a_e is the effective radious of the circular patch.

6. CLASSICAL RECTANGULAR PATCH MICROSTRIP ANTENNA

In this section, classical rectangular microstrip patch antennas are designed and analyzed in the UWB frequency range by CST MicroWave Studio (MWS) computer program. This antenna does not satisfy UWB requirements.

6.1. Design-1

The antenna structure has three layers - ground, substrate and rectangular patch which are overlapped on each other. The rectangular patch is placed on the substrate and it is connected to the feeding port via microstrip transmission line.

6.1.1. Antenna Design and Parameters

Classical rectangular patch antenna is shown in Figure 6.1. This patch antenna is designed and analyzed according to the values given in Table 6.1.

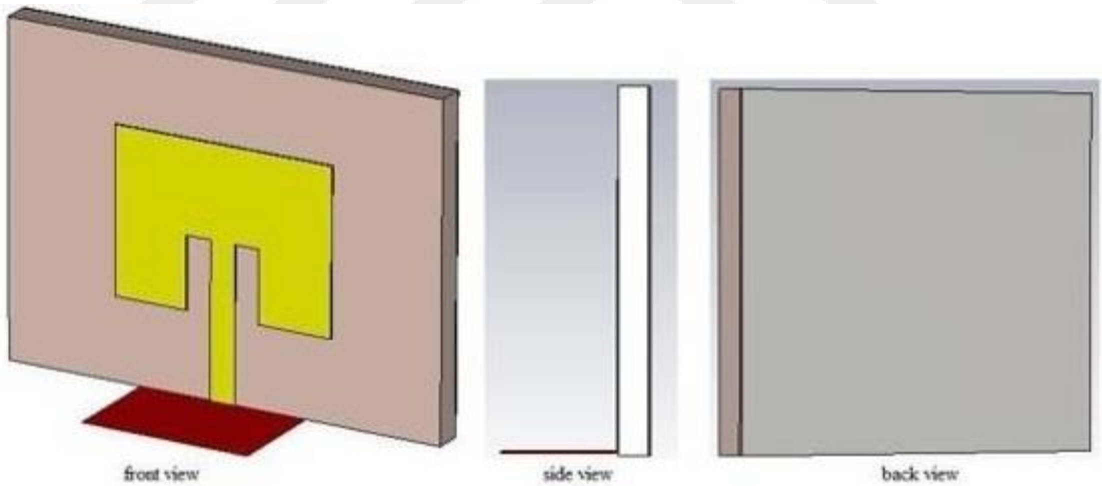


Figure 6.1: Classical Rectangular Patch Microstrip Antenna

Table 6.1: Antenna Parameters for Design 6.1

Symbol	Definition	Value	Unit
Ws	Substrate Width	26.88	mm
Ls	Substrate Lenght	19.84	mm
Wg	Ground Plane Width	26.88	mm
Lg	Ground Plane Lenght	19.84	mm
Wp	Patch Width	13.44	mm
Lp	Patch Lenght	9.92	mm
Wf	Feed Line Width	1.493	mm
Lf	Feed Line Lenght	9.32	mm
ht	Substrate Thickness	1.6	mm
hg	Ground Thichness	0.1	mm
hp	Patch Thickness	0.1	mm
ε_r	Relative Permitivity	4.3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

6.1.2. Simulation Results

A rectangular patch is used for antenna design. This antenna is examined in UWB frequency range and its Return Loss, VSWR and Radiation Pattern characterictics are investigated in Figures 6.2, 6.3 and 6.4.

The resonant frequency of the designed antenna is 10.567 GHz and return loss parameter is -16.613 dB in Figure 6.2. In the same way, its resonant frequency range is 293 MHz from 10.274 to 10.567 GHz. According to the simulation result, the bandwidth of the designed rectangular microstrip patch antenna is narrow band for UWB applications.

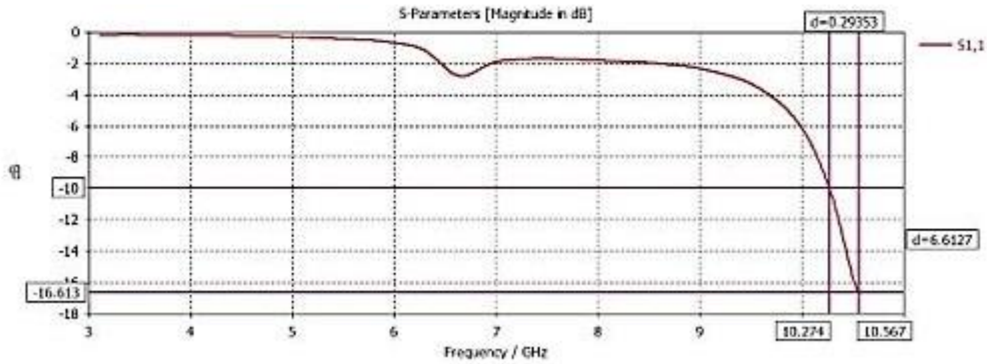


Figure 6.2: Return Loss performance of the designed antenna with measurement points

The VSWR performance of the designed antenna is illustrated in Figure 6.3. The minumum resonance frequency in the graphic is 10.549 GHz and VSWR value is 1.275.

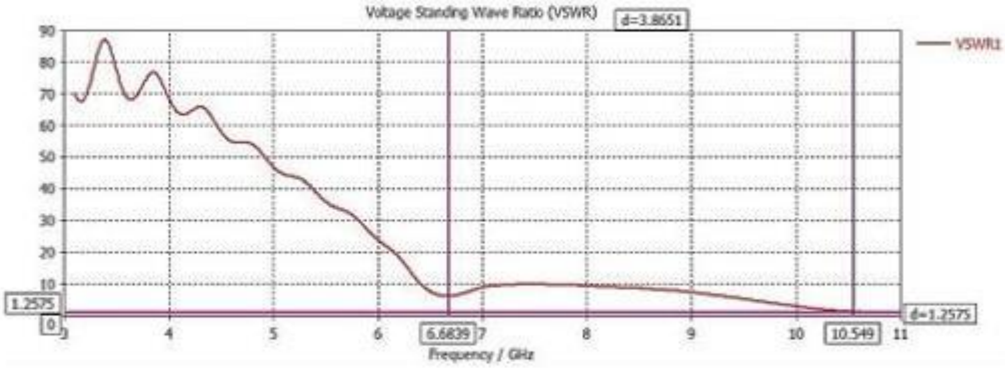
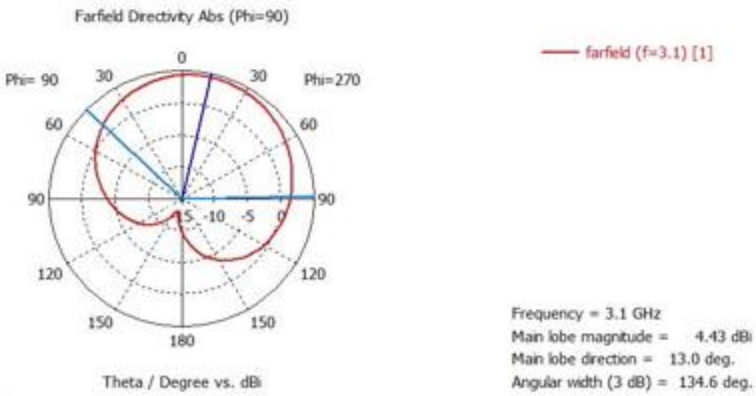
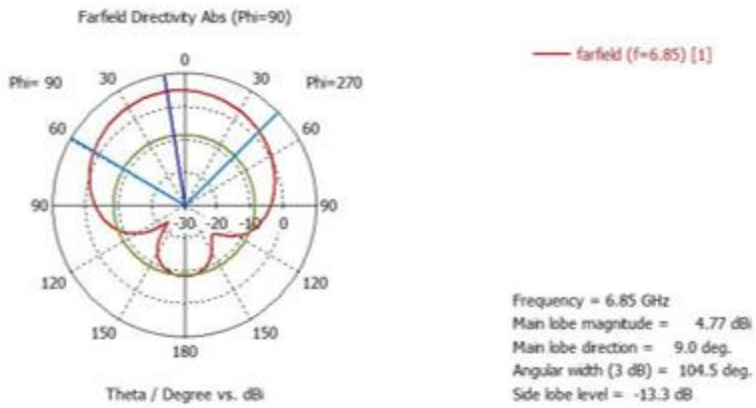


Figure 6.3: VSWR performance of the designed antenna with measurement points

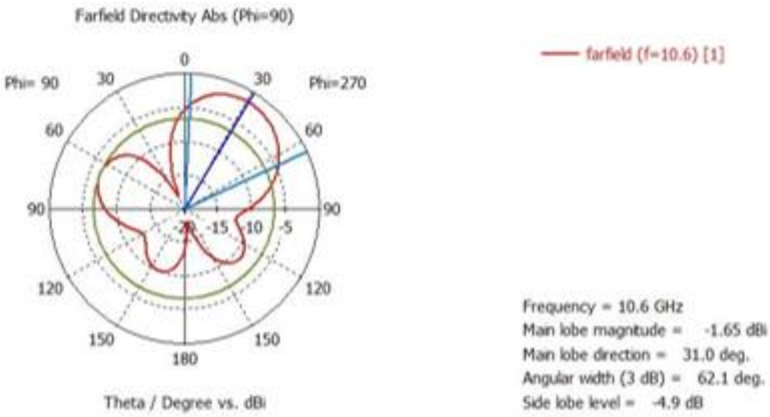
The radiation pattern for designed antenna is given in Figure 6.4. The performance of the antenna is examined at different frequencies 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction is 4.43 dBi and 13° respectively, when the operation frequency is 3.1 GHz. As the frequency is changed to 6.85 GHz, the magnitude and direction of the main lobe becomes 4.77 dBi and 9°. In the last operation frequency at 10.6 GHz, main lobe magnitude is -1.65dBi and 31°. Otherwise, the angular widths (3 dB) of the designed antenna are 134.6°, 104.5° and 62.1° in order of examined frequencies. Meanwhile, there is not side lobe at 3.1 GHz, but it occurs at 6.85 GHz and 10.6 GHz. As a result, the radiation pattern of the designed antenna has directional characteristic and the antenna has narrow band behavior. Although it is desirable for some aplications such as WLAN and GPS, it is not suitable to be used in UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 6.4: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz.

6.2. Design-2

In this part, the method of designing antenna is the same as in Design-1, but the appreance of the antenna differs because various geometric pieces have been removed to operate antenna in UWB.

6.2.1. Antenna Design and Parameters

The designed rectangular patch antenna is presented in Figure 6.5 and its parameters are given in Table 6.2.

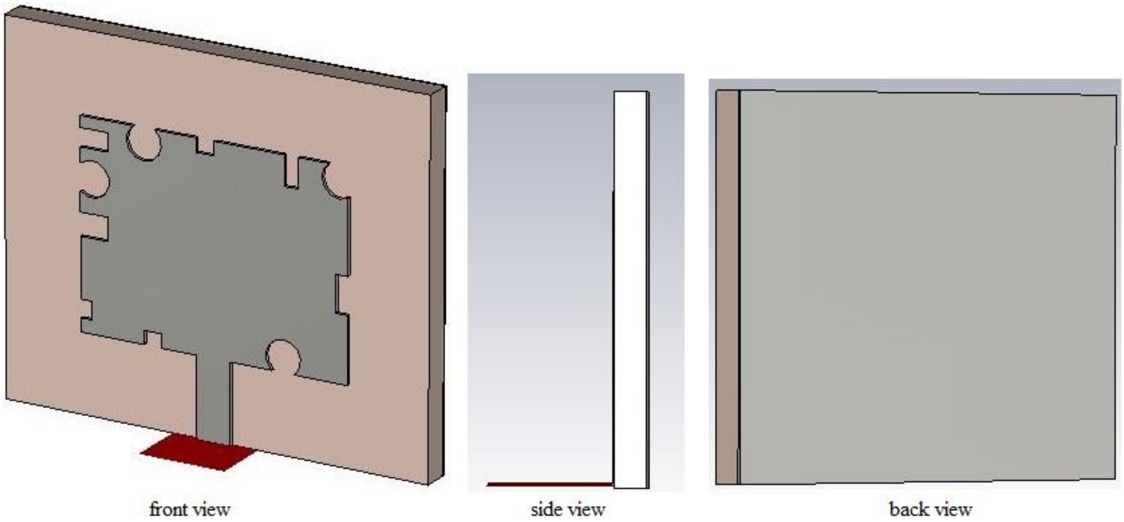


Figure 6.5: Rectangular patch antenna with various ejected pieces

Table 6.2: Antenna Parameters for Design 6.2

Symbol	Definition	Value	Unit
Ws	Substrate Width	24.35	mm
Ls	Substrate Lenght	20.53	mm
Wg	Ground Plane Width	24.35	mm
Lg	Ground Plane Lenght	20.53	mm
Wp	Patch Width	15.35	mm
Lp	Patch Lenght	11.53	mm
Wf	Feed Line Width	1.918	mm
Lf	Feed Line Lenght	4.5	mm
ht	Substrate Thickness	1 - 1.2 - 1.5	mm
hg	Ground Thickness	0.1	mm
hp	Patch Thickness	0.2	mm
ε_r	Relative Permitivity	4.3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

6.2.2. Simulation Results

A microstrip patch antenna is designed by removing various geometric pieces from rectangular patch and then examining the antenna in the UWB frequency range. The Return Loss, VSWR and Radiation Pattern characterictics of the designed antenna are determined with different substrate thicknesses in Figure 6.6, 6.7 and 6.8.

The resonant frequency of the designed antenna is 8.576 GHz. The Return Loss parameter is -33.587dB when substrate thickness is 1.2 mm in Figure 6.6. These simulation results show that the bandwidth of the designed antenna is narrow band and the antenna is not appropriate for UWB applications.

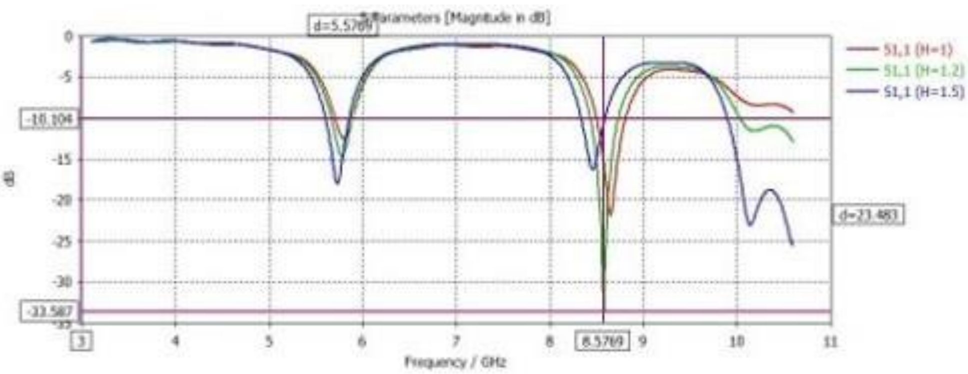


Figure 6.6: Return Loss characteristic of the designed antenna with measurement points.

The VSWR characteristic of the designed antenna is shown in Figure 6.7. The minumum resonance frequency in the graph is 8.596 GHz and its VSWR value is 1.186 when substrate thickness is 1.2 mm.

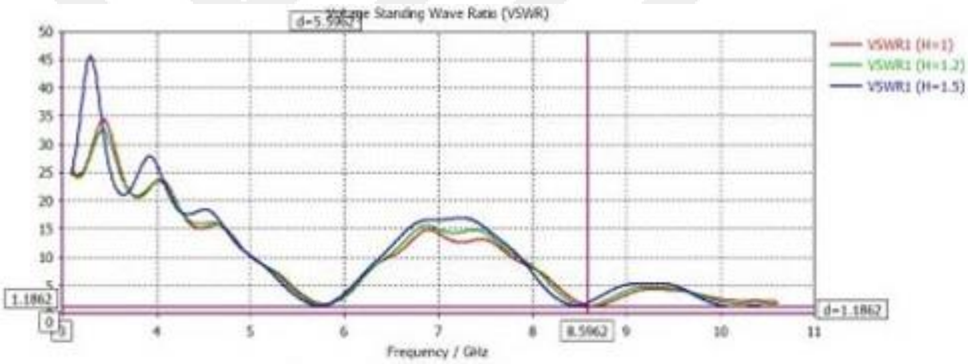
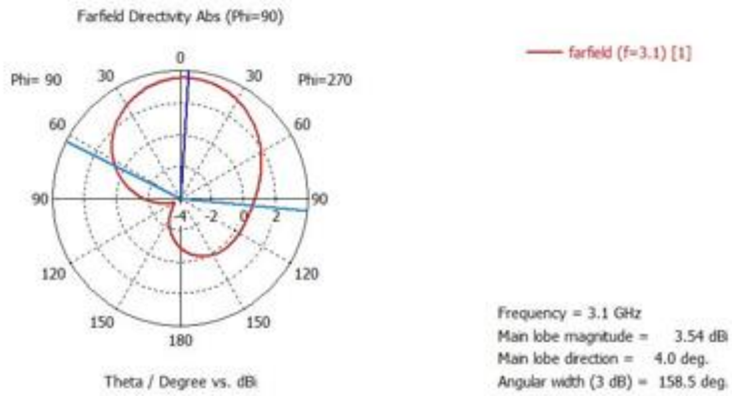
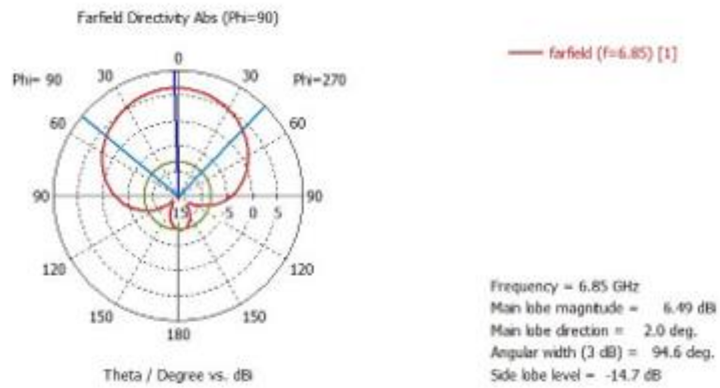


Figure 6.7: VSWR performance of the designed antenna with measurement points

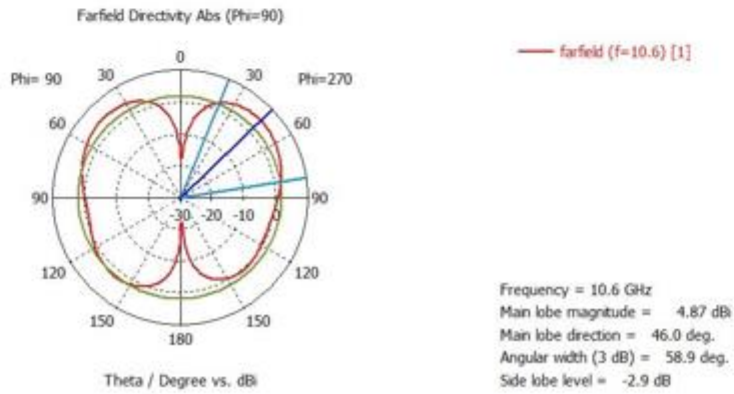
The radiation pattern for designed antenna is given in Figure 6.8 for 1.2 mm substrate thickness. The performance of the antenna is analyzed at different frequencies, 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction is 3.54 dBi and 4° respectively, when the operation frequency is 3.1 GHz. As the setting frequency at 6.85 GHz, the magnitude and direction of the main lobe is 6.49 dBi and 2°. The last operation frequency at 10.6 GHz, main lobe magnitude and direction is 4.87 dBi and 46°. Additionally, the angular widths (3 dB) of the designed antenna are 158.5°, 94.6° and 58.9° in order of analyzing frequency. Meanwhile, there is not side lobe at 3.1 GHz, but it occurs at 6.85 GHz and 10.6 GHz. As a result, the radiation pattern of the designed antenna has directional characteristic and the antenna is narrow band. Thus, this designed antenna is not compatible with UWB applications, but it is suitable for some applications such as WLAN and GPS.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 6.8: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

7. CLASSICAL CIRCULAR PATCH MICROSTRIP ANTENNA

In this section, classical circular microstrip patch antennas are designed and analyzed in the UWB frequency range by CST Microwave Studio (MWS) computer program.

7.1. Design-1

Classical circular patch microstrip antenna structure comprise of three layers as ground, substrate and rectangular patch, which are overlapped on each other. The circular patch is located on the substrate and ground is the bottom layer. The circular patch is connected to feeding point by microstrip transmission line.

7.1.1. Antenna Design and Parameters

Classical circular patch antenna is shown in Figure 7.1. This antenna is sketched and examined according to the values in Table 7.1.

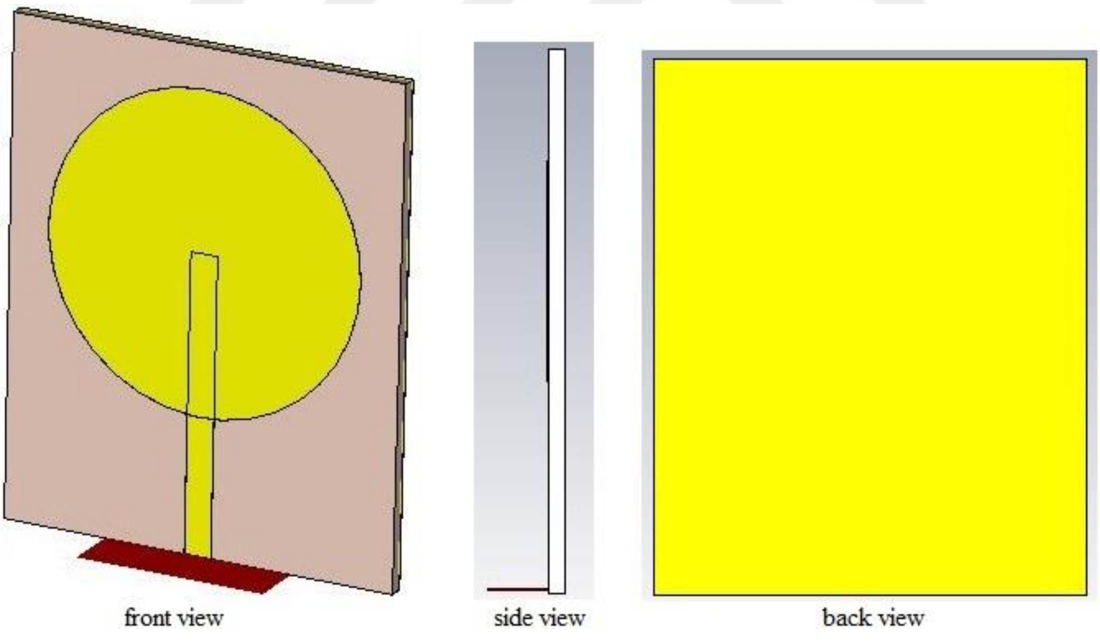


Figure 7.1: Classical Circular Patch Microstrip Antenna

Table 7.1: Antenna Parameters for Design 7.1

Symbol	Definition	Value	Unit
Ws	Substrate Width	44.68	mm
Ls	Substrate Lenght	55.395	mm
Wg	Ground Plane Width	44.68	mm
Lg	Ground Plane Lenght	55.395	mm
a	Radius	17.840	mm
Wf	Feed Line Width	3.057	mm
Lf	Feed Line Lenght	33.055	mm
hs	Substrate Thickness	1.6	mm
hg	Ground Thichness	0.1	mm
hp	Patch Thickness	0.035	mm
ε_r	Relative Permitivity	4.3	-
c	Speed of the Light	3×10^8	m/sec
f_c	Center Frequency	6.85	GHz

7.1.2. Simulation Results

A circular patch is used for antenna design. This antenna is examined between 3.1 GHz and 10.6 GHz in UWB frequency interval and its Return Loss, VSWR and Radiation Pattern characterictics are determined in Figure 7.2, 7.3 and 7.4.

The resonant frequency of the designed antenna is 9.898 GHz and return loss parameter is -33.144 dB in Figure 7.2. As a result of this simulation, the bandwidth of the designed antenna is narrow band and the antenna is not good for UWB applications.

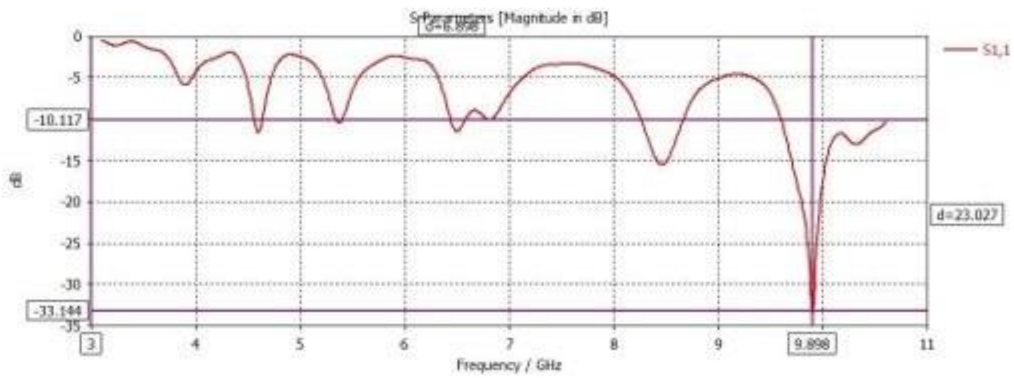


Figure 7.2: Return Loss characteristic of the designed antenna with measurement points

The VSWR of the designed antenna is shown in Figure 7.3. The minumum resonance frequency in the graphic is 9.898 GHz and VSWR value is 1.047.

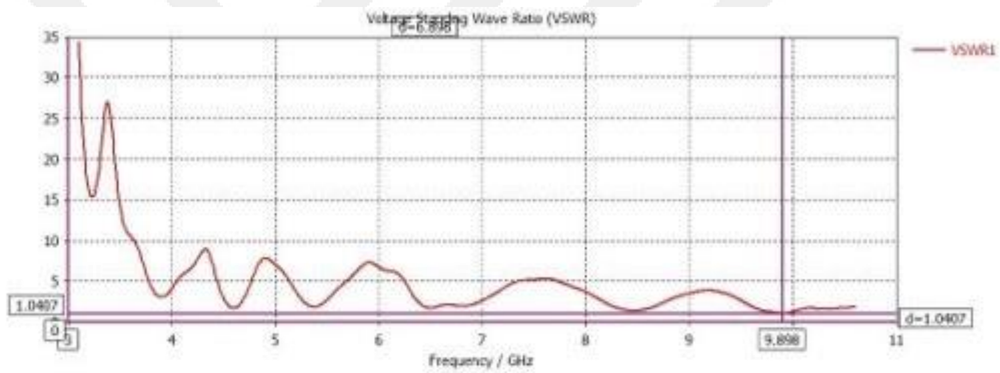
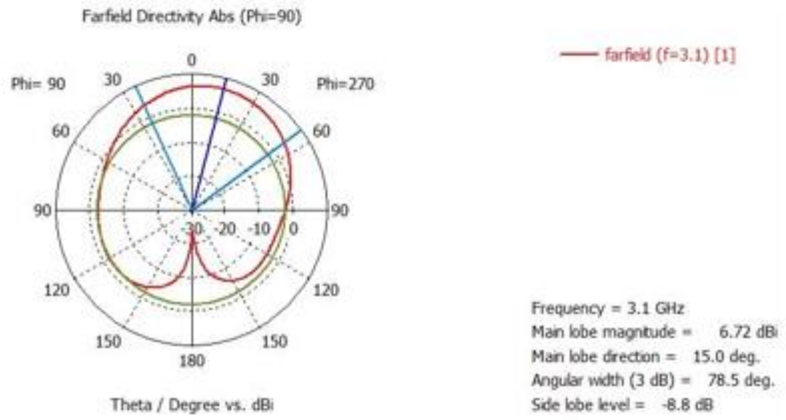
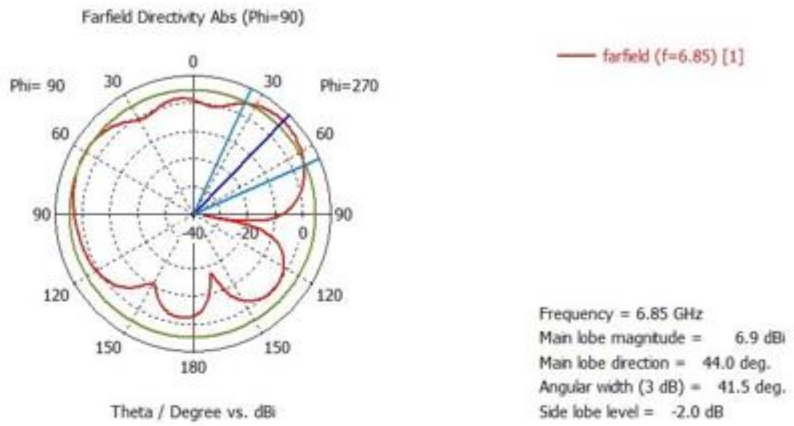


Figure 7.3: VSWR performance of the designed antenna with measurement points

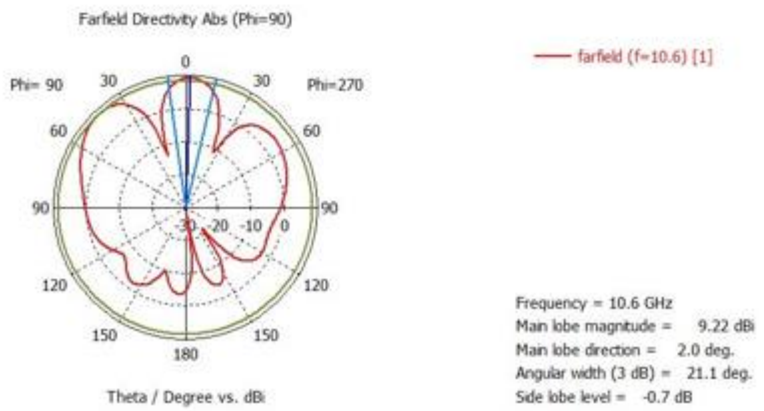
The radiation pattern for designed antenna is shown in Figure 7.4. The designed antenna is operated and investigated at different frequencies 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction is 6.72 dBi and 15° respectively, when the operation frequency is 3.1 GHz. As the setting frequency at 6.85 GHz, the magnitude and direction of the main lobe is 6.9 dBi and 44°. The last operation frequency at 10.6 GHz, main lobe magnitude and direction is 9.22 dBi and 2°. On the other hand, the angular widths (3 dB) of the designed antenna are 78.5°, 41.5° and 21.1° and also its side lobe levels are -8.8 dB, -2 dB, -0.7 dB in order of analyzing frequency. Consequently, the radiation pattern has directional characteristic and the structure is narrow band. Thus, this designed antenna is not useful for UWB applications, but it can be suitable for some applications such as WLAN, wireless and GPS.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 7.4: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

7.2. Design-2

In this part, the designed antenna is similar to the Designed-1, but its parameters have different values.

7.2.1. Antenna Design and Parameters

Classical circular patch antenna is shown in Figure 7.5. This patch antenna is sketched and examined according to the values in Table 7.2.

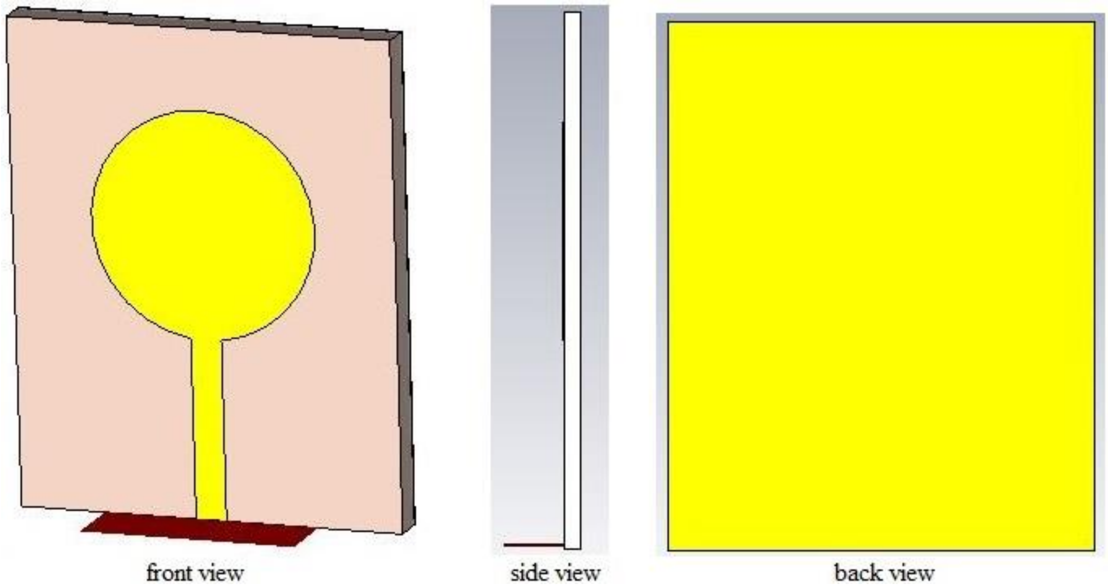


Figure 7.5: Classical Circular Patch Microstrip Antenna

Table 7.2: Antenna Parameters for Design 7.2

Symbol	Definition	Value	Unit
Ws	Substrate Width	40	mm
Ls	Substrate Lenght	50	mm
Wg	Ground Plane Width	40	mm
Lg	Ground Plane Lenght	50	mm
a	Radius	11.68	mm
Wf	Feed Line Width	3.2	mm
Lf	Feed Line Lenght	30	mm
hs	Substrate Thickness	3.5	mm
hg	Ground Thichness	0.1	mm
hp	Patch Thickness	0.2	mm
ε_r	Relative Permitivity	2.2	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

7.2.2. Simulation Results

The designed antenna is examined between 3.1GHz-10.6 GHz in the UWB frequency interval and its Return Loss, VSWR and Radiation Pattern characterictics are determined in Figure 7.6, 7.7 and 7.8.

The resonant frequency of the designed antenna is 10.205 GHz and return loss is -42.286 dB in Figure 7.6. To sum up, the bandwidth of the designed antenna is narrow, and the proposed structure is not appropriate to be used for UWB applications.

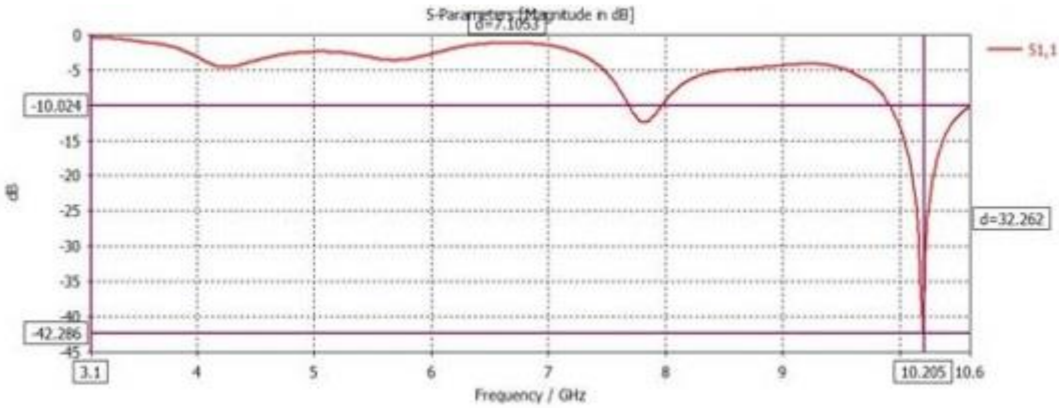


Figure 7.6: Return Loss characteristic of the designed antenna with measurement points

The VSWR is shown in Figure 7.7. The resonance frequency in the graphic is 10.214 GHz and its VSWR value is 1.1527.

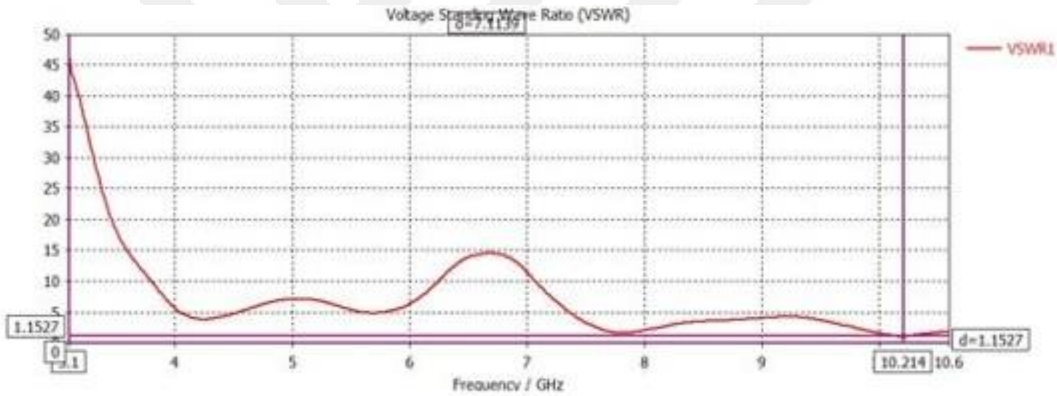
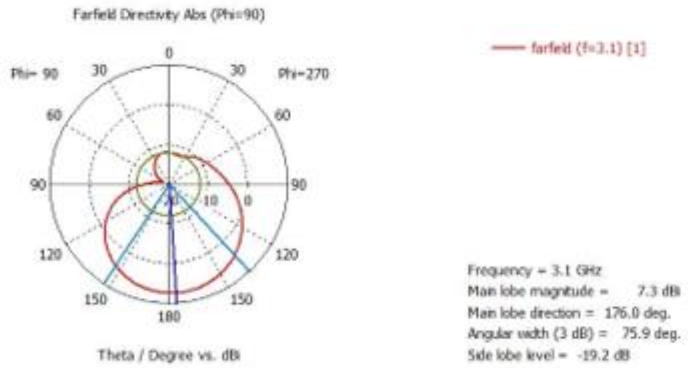
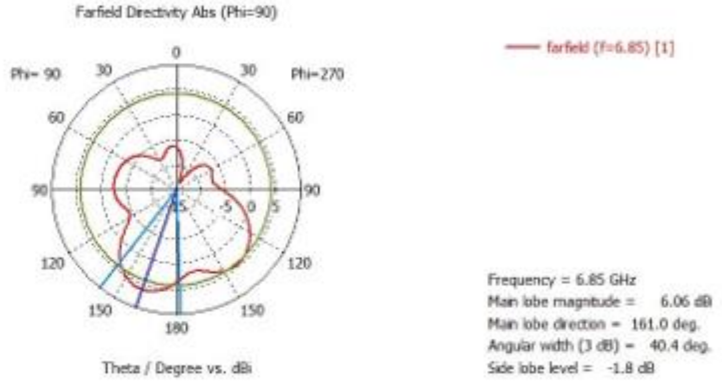


Figure 7.7: VSWR performance of the designed antenna with measurement points

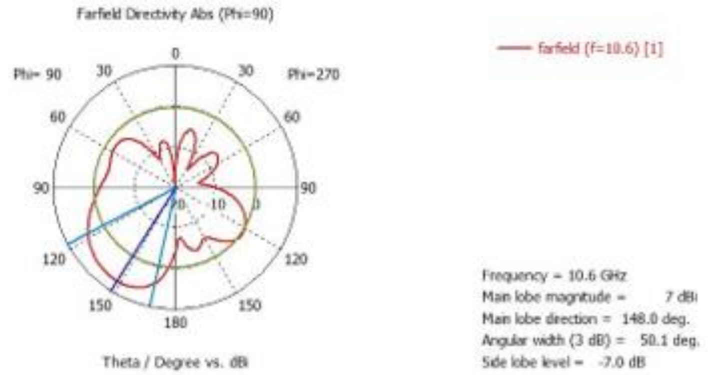
The radiation pattern for designed antenna is shown in Figure 7.8. The designed antenna is operated and analyzed at different frequencies, 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction is 7.3 dBi and 176° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is increased to 6.85 GHz, the magnitude and direction of the main lobe become 6.06 dBi and 161°. When the last operation frequency is at 10.6 GHz, main lobe magnitude and direction are 7dBi and 148°. Moreover, the angular widths (3 dB) of the designed antenna are 75.9°, 40.4° and 50.1°. Side lobe levels are -19.2 dB, -1.8 dB, -7 dB in order of analyzing frequency. Consequently, the radiation pattern is directional. It has narrow band characteristic and not useful for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 7.8: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

8. ULTRA-WIDEBAND MODIFIED RECTANGULAR PATCH MICROSTRIP ANTENNA

According to FCC rules, UWB antennas need to work in the 3.1 GHz and 10.6 GHz frequency interval. Its bandwidth should be 7.5 GHz. The power density is required to be -41.3 dBm/MHz (Molisch, 2009; Vikas et al., 2014). In the previous sections, these conditions are not satisfied with the proposed antennas.

In this section, various microstrip patch antennas are modified and analyzed in UWB frequency range by CST MWS computer program. The aim here is to design antennas which works in the 3.1 GHz - 10.6 GHz frequency interval. Radiation parameters are examined, and the results are compared for the designed antennas.

8.1. Design-1

The propsed antenna is designed by modifying the patch shape of the classical microstrip antenna with rectangular patch shape. The ground layer of the designed antenna consists of Perfect Electric Conductor (PEC), substrate is Taconic TLC-30 and patch and microstrip transmission line are Silver.

8.1.1. Antenna Design and Parameters

UWB modified rectangular patch microstrip antenna is shown in Figure 8.1. It is investigated according to the values given in Table 8.1.

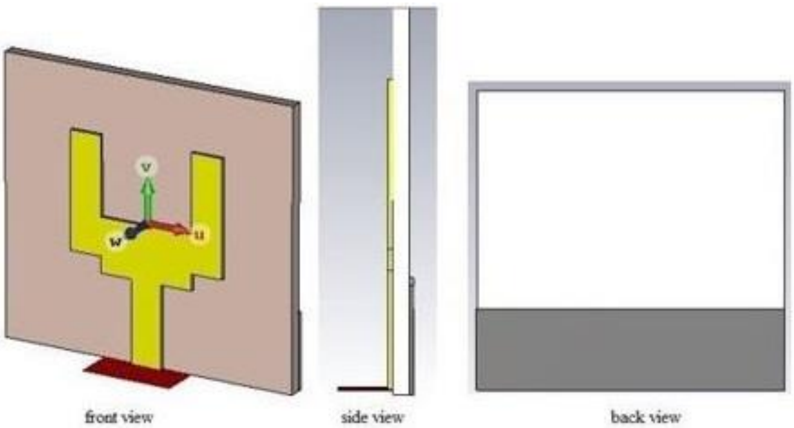


Figure 8.1: Modified Rectangular Patch Antenna for UWB

Table 8.1: Antenna Parameters for Design 8.1

Symbol	Definition	Value	Unit
Ws	Substrate Width	40	mm
Ls	Substrate Lenght	35	mm
Wg	Ground Plane Width	40	mm
Lg	Ground Plane Lenght	9.5	mm
Wp	Patch Width	20	mm
Lp	Patch Lenght	19.5	mm
Wf	Feed Line Width	3.9	mm
Lf	Feed Line Lenght	10.5	mm
ht	Substrate Thickness	1.575	mm
hg	Ground Thickness	0.472	mm
hp	Patch Thickness	0.472	mm
ε_r	Relative Permitivity	3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

8.1.2. Simulation Results

UWB modified rectangular patch microstrip antenna is designed by using different substrate widths as 38, 40 and 42 mm. In Figure 8.2, Return loss for the designed antenna is illustrated according to these different substrate widths. The resonant frequency is 7.375 GHz and return loss is -32.447 dB, -41.664 dB, -47.246 in order of substrate widths 38, 40 and 42 mm. The performance of the antenna is near to UWB conditions.

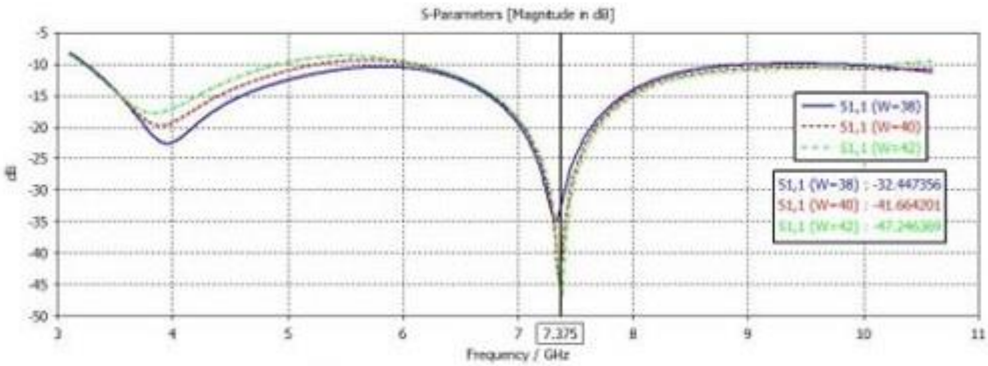


Figure 8.2: Return Loss performance of the designed antenna with measurement points for different substrate widths

The VSWR is shown for different substrate widths in Figure 8.3. The resonance frequency in the graphic is 7.375 GHz and VSWR values are 1.048, 1.016 and 1.008 for 38 mm, 40 mm and 42 mm substrate widths respectively.

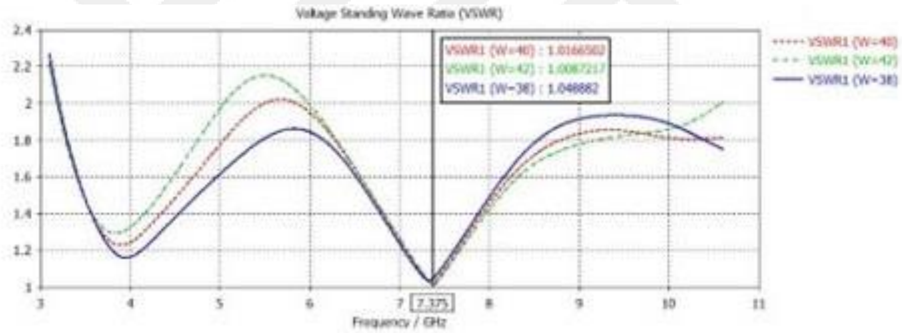
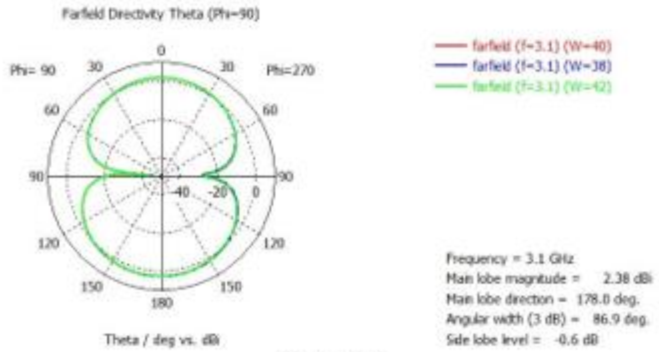
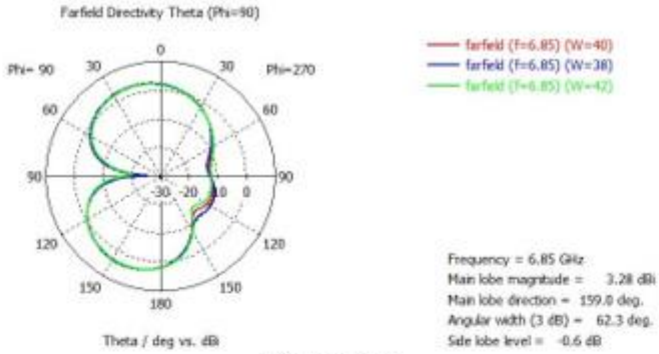


Figure 8.3: VSWR performance of the designed antenna with measurement points for different substrate widths

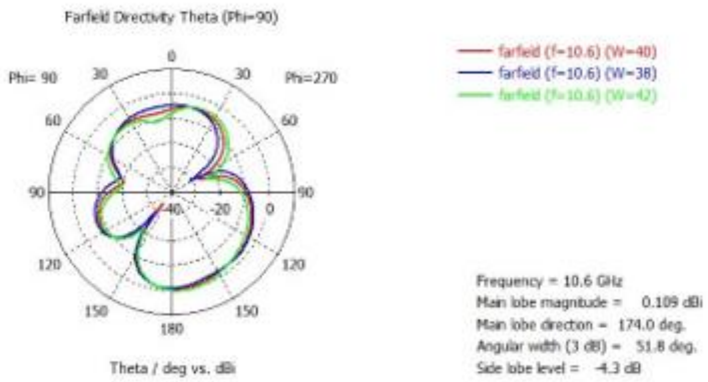
The radiation patterns for designed antenna are shown at different substrate widths in Figure 8.4. The designed antenna is worked and investigated with respect to the different substrate widths in UWB frequency range. The main lobe magnitude and its direction are 2.38 dBi and 178° respectively, when the operation frequency is 3.1 GHz. As the operating frequency at 6.85 GHz, the magnitude and direction of the main lobe are 3.28 dBi and 159°. The last operation frequency at 10.6 GHz, main lobe magnitude and direction are 0.109 dBi and 174°. Moreover, the angular widths (3 dB) of the designed antenna are 86.9°, 62.3° and 51.8° and the side lobe levels are -0.6 dB, -0.6 dB, -4.3 dB in order of analyzing frequency. Consequently, it has directional characteristics while the antenna has almost UWB characteristics.



a) 3.1 GHz



b) 6.85 GHz



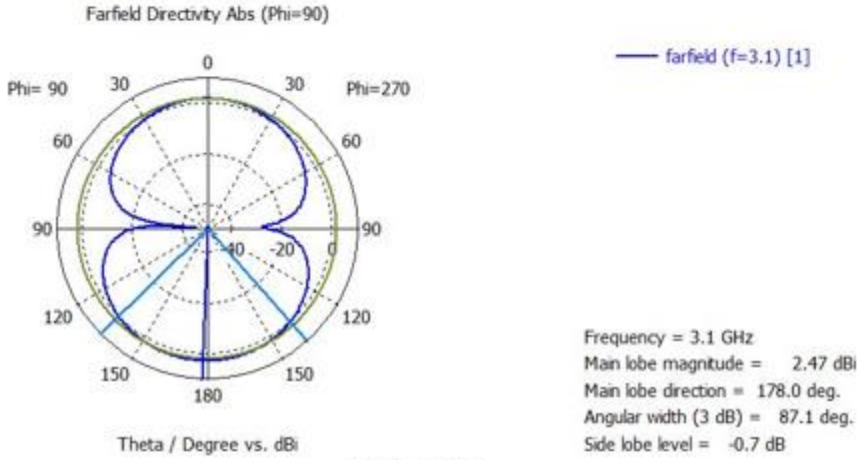
c) 10.6 GHz

Figure 8.4: Radiation Pattern of the designed antenna with respect to different widths and frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

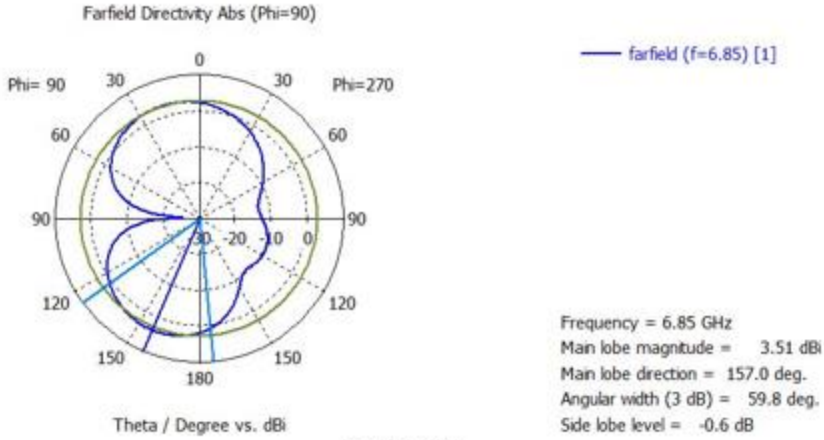
The radiation pattern parameters are nearly same for different substrate widths. Each radiation pattern graphes and their values are given in Figure 8.5, 8.6, 8.7 and Table 8.2 according to the substarte width.

Table 8.2: The Radiation Pattern Parameters for different substrate widths

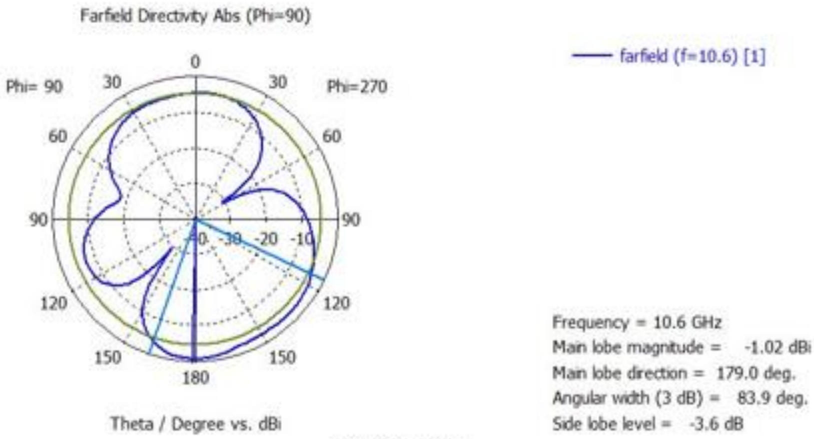
Radiation Pattern Parameters									
Width	38 mm			40 mm			42 mm		
Frequency (GHz)	3.1	6.85	10.6	3.1	6.85	10.6	3.1	6.85	10.6
Main Lobe Magnitude (dBi)	2.47	3.51	-1.02	2.4	3.41	-0.612	2.38	3.28	0.109
Main Lobe Direction	178°	157°	179°	178°	158°	177°	178°	159°	174°
Angular Width (3 dB)	87.1°	59.8°	83.9°	86.9°	60.9°	71°	86.9°	62.3°	51.8°
Side Lobe Level (dB)	-0.7	-0.6	-3.6	-0.6	-0.6	-4.1	-0.6	-0.6	-4.3



a) 3.1 GHz

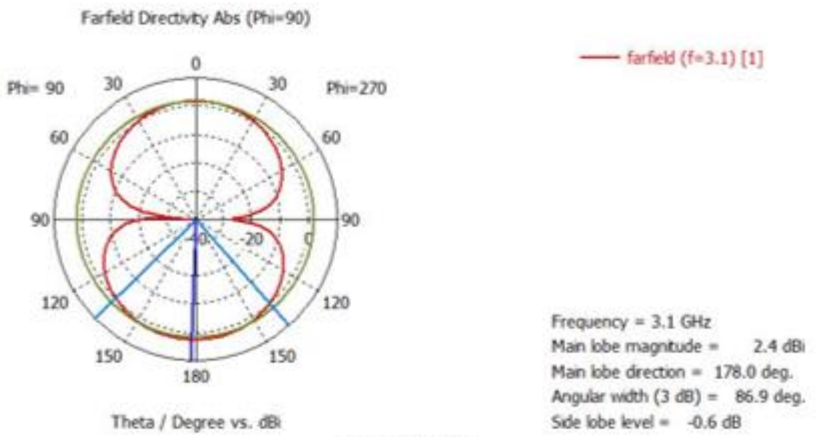


b) 6.85 GHz

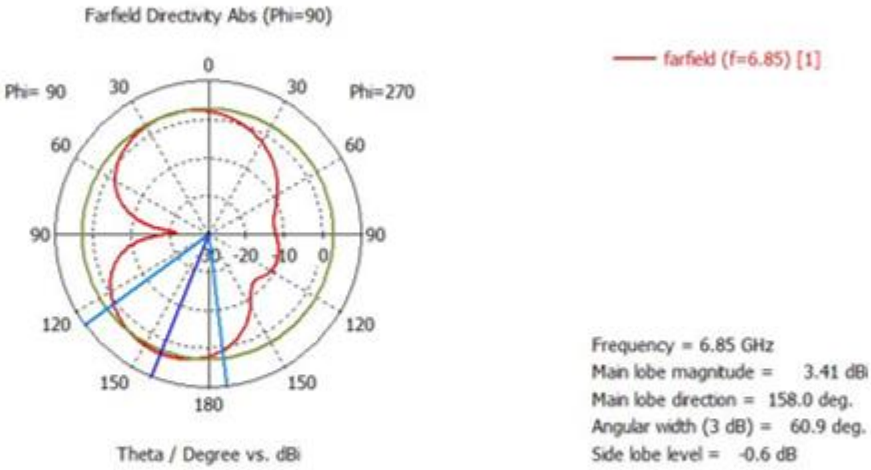


c) 10.6 GHz

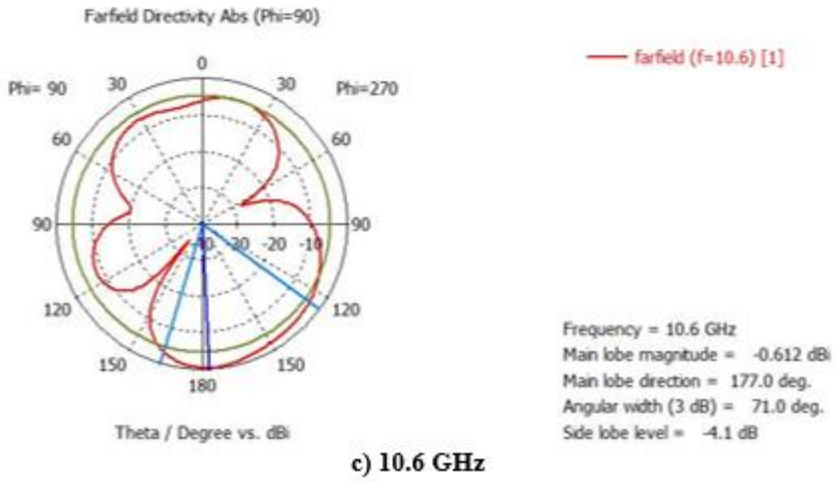
Figure 8.5: Radiation Pattern for substrate width is 38 mm **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz



a) 3.1 GHz

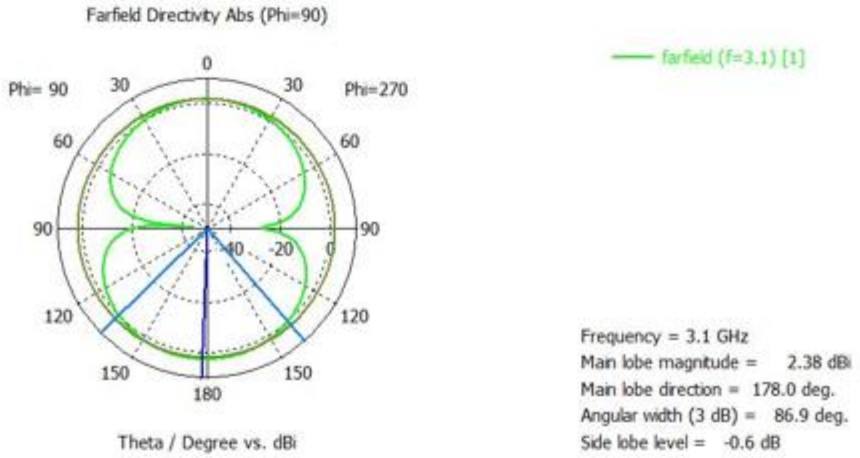


b) 6.85 GHz

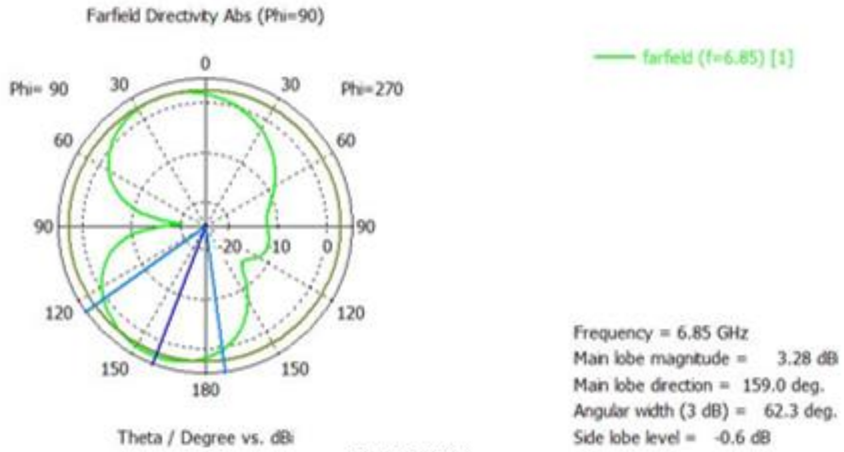


c) 10.6 GHz

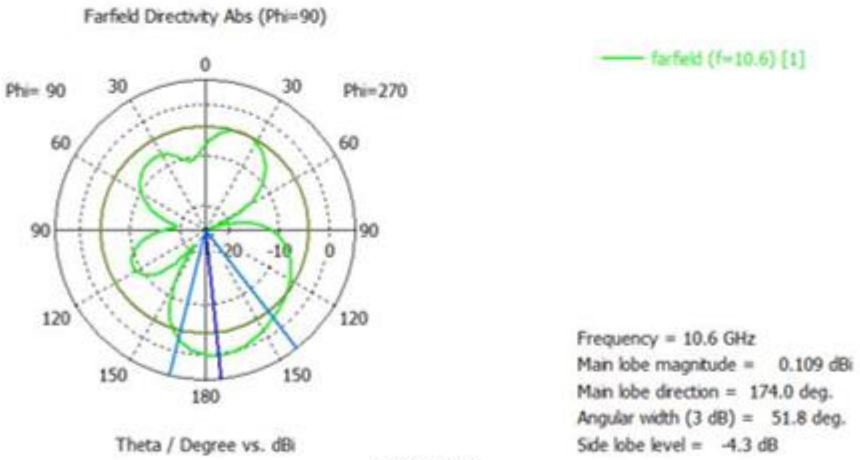
Figure 8.6: Radiation Pattern for substrate width is 40 mm **a)** 3.1 GHz **b)** 6.8 5 GHz **c)** 10.6 GHz



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 8.7: Radiation Pattern for substrate width is 42 mm **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

8.2. Design-2

In this part, the same antenna structure is chosen with 8.1. Design-1 and also the same materials are preferred in the layers such that PEC is ground layer, Taconic TLC-30 is substrate and patch and transmission line are Silver. There are also some differences such as, small notch on the patch and variety of the substrate width.

8.2.1. Antenna Design and Parameters

UWB modified rectangular patch microstrip antenna is plottedin Figure 8.8. It is conceived and analyzed according to the Table 8.3 values.

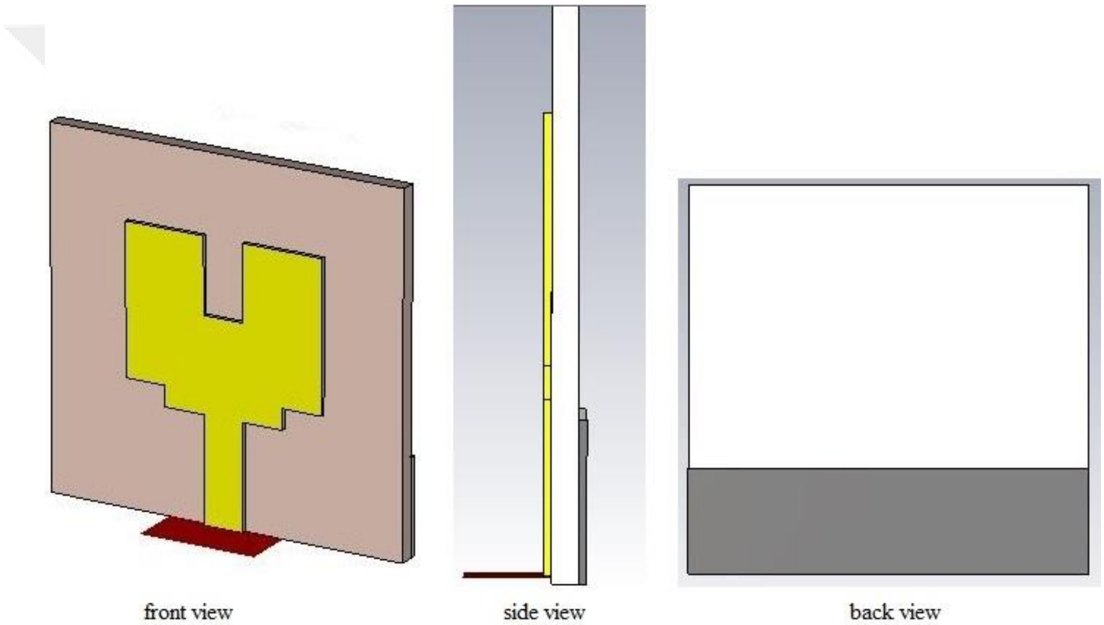


Figure 8.8: Modified Rectangular Patch Microstrip Antenna for UWB

Table 8.3: Antenna Parameters for Design 8.2

Symbol	Definition	Value	Unit
Ws	Substrate Width	40-38-36	mm
Ls	Substrate Lenght	35	mm
Wg	Ground Plane Width	40-38-36	mm
Lg	Ground Plane Lenght	9.5	mm
Wp	Patch Width	20	mm
Lp	Patch Lenght	19.5	mm
Wf	Feed Line Width	3.9	mm
Lf	Feed Line Lenght	10.5	mm
ht	Substrate Thickness	1.575	mm
hg	Ground Thichness	0.472	mm
hp	Patch Thickness	0.472	mm
ε_r	Relative Permitivity	3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

8.2.2. Simulation Results

UWB modified rectangular microstrip antenna is conceived with different substrate widths as 36, 38 and 40 mm. The Return Loss is given at these different substrate widths in Figure 8.9. The resonant frequency for the designed antenna with W = 36 mm is 3.925 GHz and the others have resonance frequencies very near to this value. The return loss values are -31.922 dB, -25.022 dB, and -21.322, respectively for substrate widths of 36, 38 and 40 mm. In all cases, the performance of the antenna is good for UWB applications.

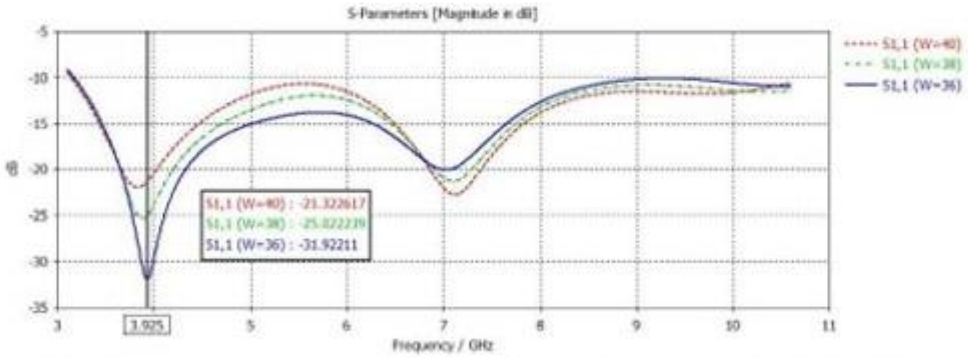


Figure 8.9: Return Loss performance of the designed antenna with measurement points for different substrate width

The VSWR is given for different substrate widths in Figure 8.10. The resonance frequencies in the graph are compatible with resonance frequencies of Return Loss graph in Figure 8.9. VSWR values are 1.052, 1.118 and 1.187.

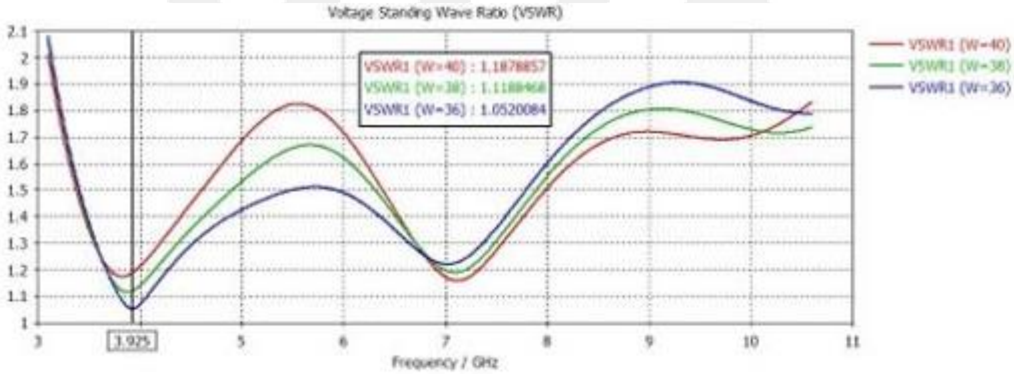


Figure 8.10: VSWR performance of the designed antenna with measurement points for different substrate width

The radiation pattern is determined for different substrate widths in Figure 8.11. The designed antenna is operated and examined with respect to the different substrate widths in UWB frequency range. The main lobe magnitude and its direction is 2.46 dBi and 178° respectively, when the operation frequency is 3.1 GHz. As the operating frequency increases to 6.85 GHz, the magnitude and direction of the main lobe become 2.94 dBi and 156°. When the operation frequency is at 10.6 GHz, these values are -3.56 dBi and 176°, respectively. Furthermore, the angular widths (3 dB) of the designed antenna are 86.9°, 57.7° and 100.6°, respectively. Also, the side lobe levels are -0.7 dB, -0.7 dB, -3.4 dB in order of analyzing frequency. Consequently, this antenna is directional characteristics.

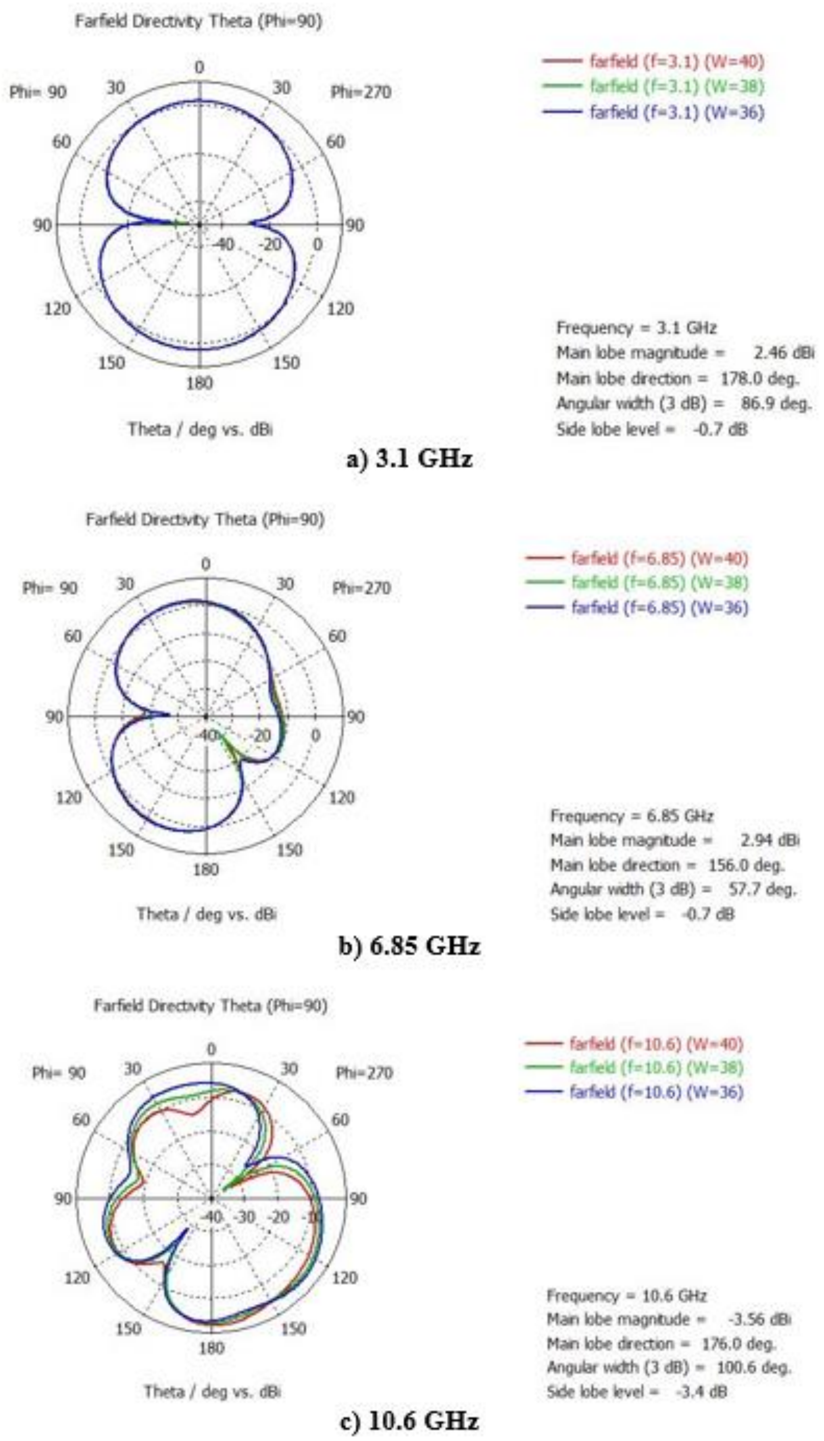
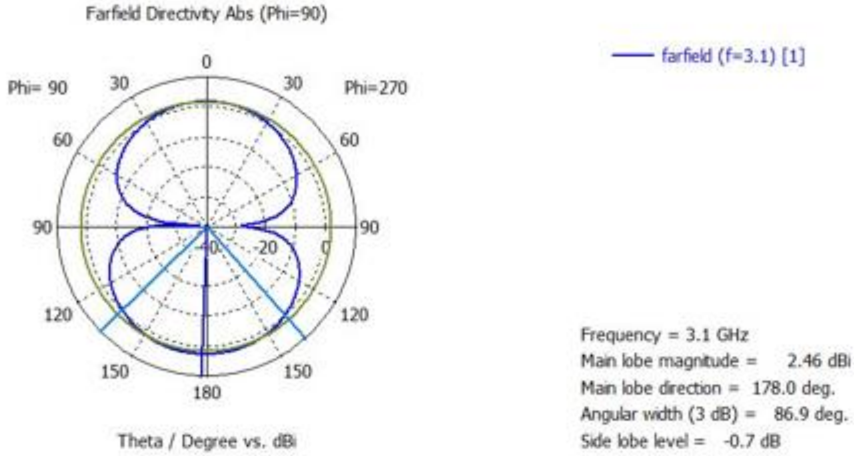


Figure 8.11: Radiation Pattern of the designed antenna with respect to different widths and frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

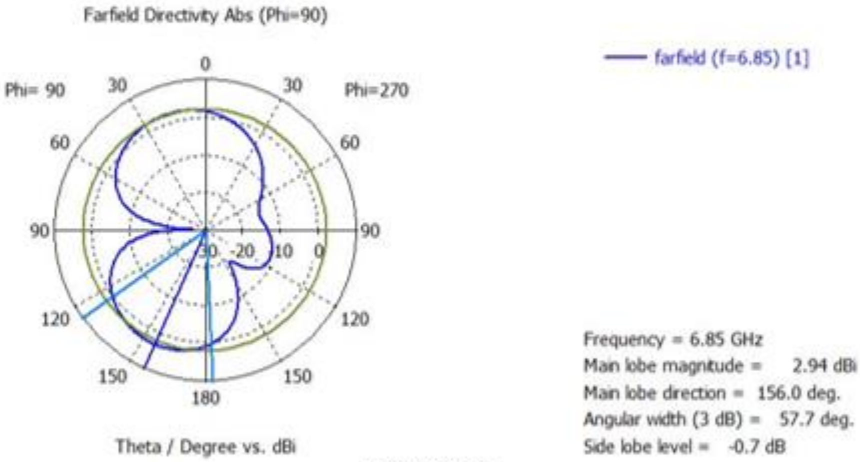
The radiation pattern parameters are nearly the same for different substrate widths. Radiation pattern parameters are given in Table 8.4 and the patterns are shown in Figure 8.12, 8.13, 8.14 according to the substrate width.

Table 8.4: The Radiation Pattern Parameters for different substrate width

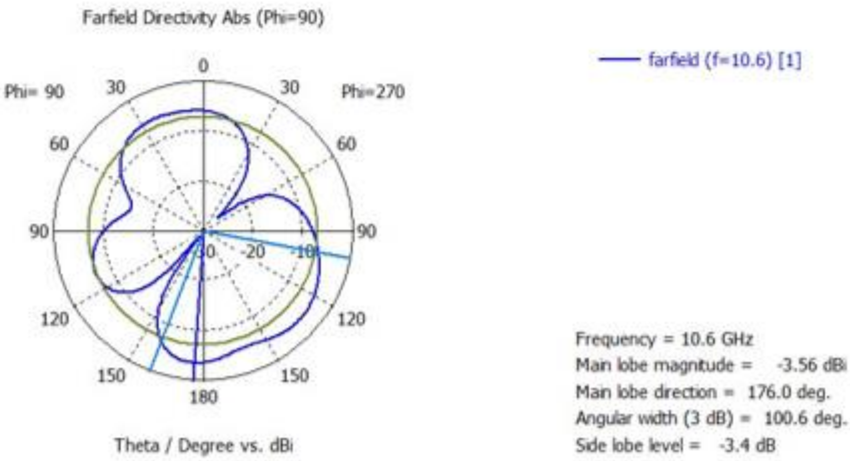
Radiation Pattern Parameters									
Width	36 mm			38 mm			40 mm		
Frequency (GHz)	3.1	6.85	10.6	3.1	6.85	10.6	3.1	6.85	10.6
Main Lobe Magnitude (dBi)	2.46	2.94	-3.56	2.47	2.74	-3.12	2.42	2.6	2.42
Main Lobe Direction	178°	156°	176°	178°	157°	180°	178°	157°	177°
Angular Width (3 dB)	86.9°	57.7°	100.6°	87°	58°	88.2°	87°	59.2°	55.8°
Side Lobe Level (dB)	-0.7	-0.7	-3.4	-0.7	-0.6	-4.5	-0.6	-0.6	-5.1



a) 3.1 GHz

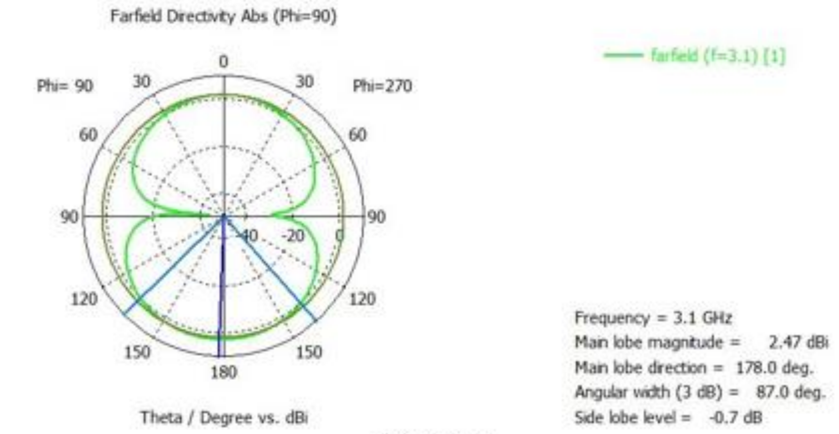


b) 6.85 GHz

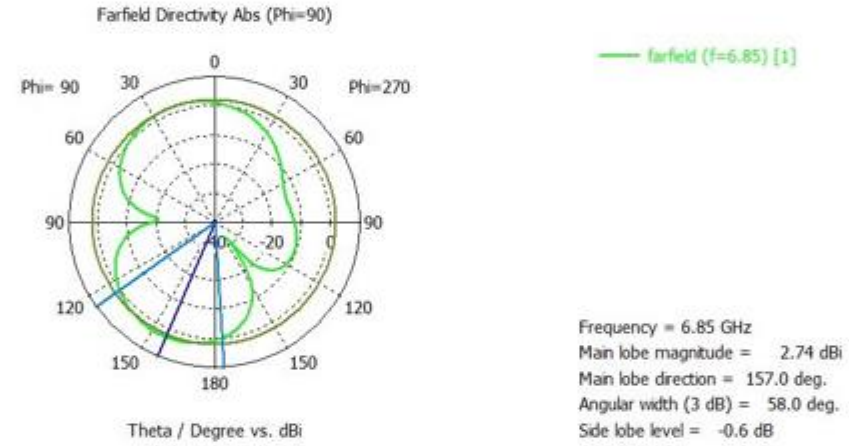


c) 10.6 GHz

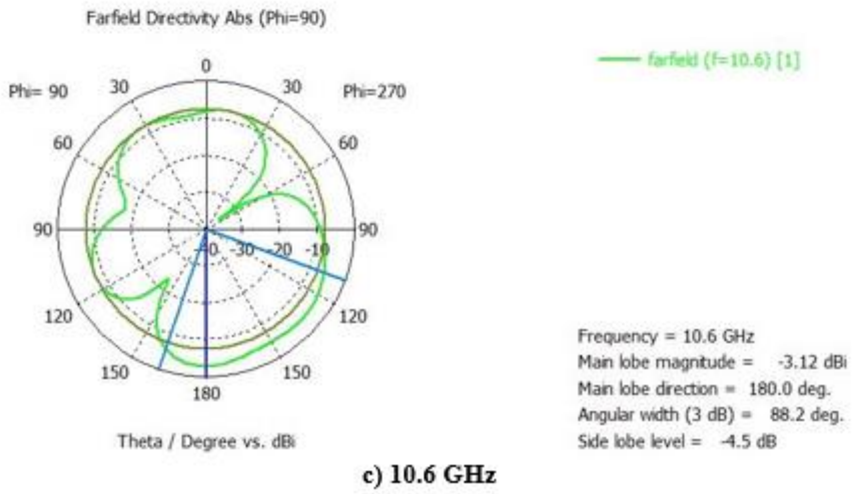
Figure 8.12: Radiation Pattern for substrate width is 36 mm **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6GHz



a) 3.1 GHz

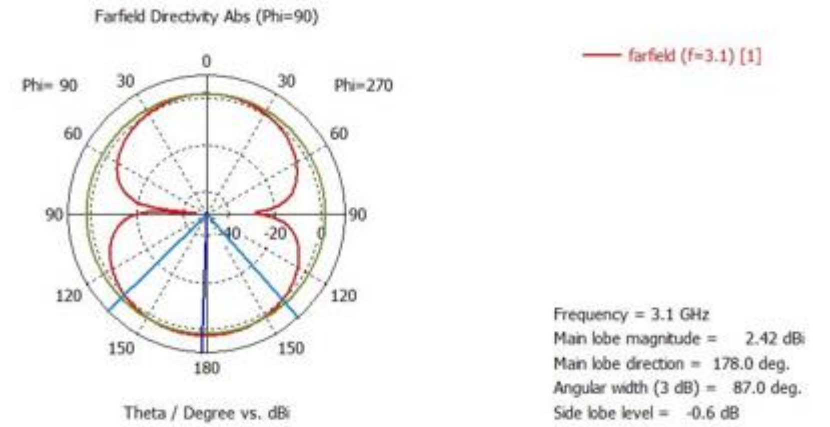


b) 6.85 GHz

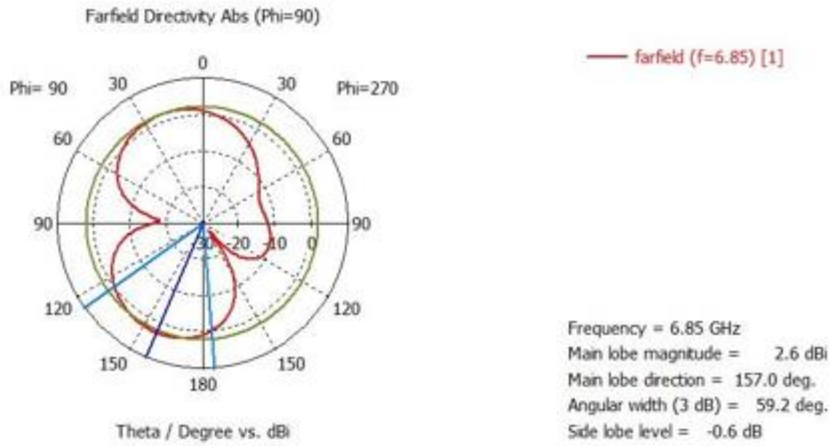


c) 10.6 GHz

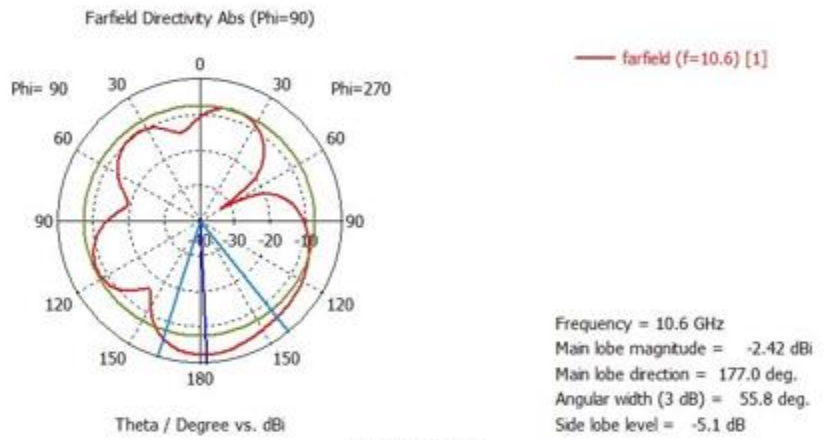
Figure 8.13: Radiation Pattern for substrate width is 38 mm **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6GHz



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 8.14: Radiation Pattern for substrate width is 40 mm **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6GHz

8.3. Design-3

In this section, it is preferred to investigate the same antenna structure as in Design-2. The layers of the designed antenna consist of the same materials. One exception is that the arm widths of the modified patch are made narrower in the designed structure.

8.3.1. Antenna Design and Parameters

UWB modified rectangular patch microstrip antenna is denoted in Figure 8.15. It is conceived and analyzed according to the values given in Table 8.5.

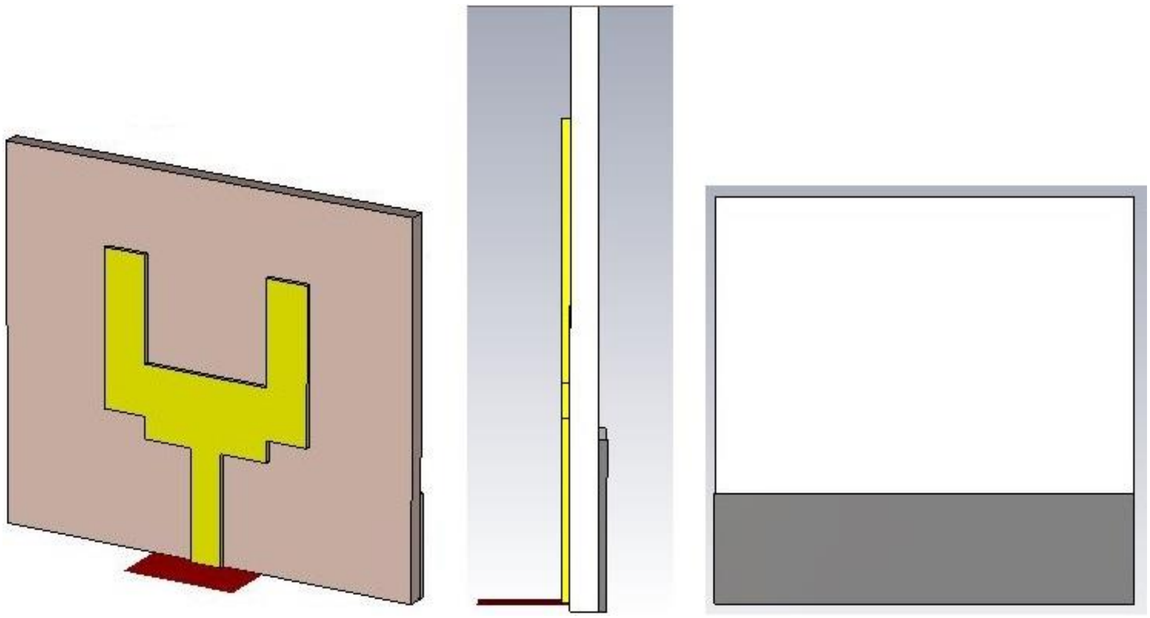


Figure 8.15: Modified Rectangular Patch Microstrip Antenna for UWB

Table 8.5: Antenna Parameters for Design 8.3

Symbol	Definition	Value	Unit
Ws	Substrate Width	40	mm
Ls	Substrate Lenght	35	mm
Wg	Ground Plane Width	40	mm
Lg	Ground Plane Lenght	9.5	mm
Wp	Patch Width	20	mm
Lp	Patch Lenght	19.5	mm
Wf	Feed Line Width	3.9	mm
Lf	Feed Line Lenght	10.5	mm
ht	Substrate Thickness	1.575	mm
hg	Ground Thickness	0.472	mm
hp	Patch Thickness	0.472	mm
ε_r	Relative Permitivity	3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

8.3.2. Simulation Results

The conceived antenna is examined for the range 3.1 GHz - 10.6 GHz in the UWB frequency interval. Its Return Loss, VSWR and Radiation Pattern characterictics are shown in Figure 8.16, 8.17 and 8.18.

The resonant frequency is 7.537 GHz while the return loss is -34.225 dB in Figure 8.16. To sum up, the bandwidth is wide enough to be used for UWB applications.

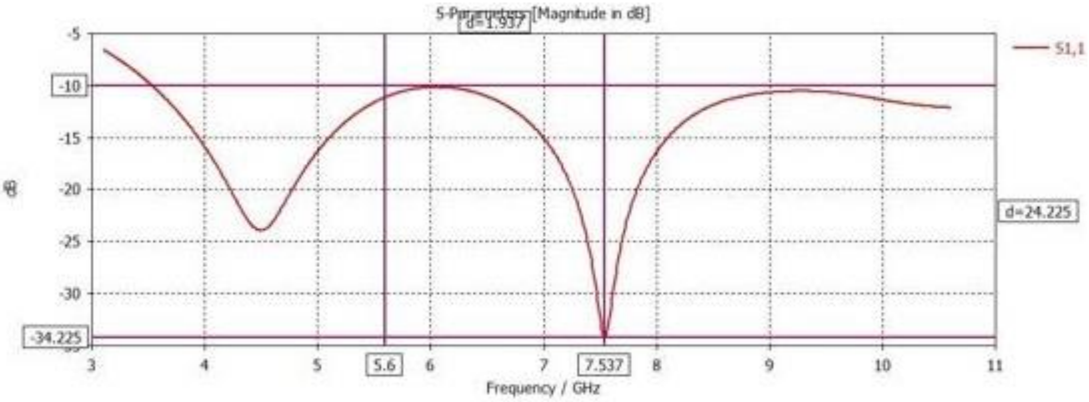


Figure 8.16: Return Loss performance of the designed antenna

The VSWR is shown in Figure 8.17. The resonance frequency in the graph is 7.54 GHz and its VSWR value is 1.0396.

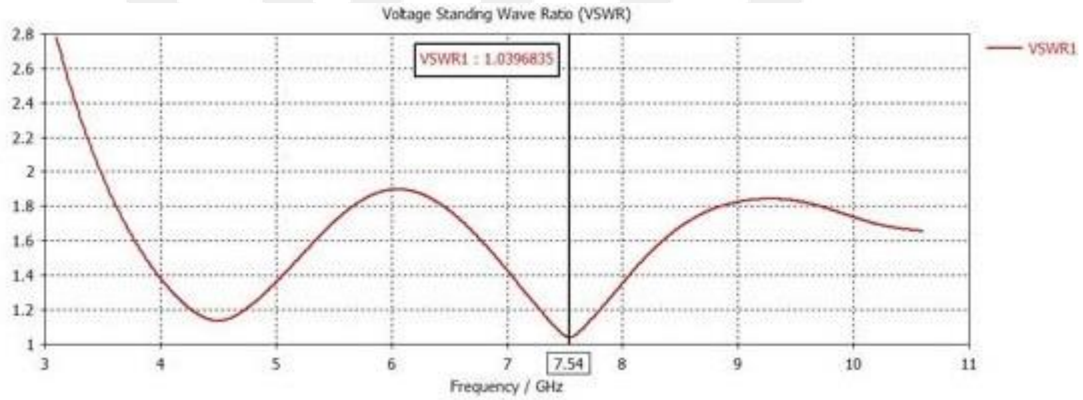
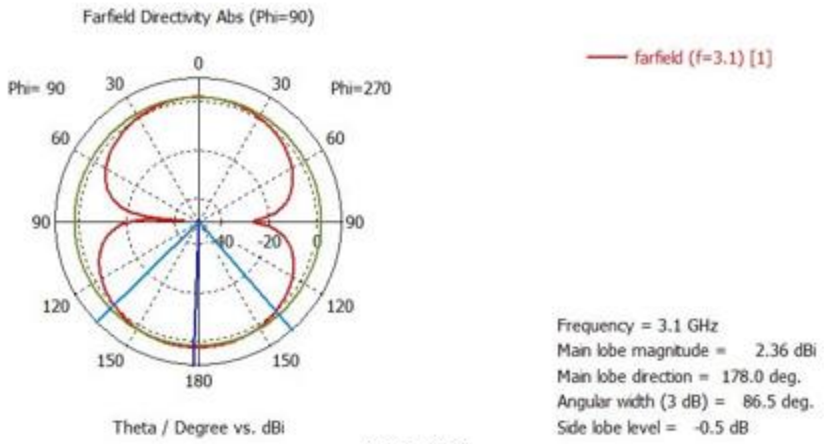
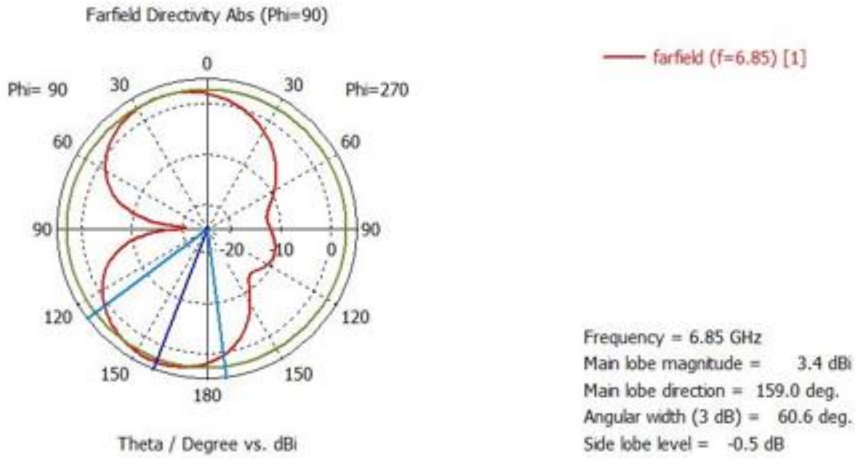


Figure 8.17: VSWR performance of the designed antenna with measurement points

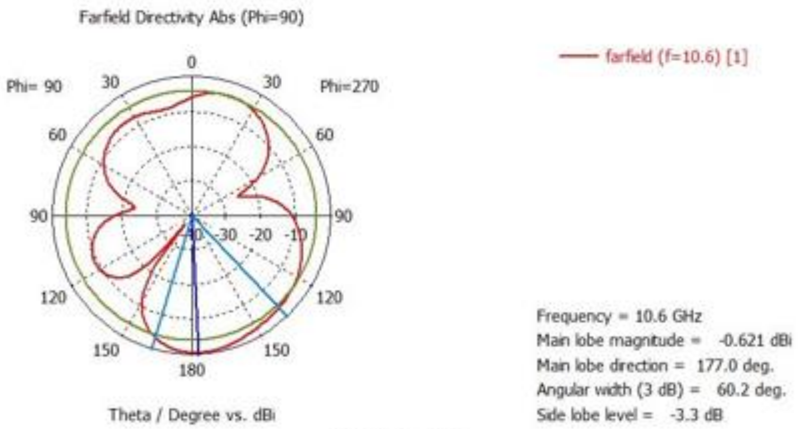
The radiation pattern is denoted in Figure 8.18. It is operated and analyzed at different frequencies for 3.1 GHz, 6.85 GHz and 10.6 GHz with ϕ=90°. The main lobe magnitude and its direction are 2.36 dBi and 178° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is increased to 6.85 GHz, the magnitude and direction of the main lobe are 3.4 dBi and 159°. The last operation frequency is at 10.6 GHz, and main lobe magnitude and direction are -0.621 dBi and 177°. Moreover, the angular widths (3 dB) of the designed antenna are 86.5°, 60.6° and 60.2° and side lobe levels are -0.5 dB, -0.5 dB, -3.3 dB in order of analyzing frequency. Consequently, the radiation pattern of the designed antenna has directional characteristic and ultra wide bandwidth. Thus, it is useful for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 8.18: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

9. ULTRA-WIDEBAND MODIFIED CIRCULAR PATCH MICROSTRIP ANTENNA

In this chapter, UWB circular microstrip patch antennas are configured and investigated in UWB frequency range by CST MWS computer program and their results are compared.

9.1. Design-1

The antenna structure has three layers which are overlapped on each other. The materials of the designed antenna are preferred as copper for both ground plane and circular patch. The substrates are Rogers RT 5880 and FR-4. The material of the transmission line is nickel which is connected between circular patch and feeding port.

9.1.1. Antenna Design and Parameters

The UWB modified circular microstrip antenna is shown in Figure 9.1. It is conceived and analyzed according to the values given in Table 9.1.

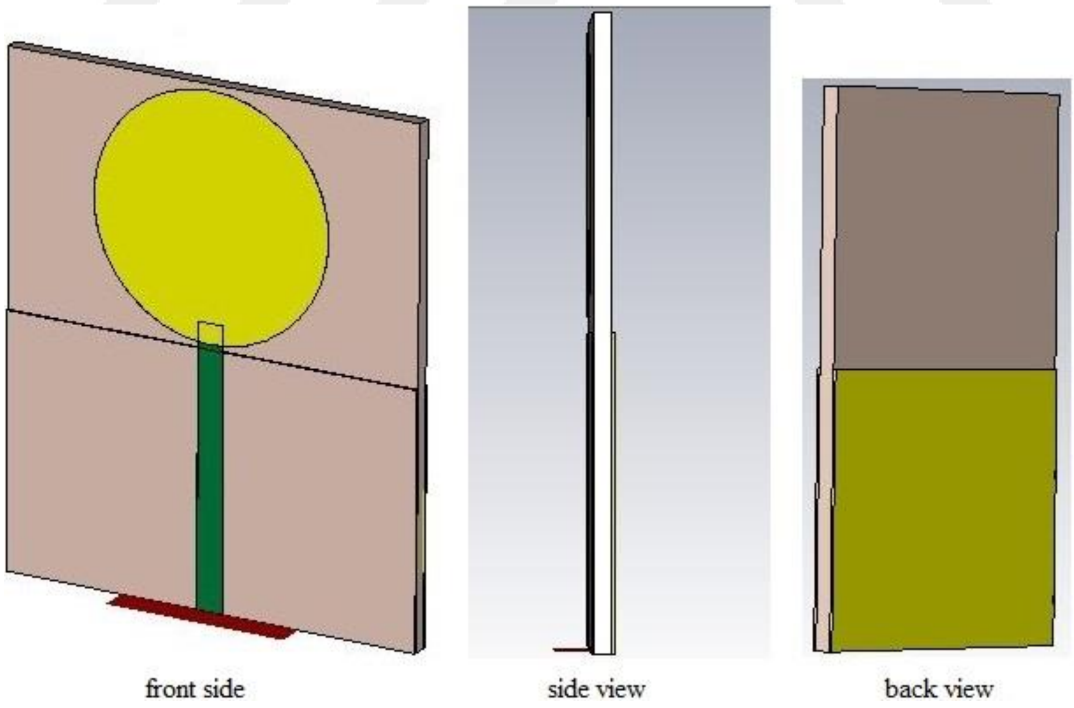


Figure 9.1: Circular Patch Microstrip Antenna

Table 9.1: Antenna Parameters for Design 9.1

Symbol	Definition	Value	Unit
Ws	Substrate Width	42	mm
Ls	Substrate Lenght	50	mm
Wg	Ground Plane Width	42	mm
Lg	Ground Plane Lenght	25	mm
a	Radius	12	mm
Wf	Feed Line Width	2.6	mm
Lf	Feed Line Lenght	27.5	mm
hs	Substrate Thickness	1.4	mm
hg	Ground Thichness	0.2	mm
hp	Patch Thickness	0.035	mm
ε_r	Relative Permitivity	4.4	-
ε_r	Relative Permitivity	2.2	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

9.1.2. Simulation Results

The designed antenna is examined in the UWB frequency interval and its Return Loss, VSWR and Radiation Pattern characterictics are given in Figures 9.2, 9.3 and 9.4.

The resonant frequency is 4.6465 GHz and return loss is -26.07 dB in Figure 9.2. Since Return Loss is below -10 dB throughout the interval of 3.1 GHz and 10.6 GHz, it clearly satisfies the bandwidth requirement specified by FCC rules. To sum up, the bandwidth of the designed antenna is suitable for UWB applications.

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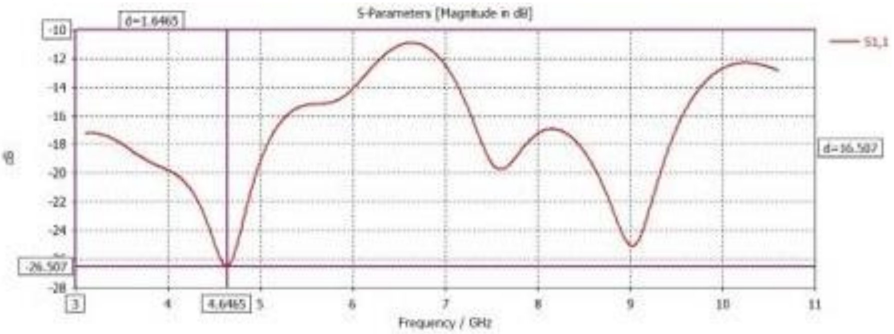


Figure 9.2: Return Loss performance of the designed antenna with measurement points

The VSWR performance of the antenna is explained in Figure 9.3. The minumum resonance frequency in the graph is 4.6375 GHz and its VSWR value is 1.0992. Similarly, VSWR is smaller than 2 throughout the 3.1 GHz - 10.6 GHz UWB frequency interval. Thus, this graph also satisfies the requirement specified by FCC rules for UWB systems.

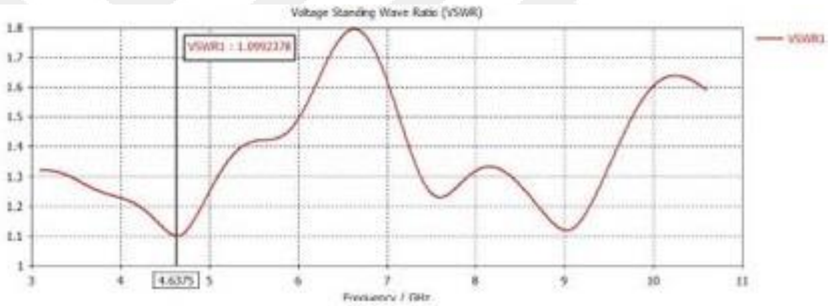
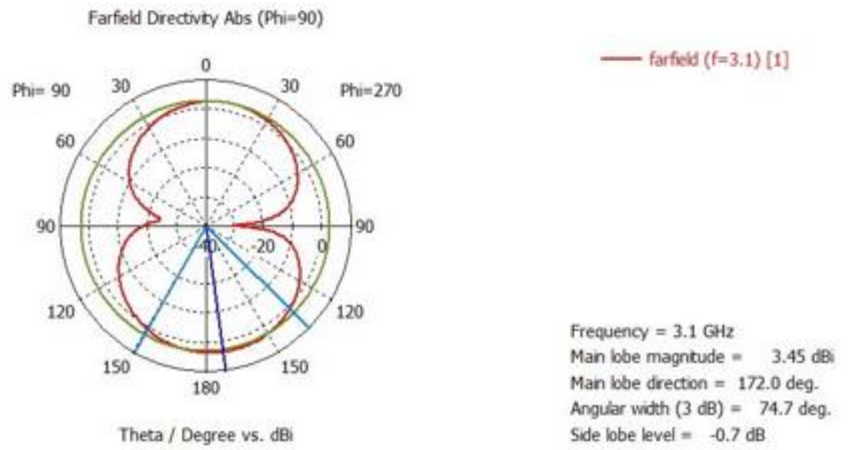
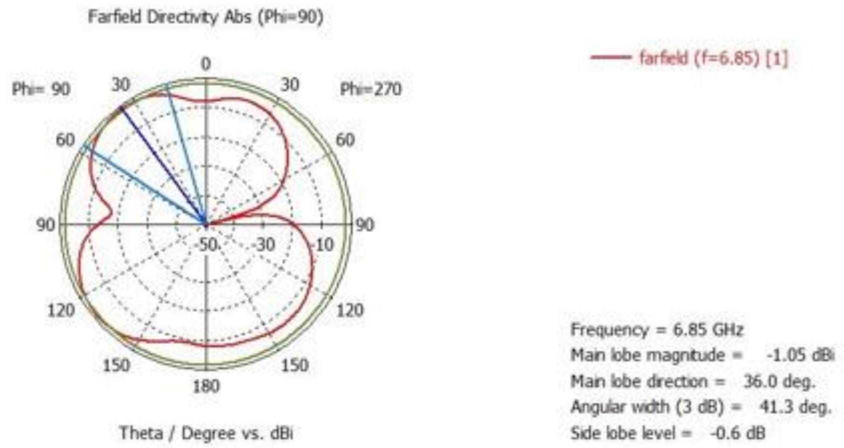


Figure 9.3: VSWR performance of the designed antenna with measurement points

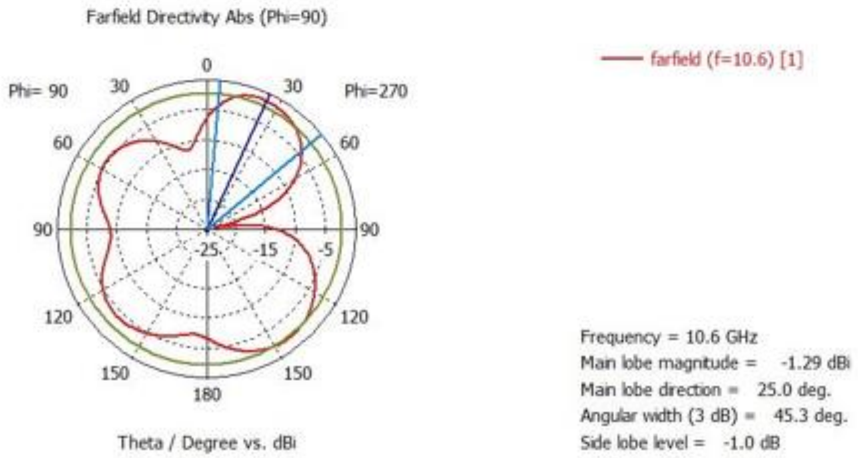
The radiation pattern is explained in Figure 9.4. The designed antenna is operated and investigated at different frequencies, 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction are 3.45 dBi and 172° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is at 6.85 GHz, the magnitude and direction of the main lobe are -1.05 dBi and 36°. The last operation frequency is at 10.6 GHz, and main lobe magnitude and direction are -1.29 dBi and 25°. Besides, the angular widths (3 dB) of the designed antenna are 74.7°, 41.3° and 45.3°, respectively. As the frequency increases, more lobes start to appear. The side lobe levels are -0.7 dB, -0.6 dB, -1 dB in order of analyzing frequency. Consequently, the radiation pattern acts directional characteristics. Thus, this designed antenna is applicable for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 9.4: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

9.2. Design-2

The antenna structure is the same with Design-1 in Section 9.1. On the other hand, Taconic CER-10 is choosen instead of Rogers RT 5880 as the substrate material of the designed antenna.

9.2.1. Antenna Design and Parameters

The UWB modified circular patch microstrip antenna is given in Figure 9.5. It is plotted and examined according to the values given in Table 9.2.

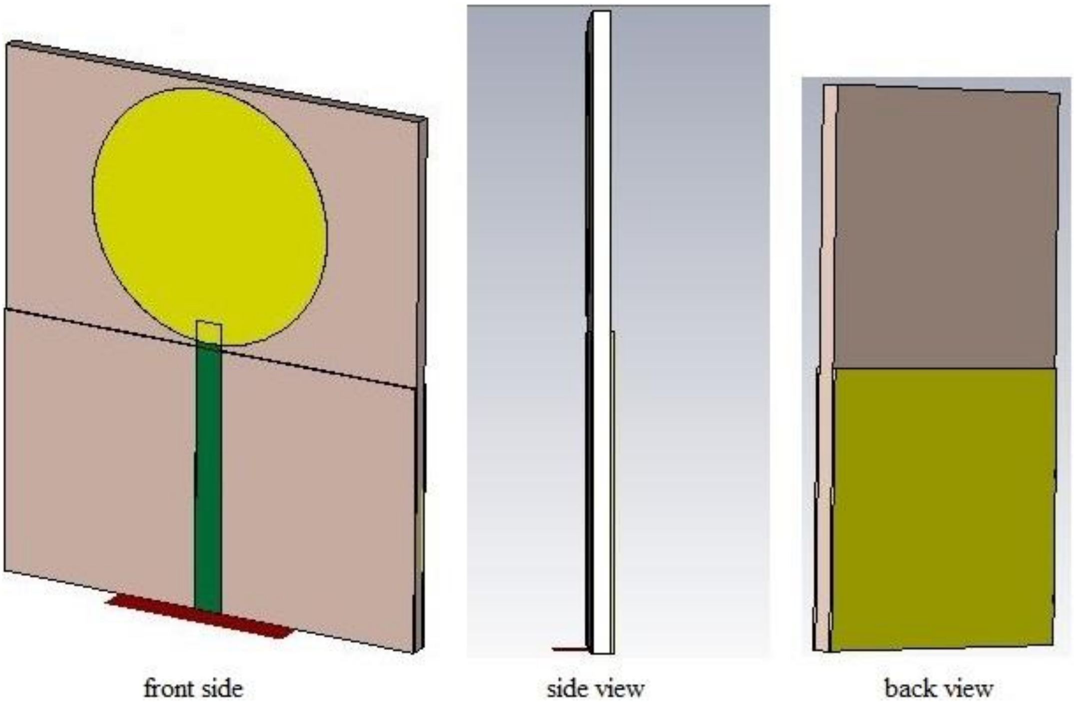


Figure 9.5: Modified Circular Patch Microstrip Antenna

Table 9.2: Antenna Parameters for Design 9.2

Symbol	Definition	Value	Unit
Ws	Substrate Width	42	mm
Ls	Substrate Lenght	50	mm
Wg	Ground Plane Width	42	mm
Lg	Ground Plane Lenght	25	mm
a	Radius	12	mm
Wf	Feed Line Width	2.6	mm
Lf	Feed Line Lenght	27.5	mm
hs	Substrate Thickness	1.4	mm
hg	Ground Thichness	0.2	mm
hp	Patch Thickness	0.035	mm
ε_r	Relative Permitivity	4.4	-
ε_r	Relative Permitivity	10	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

9.2.2. Simulation Results

The designed antenna is examined in UWB frequency interval and its Return Loss, VSWR and Radiation Pattern characterictics are denoted in Figures 9.6, 9.7 and 9.8.

The resonant frequency is 8.2453 GHz and return loss is -31.854 dB in Figure 9.6. It is clearly seen in the figure that; Return Loss is below -10 dB throughout the 3.1 GHz – 10.6 GHz UWB frequency range. As a result, the bandwidth of the conceived antenna is convenient to use for UWB applications.

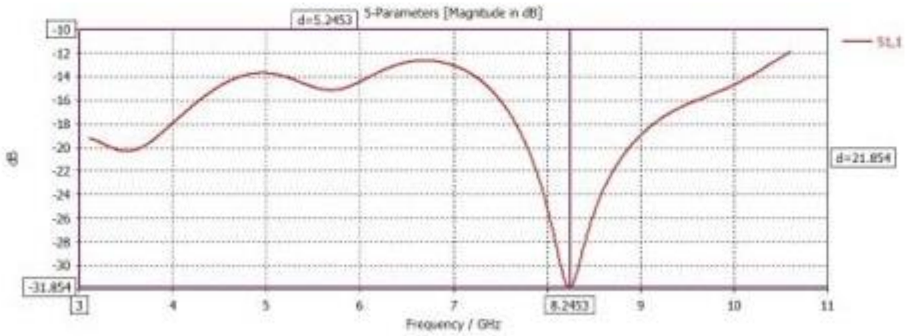


Figure 9.6: Return Loss performance of the designed antenna with measurement points

The VSWR is shown in Figure 9.7. The minumum resonance frequency in the graph is 8.2375 GHz and its VSWR value is 1.0523. It is seen from the figure that, VSWR is below 2 throughout the interval from 3.1 GHz to 10.6 GHz. Therefore, VSWR graph satisfies the conditions specified by FCC rules for UWB systems.

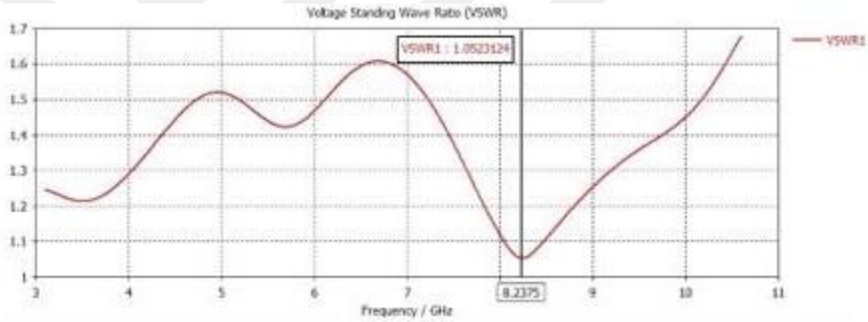
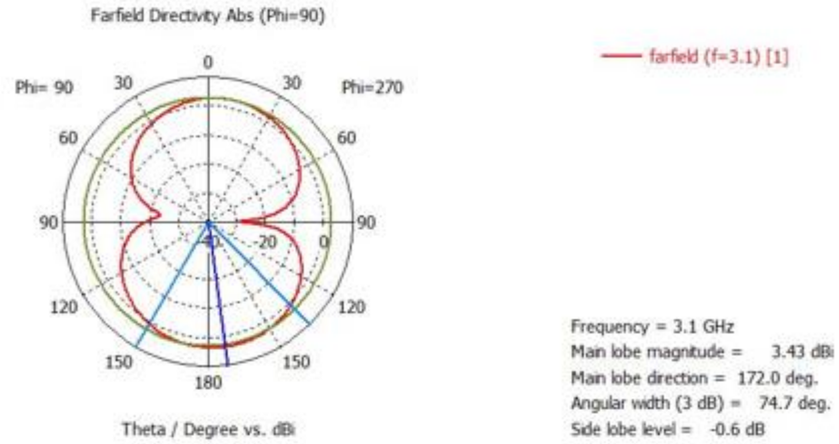
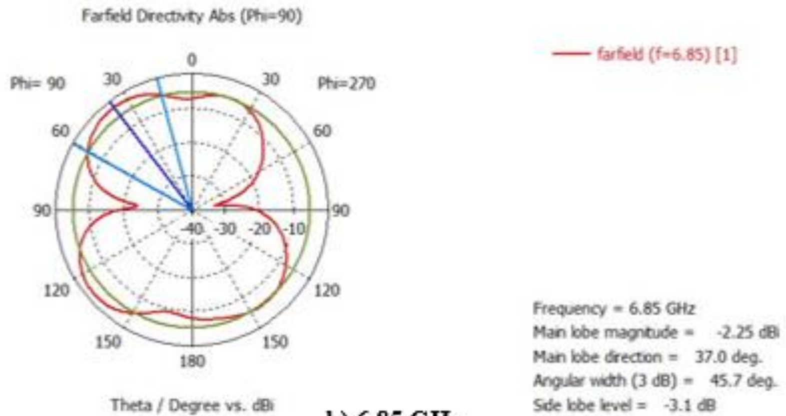


Figure 9.7: VSWR performance of the designed antenna with measurement points

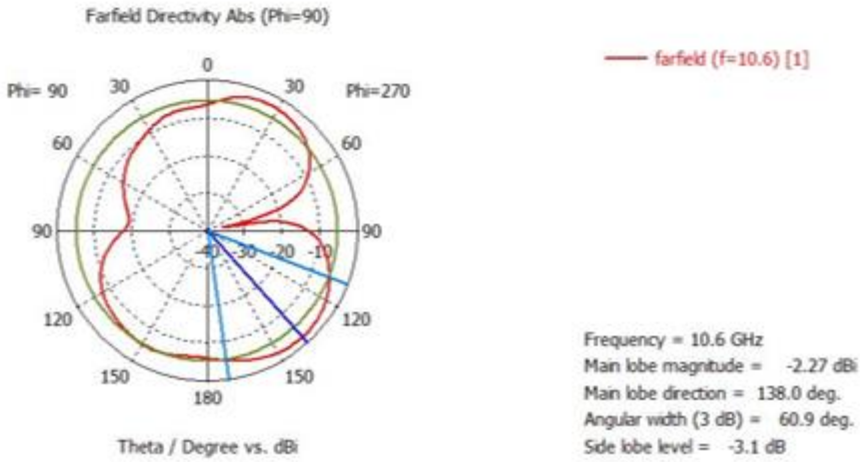
The radiation pattern for designed antenna is given in Figure 9.8. The designed antenna is operated and investigated at three frequencies of 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction are 3.43 dBi and 172° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is at 6.85 GHz, the magnitude and direction of the main lobe are -2.25 dBi and 37°. The last operation frequency is at 10.6 GHz. In that case, main lobe magnitude and direction are -2.27 dBi and 138°. On the other hand, the angular widths (3 dB) of the designed antenna are 74.7°, 45.7° and 60.9°. Besides, the side lobe levels are -0.6 dB, -3.1 dB, -3.1 dB in order of analyzing frequency. In conclusion, the radiation pattern is directional characteristic. Hence, this designed antenna is perfect to be used for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 9.8: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

9.3. Design-3

The antenna configuration is similar to Design-1 in Section 9.1. However, Glass Prex is preferred instead of Taconic CER-10.

9.3.1. Antenna Design and Parameters

The UWB modified circular microstrip antenna is denoted in Figure 9.9. This patch antenna is designed and analyzed according to the values given in Table 9.3.

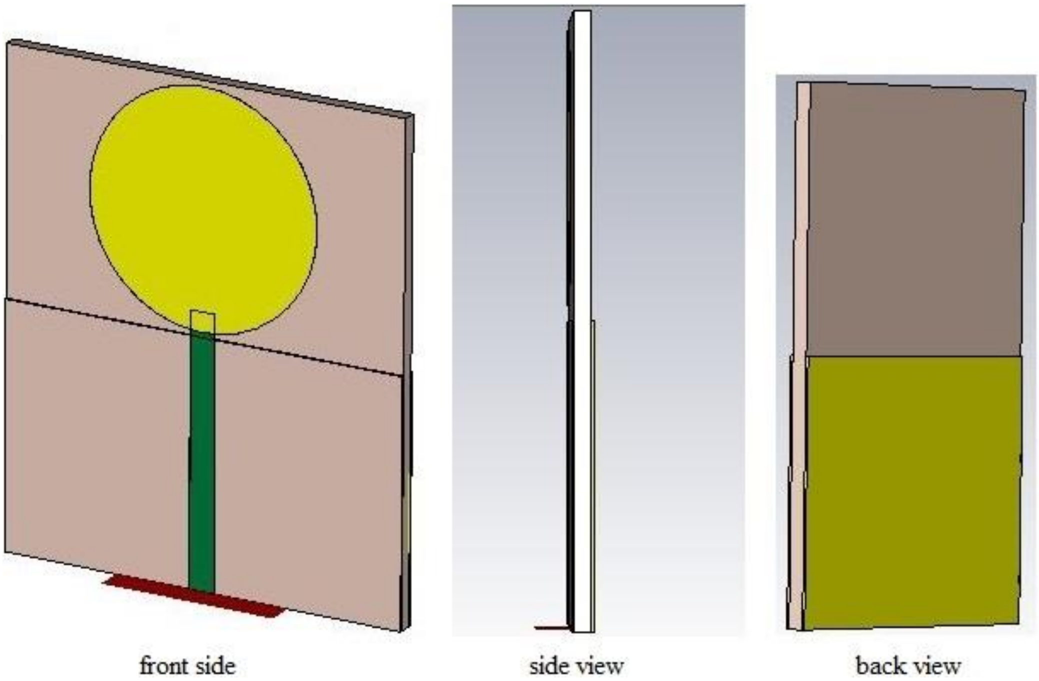


Figure 9.9: Modified Circular Patch Microstrip Antenna for UWB

Table 9.3: Antenna Parameters for Design 9.3

Symbol	Definition	Value	Unit
Ws	Substrate Width	42	mm
Ls	Substrate Lenght	50	mm
Wg	Ground Plane Width	42	mm
Lg	Ground Plane Lenght	25	mm
a	Radius	12	mm
Wf	Feed Line Width	2.6	mm
Lf	Feed Line Lenght	27.5	mm
hs	Substrate Thickness	1.4	mm
hg	Ground Thickness	0.2	mm
hp	Patch Thickness	0.035	mm
ε_r	Relative Permitivity	4.4	-
ε_r	Relative Permitivity	4.82	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

9.3.2. Simulation Results

The designed antenna is examined in the UWB frequency interval and its Return Loss, VSWR and Radiation Pattern characterictics are illustrated in Figure 9.10, 9.11 and 9.12.

The resonant frequency is 8.4905 GHz and return loss is -28.406 dB in Figure 9.10. According to the figure, Return Loss is below -10 dB throughout the whole 3.1 GHz – 10.6 GHz UWB frequency interval. Then, according to this -10 dB bandwidth characteristic, the designed antenna is quite appropriate to be used for UWB applications.

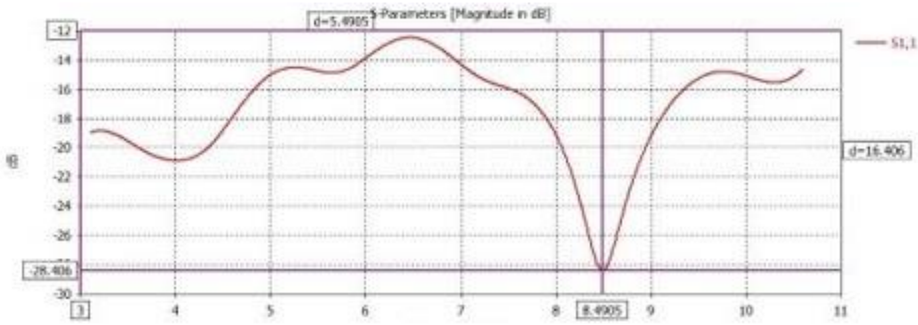


Figure 9.10: Return Loss performance of the designed antenna

The VSWR is shown in Figure 9.11. The minumum resonance frequency in the graph is 8.4925 GHz and its VSWR value is 1.0789. As seen seen from the figure, VSWR is below 2 throughout the interval from 3.1 GHz to 10.6 GHz. Therefore, this VSWR graph also satisfies the conditions regulated by FCC rules for UWB systems.

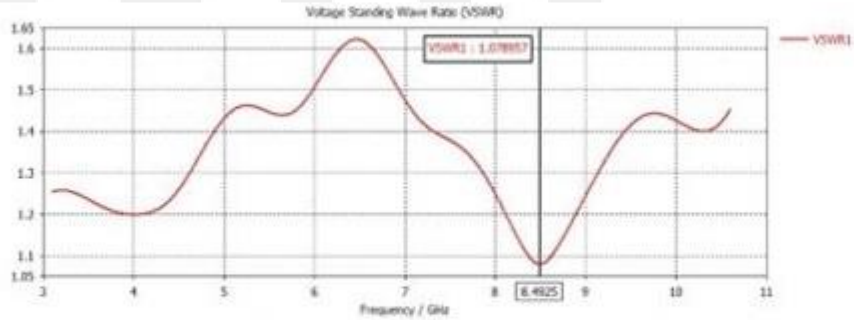
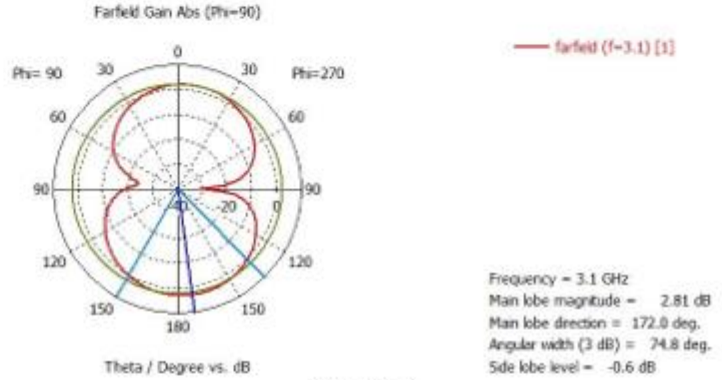
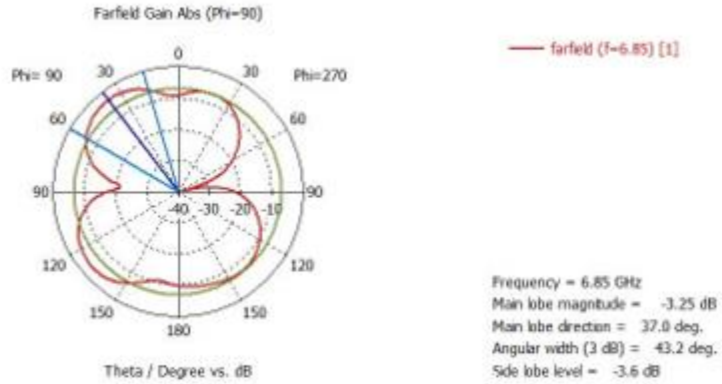


Figure 9.11: VSWR performance of the designed antenna

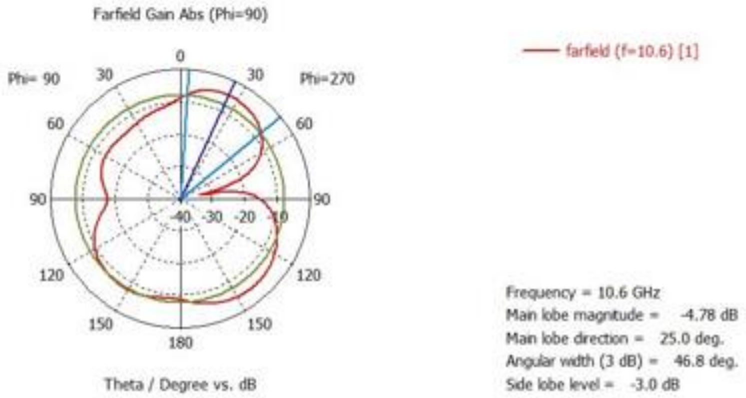
The radiation pattern is given in Figure 9.12. The designed antenna is operated and investigated at different frequencies 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and main lobe direction are 2.81 dBi and 172° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is at 6.85 GHz, the magnitude and direction of the main lobe are obtained as -3.25 dBi and 37°, respectively. When the operation frequency is at 10.6 GHz, main lobe magnitude and direction are -4.78 dBi and 25°, respectively. On the other hand, the angular widths (3 dB) of the designed antenna are 74.8°, 43.2° and 46.8°, in order. The side lobe levels are -0.6 dB, -3.6 dB, -3 dB in order of analyzing frequency. As the frequency increases, the pattern becomes more irregular. As a result, it behaves directional characteristics and ultra wide bandwidth. So, this designed antenna is also preferable for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 9.12: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

10.ARRAYS OF RECTANGULAR PATCH MICROSTRIP ANTENNA

In this section, array form of rectangular microstrip patch antennas are designed and analysed in UWB frequency range by CST MWS computer program. Return Loss, VSWR and radiation pattern are examined in the 3.1 GHz - 10.6 GHz frequency interval and analysis results are compared.

10.1. Design-1

The antenna array structure consists of four rectangular patch antennas which are related to each other by microstrip transmission line. The materials of the designed antenna array are preferred as PEC for ground plane and Taconic TLC-30 for substrate. The rectangular patch and transmission line are choosen as silver.

10.1.1. Antenna Design and Parameters

The array of modified rectangular patch microstrip antennas is determined in Figure 10.1. It is conceived and examined according to the values listed in Table 10.1.

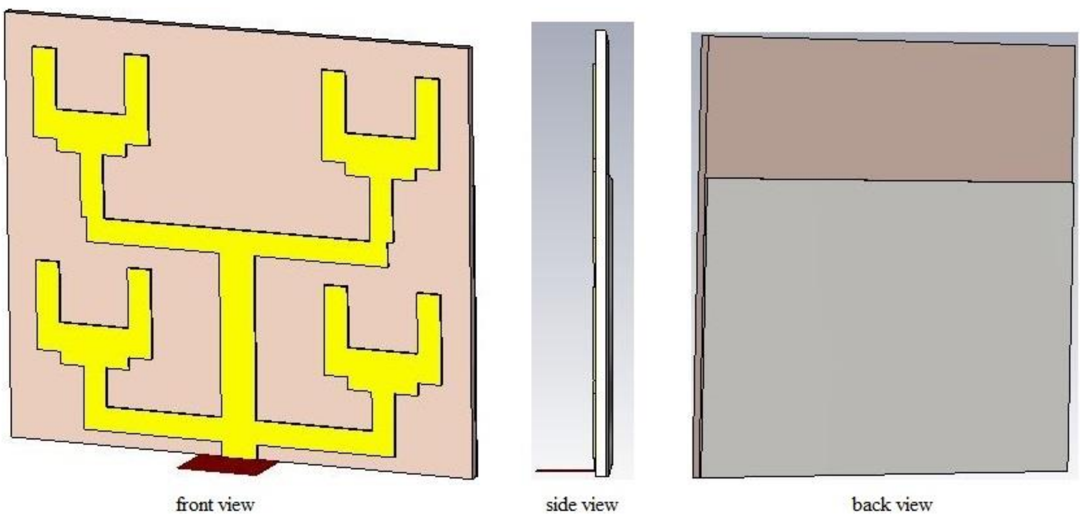


Figure 10.1: Array of Modified Rectangular Patch Microstrip Antennas

Table 10.1: Antenna Parameters for Design 10.1

Symbol	Definition	Value	Unit
Ws	Substrate Width	80	mm
Ls	Substrate Lenght	70	mm
Wg	Ground Plane Width	80	mm
Lg	Ground Plane Lenght	42.5	mm
Wp	Patch Width	20	mm
Lp	Patch Lenght	19.5	mm
ht	Substrate Thickness	1.575	mm
hg	Ground Thichness	0.472	mm
hp	Patch Thickness	0.472	mm
ε_r	Relative Permitivity	3	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

10.1.2. Simulation Results

The modified rectangular patches are used for the array antenna design. This is run in the UWB frequency range and its Return Loss, VSWR and Radiation Pattern characterictics are investigated in Figure 10.2, 10.3 and 10.4.

The resonant frequency is 6.9893 GHz and return loss parameter is -43.092 dB in Figure 10.2. According to the simulation result, the bandwidth of conceived array microstrip antenna is narrow. Only a small portion of the Return Loss is below -10 dB. It does not cover the whole band, and hence in terms of Return Loss, this array is not appropriate for UWB applications.

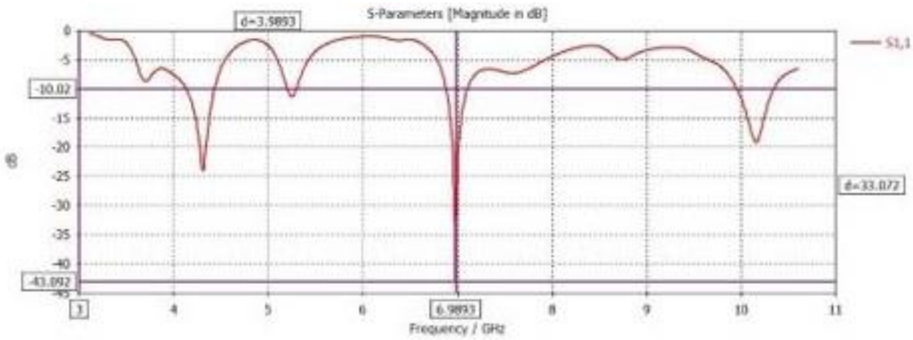
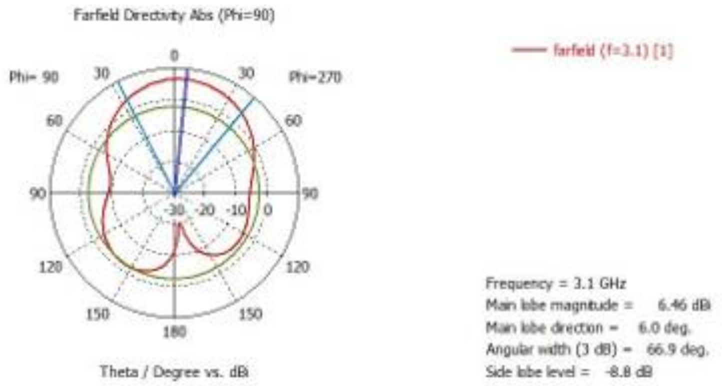


Figure 10.2: Return Loss performance of the designed antenna

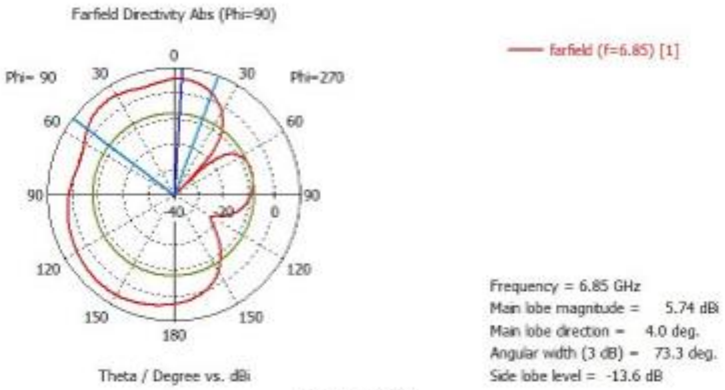
The VSWR is given in Figure 10.3. The resonance frequency in the graph is 6.9775 GHz and its VSWR value is 1.0140. As like Return Loss graph, VSWR is not below to over the whole UWB range. Then it does not satisfy requirements for UWB communications specified by FCC regulations.

Figure 10.3: VSWR performance of the designed antenna

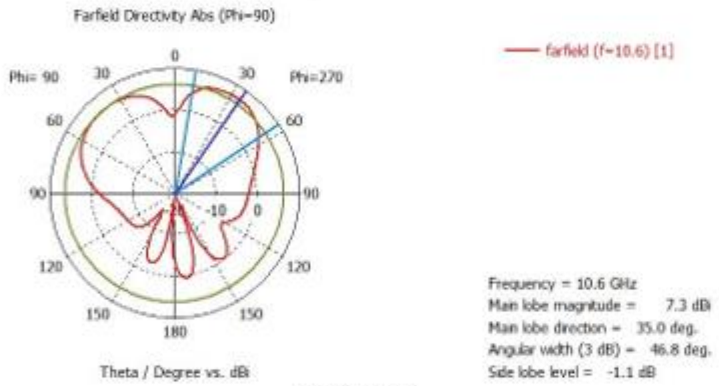
The radiation pattern is given in Figure 10.4. The performance of the antenna is investigated at different frequencies such as 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. The main lobe magnitude and its direction are 6.46 dBi and 6° respectively, when the operation frequency is 3.1 GHz. As the setting frequency is at 6.85 GHz, the magnitude and direction of the main lobe are 5.74 dBi and 4°. The last operation frequency is set at 10.6 GHz, main lobe magnitude is 7.3 dBi and main lobe direction is 35°. On the other hand, the angular widths (3 dB) of the designed antenna are 66.9°, 73.3° and 46.8° in order of examining frequency. The side lobe level is -8.8 dB for 3.1 GHz, -13.6 dB for 6.85 GHz and -1.1 dB for 10.6 GHz. As frequency increases, more lobes appear in the radiation pattern. As a result, this plotted array microstrip antenna has directional characteristic and the array does not have UWB characteristic. In fact, the array behaves as multi-band antenna. Because Return Loss is below -10 dB in only a few frequency intervals. Therefore, the proposed structure is not acceptable for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 10.4: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

10.2. Design-2

The architecture of the antenna array comprises of four inset fed rectangular patches which are connected to each other by stripline transmission lines. The materials of the designed antenna are choosen as PEC for ground plane, patches and transmission lines. The Antenna Magus Computer Program have been used for designing and CST Microwave Studio haven been used for analyzing.

10.2.1. Antenna Design and Parameters

The structure for the array of inset fed rectangular patch microstrip antennas is denoted in Figure 10.5. It is conceived and examined according to the values given in Table 10.2.

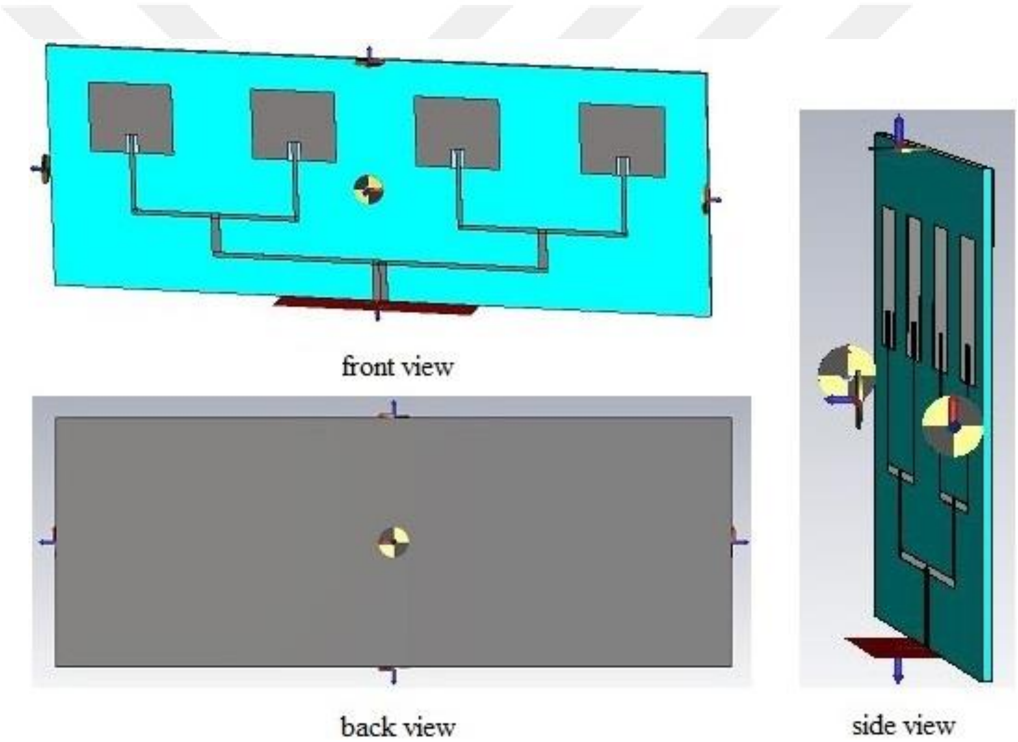


Figure 10.5: Array of Inset Fed Rectangular Patch Microstrip Antennas

Table 10.2: Antenna Parameters for Design 10.2

Symbol	Definition	Value	Unit
Ws	Substrate Width	140.771	mm
Ls	Substrate Lenght	51.9	mm
Wg	Ground Plane Width	140.771	mm
Lg	Ground Plane Lenght	51.9	mm
Wp	Patch Width	17.867	mm
Lp	Patch Lenght	14.908	mm
ht	Substrate Thickness	1	mm
hg	Ground Thichness	1	mm
hp	Patch Thickness	4.376	mm
ε_r	Relative Permitivity	2.2	-
c	Speed of the Light	$3x10^8$	m/sec
f_c	Center Frequency	6.85	GHz

10.2.2. Simulation Results

The rectangular patches are used for array of microstrip antenna design. The designed antenna is examined in the 3.1 GHz- 10.6 GHz UWB frequency interval. Return Loss, VSWR and Radiation Pattern characterictics of the array are examined in Figure 10.6, 10.7 and 10.8.

The resonant frequency for the array is 6.4225 GHz while the return loss parameter is -30.0190 dB in Figure 10.6. It is clearly seen in the figure that; the antenna is narrowband, and it is not suitable to be used for UWB communications. Hence, it can be said that array configuration of these inset fed patch antennas does not have any positive effect in terms of -10 dB bandwidth characteristic.

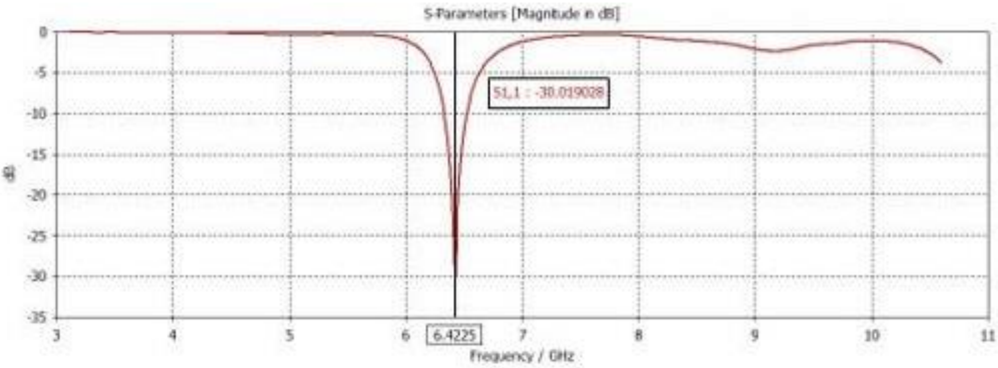


Figure 10.6: Return Loss performance of the designed antenna

The VSWR is given in Figure 10.7. The resonance frequency in the graphic is 6.4225 GHz and its VSWR value is 1.0651.

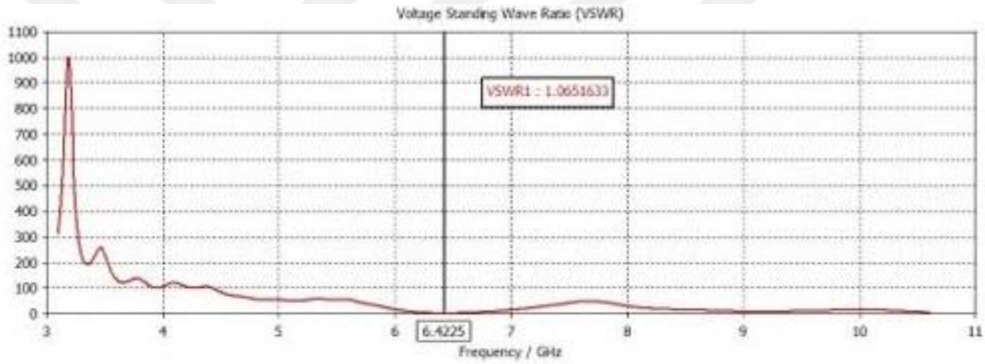
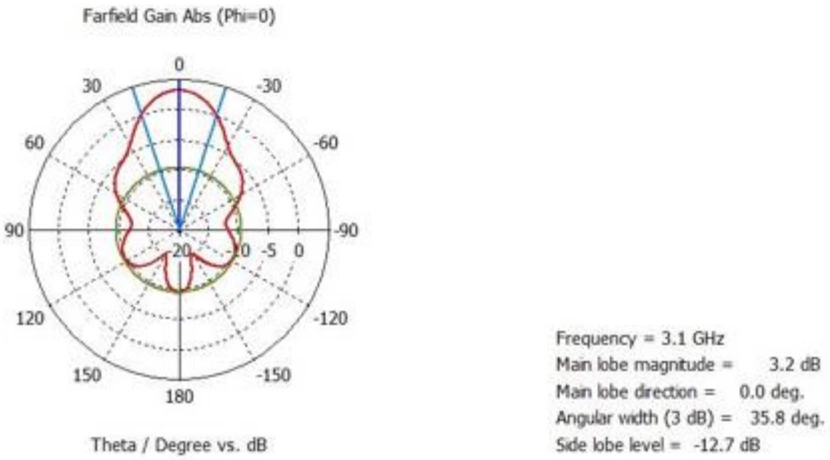
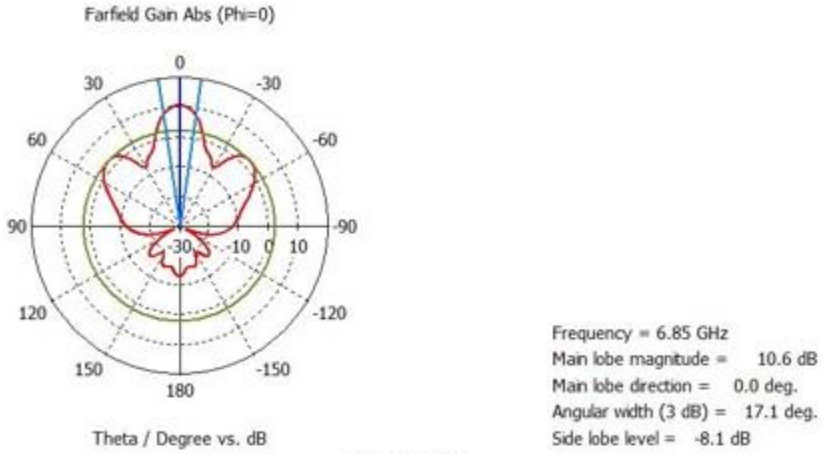


Figure 10.7: VSWR performance of the designed antenna with measurement points

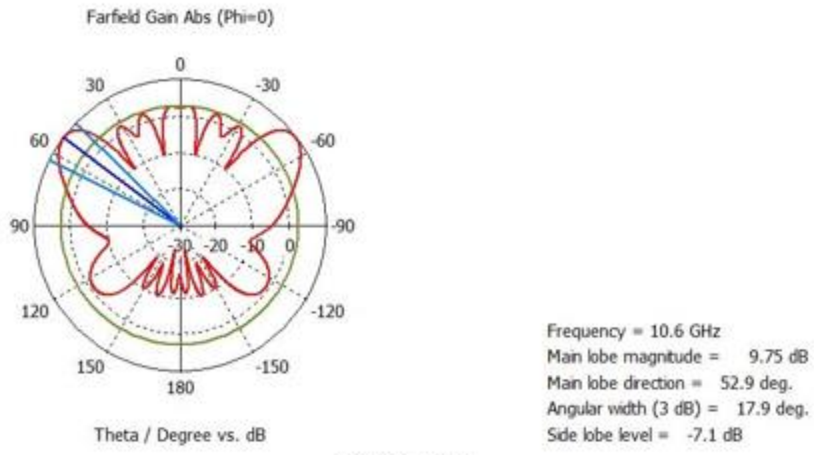
The radiation pattern for designed antenna is given in Figure 10.8. The performance of the antenna is investigated at different frequencies such as 3.1 GHz, 6.85 GHz and 10.6 GHz for ϕ=90°. At 3.1 GHz, the main lobe magnitude and direction are 3.2 dBi and 0° respectively. At 6.85 GHz, the magnitude and direction of the main lobe are 10.6 dBi and 0°, respectively. When the operation frequency is at 10.6 GHz, main lobe magnitude is 9.75 dBi while main lobe direction is 52.9°. The angular widths (3 dB) of the radiation patterns for the designed antenna are 35.8°, 17.1° and 17.9° in order of operating frequency. Besides, the side lobe is -12.7 dB for 3.1 GHz, -8.1 dB for 6.85 GHz and -7.1 dB for 10.6 GHz. The radiation pattern becomes highly irregular as the frequency rises. As a result, the designed antenna is narrowband, and its radiation pattern has a directional characteristic. Hereunder, this plotted array antenna is not possible for UWB applications.



a) 3.1 GHz



b) 6.85 GHz



c) 10.6 GHz

Figure 10.8: Radiation Pattern of the designed antenna with respect to different frequencies **a)** 3.1 GHz **b)** 6.85 GHz **c)** 10.6 GHz

11.RESULTS AND DISCUSSIONS

In all designs of the microstrip patch antennas explain that this antennas can use easy in UWB applications. The some of antenna materials may not find everytime to use antenna design such as Taconic TLC-30, Roger RT 5880, Glass Prex and at the same time, this materails could not find in nature for instance Perfect Electrical Conductor. The feature of the PEC materials represent infinite electrical conductivity and zero resistivity. They are manifactured in labratories. The consequences of the devised antennas are exhibited in the Table 11.1.

According to the design results, width of the substrate is effctive parameter for characteristic of the antenna. Its reasons to decrease Return Loss and carrying to the antenna UWB frequency range. Nevertheless, Voltage standing Wave Ratio approaches to 1.

On the other hand, the materials of the substrate is the one important parameter to obtain UWB performance of the microstrip patch antenna. In generally, FR-4 material choose easy to produce and low cost. The other substrate materials such as Taconic TLC-30, Roger RT 5880, Glass Prex, can not fabricate simply and they are a kind of problem to charge from Customs.

Moreover, the material of the ground, patch and transmissiaon line is the other of crucial parameters for antenna performance. Totally, the conductive materials, which finds simply in nature, are selected such as copper, nickel. In additionly, the shape of the patch is forceful element for performance of microstrip patch antenna in UWB frequency interval.

Taking everything into account, the narrow band speciality of the microstrip patch antennas can be reconstituted to exhibit UWB feature considering FCC. After this regenerate, it is inevitable that this antennas come out in many areas such as military, telecommunication and medical.

Table 11.1: Results of the designed UWB microstrip patch antenna

Layers	Materials	Substrate Width (mm)	Resonance Frequency (GHz)	Return Loss (dB)	WSWR
Substrate	Taconic TLC-30	38	7.375	-32.447	1.048
Ground	PEC	40	7.375	-41.664	1.016
Patch and Line	Silver	42	7.375	-47.246	1.008
Substrate	Taconic TLC-30	36	3.925	-31.922	1.052
Ground	PEC	38	3.925	-25.022	1.118
Patch and Line	Silver	40	3.925	-21.322	1.187
Substrate	Taconic TLC-30	40	7.537	-34.225	1.0396
Ground	PEC	-	-	-	-
Patch and Line	Silver	-	-	-	-
Substrate -1	FR-4	42	4.646	-26.07	1.0992
Substrate -2	Rogers RT 5880	-	-	-	-
Ground	Copper	-	-	-	-
Patch	Copper	-	-	-	-
Line	Nickel	-	-	-	-
Substrate -1	FR-4	42	8.2453	-31.854	1.0523
Substrate -2	Taconic TLC-30	-	-	-	-
Ground	Copper	-	-	-	-
Patch	Copper	-	-	-	-
Line	Nickel	-	-	-	-
Substrate -1	FR-4	42	8.4905	-28.406	1.0789
Substrate -2	Glass Prex	-	-	-	-
Ground	Copper	-	-	-	-
Patch	Copper	-	-	-	-
Line	Nickel	-	-	-	-
Substrate	Taconic TLC-30	80	6.9893	-43.092	1.0140
Ground	PEC	-	-	-	-
Patch	Silver	-	-	-	-
Line	Silver	-	-	-	-
Substrate	Dielectric 2.2	140.771	6.4225	-30.019	1.0651
Ground	PEC	-	-	-	-
Patch	PEC	-	-	-	-
Line	PEC	-	-	-	-

12.CONCLUSION

The antenna is a kind of bridge between transmitting and receiving points for communication system. They are critical component in UWB systems because of their broadband characteristics.

In this study, the performances of the microstrip patch antennas are analyzed in the 3.1-10.6 GHz UWB frequency interval. The antenna parameters such as width, lenght, thickness, material for substrate, ground plane and patch are changed to transfer the antenna from narrow band to broadband. In particular, shape of the patch and type of material are the most effective parameters for operating antenna in UWB frequency interval.

In this thesis, different antenna structures which are designed by using microstrip antennas are conceived in the UWB frequency range. Antenna parameters as Return Loss, VSWR and radiation pattern are examined in the frequency interval of interest.

Rectangular, circular and array microstrip antennas are designed by CST Microwave Studio Program. These antennas are examined and compared in 3.1 GHz – 10.6 GHz UWB frequency interval. Microstrip patch antennas are narrowband by their nature. The aim here is to make these antennas show broadband characteristics.

Rectangular patch microstrip antennas, which are inherently narrowband, show broadband characteristic after changing the form of the patch and dimension of the substrate. Circular microstrip antenna is also examined in UWB frequency range and modified to make it UWB antenna. After the analysis, modified circular patch antenna is indicated to have ultra broadband characteristic in UWB frequency range.

When the array of modified rectangular microstrip patch antennas are designed and analysed in UWB frequency range, the resulting array shows multiband characteristic in UWB frequency range. When the array is designed with four inset fed rectangular patch antennas, Return Loss does not satisfy UWB requirements.

To summarize, microstrip antennas, one of the important antennas for communication systems, are designed in accordance with UWB technology and its applications such as home network application, radar, WBAN, position, location and tracking.

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