

“Design and Optimization of a compact slotted microstrip patch antenna for low gain ultrawideband application around 3.6GHz”

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APPROVAL

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ABSTRACT

The purpose of the theses is to design a compact, cost efficient microstrip antenna using CST studio for 3.6 GHz band. After several combinations we've designed a antenna for low gain wireless application and the proposed antenna is also compatible with the upcoming 5G Telecommunication networking technology. We've used FR-04 as substrate and copper as conductive material, inset feeding technique to design the antenna. In simulation it is found that the BW of the antenna is 155MHz which is 4.27 % at -10dB point, 1.05 VSWR and 5.98 dBi directivity at a remarkably compact size which is comparable other designed antennas published in International Journals.

Key words: Slotted microstrip patch antenna, FR-04, 5G, UWB, CST Microwave, compact size, good directivity.

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AUTHORIZATION

We hereby declare that, we are the sole authors of this project. We further authorize, East West University to reproduce this project report by photocopy or other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

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Chapter 1: Introduction

1.1 Theses Approach

In modern time communication system becoming rapidly wireless and there are many applications where high speed is a must even using a compact antenna. Thus, a low profile, wide bandwidth, high directivity antennas are in great demand for commercial area. For these reasons we've conducted an experiment to designed a microstrip patch antenna with slots in the rectangular patch to have good performance. Our requirement was to design a ultrawideband compact microstrip antenna which is compatible with 5G and capable of working at a band ranging around 3.6 GHz with a good directivity. We've used FR-04 as substrate, inset feed line, there parallel slot and copper as patch and ground. For designing we've used MATLAB code and CST Microwave Studio and stimulated the proposed antenna. We had the similar result as per expectation but yet there are scopes to improve it and make it more compact and improve the performance.

1.2 Theses Organization

Chapter 1: The first chapter contains the overview and (introduction of each chapter) it describes the need of compact microstrip patch antenna and why we've designed one.

Chapter 2: This chapter gives the introduction to the antenna and the basic performance analysis parameters. Here definitions of input impedance, radiation pattern, field region, directivity, radiate etc. are given for better understanding of the data.

Chapter 3: Here we've discussed the basic of transmission line parameters, characteristics and the elements involved. We've showed the microstrip transmission line and the equations required to design a basic patch antenna.

Chapter 4: In this chapter we've briefly discussed microstrip patch antenna which include designing and feeding techniques. There's a comparison of plain and slotted microstrip patch antenna for showing the reason being designing a slotted patch antenna.

Chapter 5: This chapter contains the brief description of CST Microwave Studio which include general features, structure modification and solver technology. It also contains the design procedure with proper data, table and diagram.

Chapter 6: In this chapter we've showed the simulation data and short out them to select the proposed antenna. After that we've showed the comparison of others similar antenna to find out its pros and shortcomings.

Chapter 7: There is a short summery about our work, the antenna designing purpose and its compatibilities. We've mentioned the data and tools involved in our work and why our proposed antenna is a convenient one. We've also mentioned some point as a future work purpose.

Chapter 2: Antenna Theories

2.1 Introduction to Antenna:

An antenna is the transitional structure between free space and a guiding device. The guiding device or transmission line may take the form of a coaxial line or a waveguide, and it is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. [1]

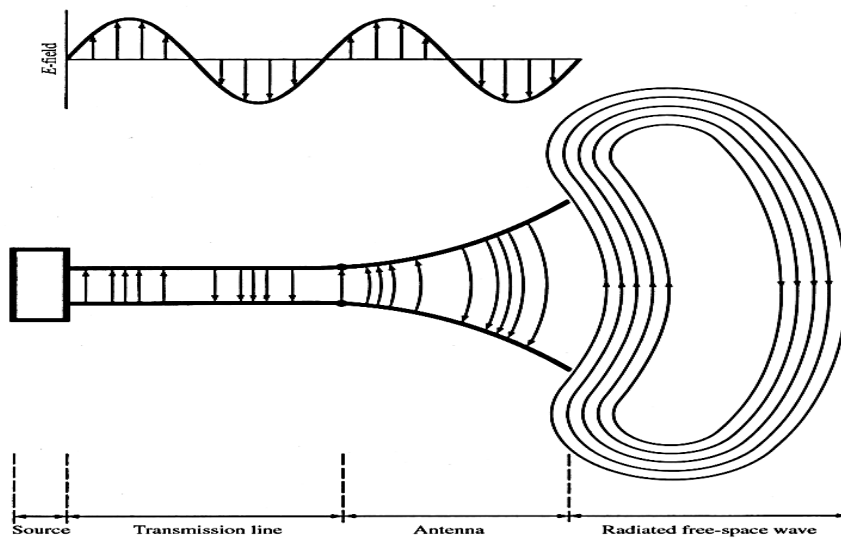


Fig 2.1: Antenna as a transition device.

Antennas have an arrangement of metallic conductors with an electrical connection to receivers or transmitters. Current is forced through these conductors by radio transmitters to create alternating magnetic fields. These fields induce voltage at the antenna terminals, which are connected to the receiver input. In the far field, the oscillating magnetic field is coupled with a similar oscillating electric field, which defines electromagnetic waves capable of propagating the signal for long distances. [2]

2.2 Input Impedance:

Input impedance is defined as the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point. [1]

In fig 2.2, $R_A = R_L + R_r$ is the real part and X_A is the imaginary part. The resistive part relates to the power dissipation, while the imaginary (reactive) part relates to power stored in the near field of the antenna.

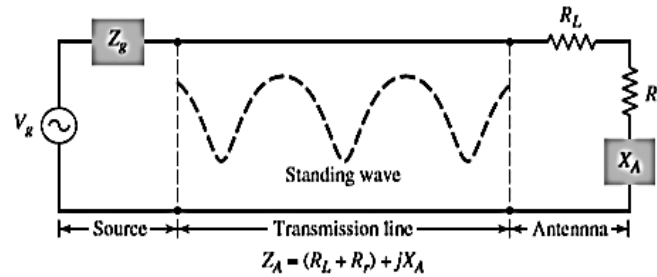


Fig 2.2: Transmission-line Thevenin equivalent of antenna in transmitting mode.

Input impedance is important to determine maximum power transfer between transmission line and the antenna. This transfer happens properly only when input impedance of antenna and input impedance of the transmission line matches. If they do not match, reflected wave will be generated at the antenna terminal and travel back towards the energy source.

2.3 Radiation Pattern

Radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. Mostly the radiation pattern is determined in the farfield region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. [1]

The radiation patterns can be field patterns or power patterns. The field patterns are plotted as a function of electric and magnetic fields. They are plotted on logarithmic scale. The power patterns are plotted as a function of square of the magnitude of electric and magnetic fields. They are plotted on logarithmic or commonly on dB scale.

The radiation pattern is a three-dimensional figure and represented in spherical coordinates (r, θ, Φ) assuming its origin at the center of spherical coordinate system. Two-dimensional pattern can be obtained from three-dimensional pattern by dividing it into horizontal and vertical planes. These resultant patterns are known as **Horizontal pattern** and **Vertical pattern** respectively. [3]

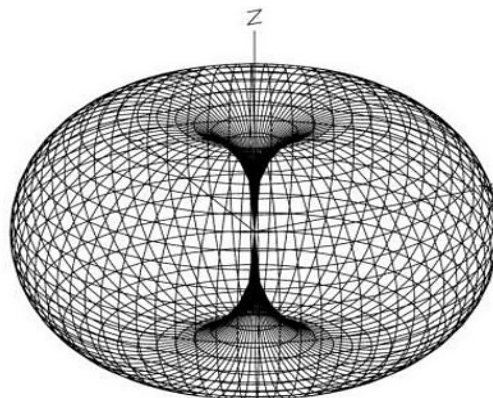


Fig 2.3: Radiation pattern in 3D.

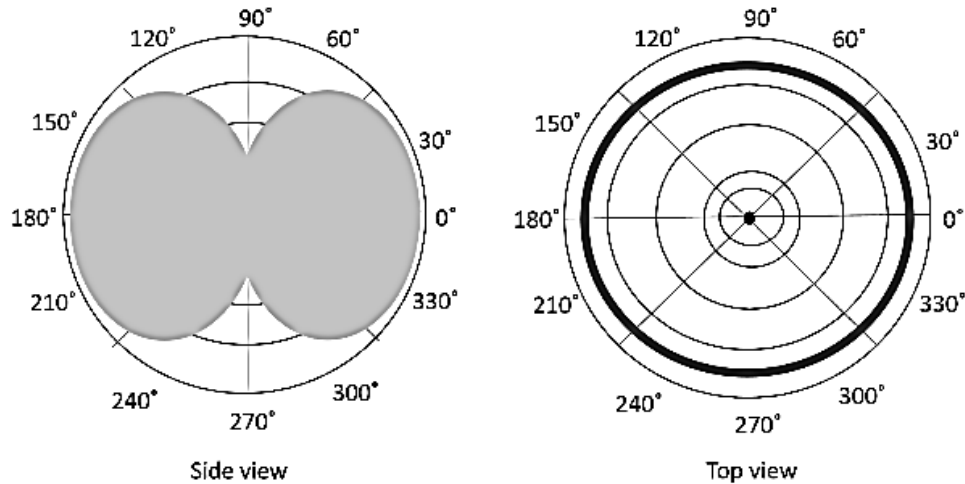


Fig 2.4: Radiation pattern in 2D.

2.4 Field regions:

The space surrounding an antenna is usually subdivided into three regions,

- Reactive Near Field Region:** This field is in the immediate vicinity of the antenna. In this region, the fields are predominately reactive fields, which means the E- and H- fields are out of phase by 90 degrees to each other. The outer boundary of this region is commonly taken to exist at a distance $R < 0.62\sqrt{D^3/\lambda}$ from the antenna surface.
- Radiating Near Field (Fresnel) Region:** This field is the region between the reactive near and far fields. In this region, the reactive fields are not dominate; the radiating fields begin to emerge. Here the shape of the radiation pattern may vary appreciably with distance. Here the boundary of the region is taken as $0.62\sqrt{D^3/\lambda} < R < 2D^2/\lambda$
- Far Field (Fraunhofer) Region:** This field is the region far from the antenna, here the radiation pattern does not change shape with. Also, this region is dominated by radiated fields, with the E- and H-fields orthogonal to each other and the direction of propagation as with plane waves. The inner boundary is taken to be the radial distance $R < 2D^2/\lambda$ and the outer one at infinity. [4]

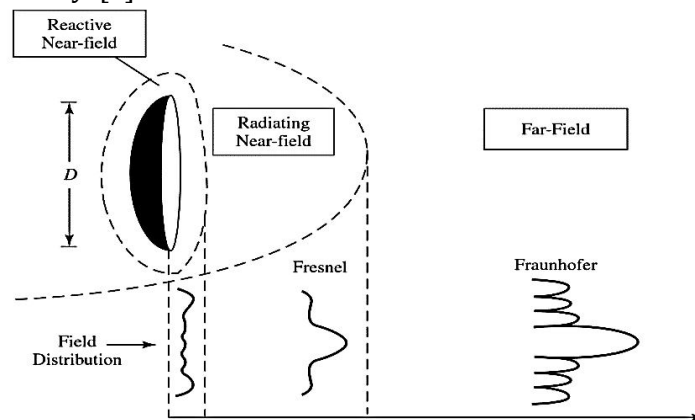


Fig 2.5: Typical changes of antenna amplitude pattern shape. [1]

2.5 Radiation Intensity:

Radiation intensity is defined as the power per unit solid angle. Radiation emitted from an antenna which is more intense in a particular direction, indicates the maximum intensity of that antenna. It is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. [1] In mathematical form it is expressed as,

$$U = r^2 W_{rad} \quad (2.01)$$

Where ' U ' is the radiation intensity, ' r ' is the radial distance and ' W_{rad} ' is the power radiated from the antenna.

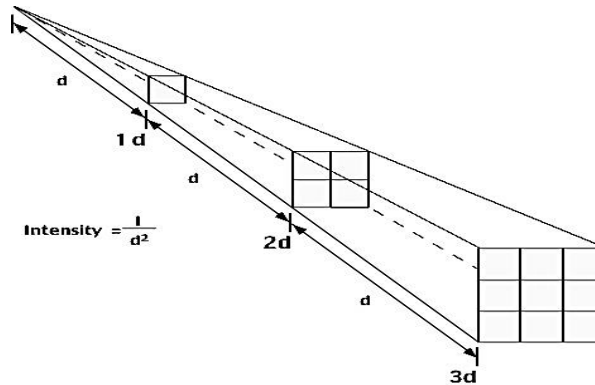


Fig 2.6: The nature of radiation.

2.6 Beamwidth:

Beam width is the aperture angle from where most of the power is radiated. It involves a trade-off because the side lobe level increases as the beamwidth decreases and vice versa. It is also used to describe the capability of the antenna to distinguish between two adjacent radiating sources or radar target. [3]

- a) **Half Power Beam Width (HPBW):** It is the angular separation, in which the magnitude of the radiation pattern decreases by 50% (or -3dB) from the peak of the main beam.
- b) **Full Power Beam Width (PPBW):** It is the angular span between the first pattern nulls adjacent to the main lobe

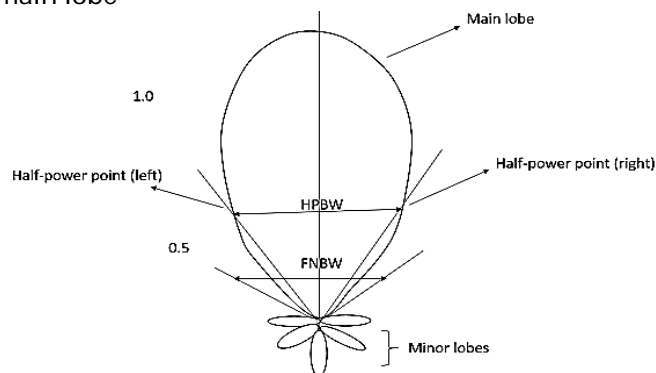


Fig 2.7: Beamwidth of an antenna.

2.7 Directivity:

The ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, radiating the same total power is called the directivity. The partial directivity of an antenna for a given polarization is, the part of the radiation intensity corresponding to that polarization, divided by the total radiation intensity averaged over all directions. [1] The mathematical expression of directivity,

$$D = \frac{U}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \quad (2.02)$$

If that particular direction is not specified, then the direction in which maximum intensity is observed, can be taken as the directivity of that antenna.

2.8 Gain:

Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. It describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Unlike directivity, antenna gain takes the losses that occur also into account and hence focuses on the efficiency. It is usually measured in dB.

$$G = 4\pi \frac{\text{Radiation intensity}}{\text{Total input (accepted) power}}$$

$$\text{or, } G = 4\pi \frac{U(\theta, \Phi)}{P_{in}} = \eta_e D \quad (2.03)$$

Where η_e is the efficiency and D is the directivity of the antenna. [1]

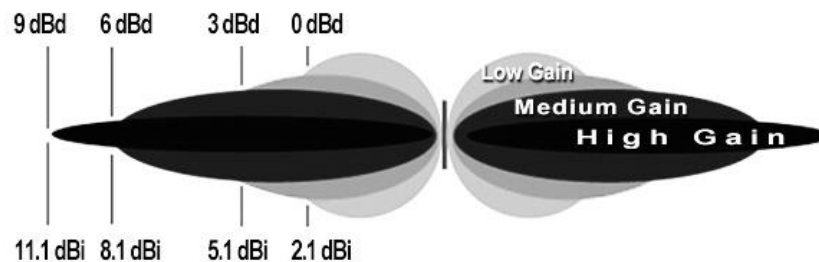


Fig 2.8: Illustration of antenna gain measurement.

2.9 Bandwidth:

Bandwidth is band of frequencies between higher and lower frequencies specified for a particular communication over which the antenna can properly radiate or receive energy. For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth. The Percentage bandwidth is calculated to know how much frequency variation either a component or a system can handle.

$$\text{Percentage Bandwidth} = \frac{\text{Abslout Bandwidth}}{\text{Center frequency}}$$

$$\text{or, \%BW} = \frac{F_H - F_L}{F_C} \quad (2.04)$$

Where F_H & F_L represents higher & lower frequency.

2.10 Polarization:

The polarization is the orientation of the electric field far from the source. It describes the time-varying direction and relative magnitude of the electric field vector. Polarization for an antenna in a given direction is defined as the polarization of the E-field transmitted by the antenna. When the direction is not stated the polarization is taken to be the polarization in the direction of maximum gain.

The polarization of a wave radiated by an antenna, in a specified direction, at a point in the far field, is defined as the polarization of the plane wave which is used to represent the radiated wave at that point. Polarization may be classified as linear, circular, elliptical, circular left hand, circular right hand, elliptical right and elliptical left hand. [1]

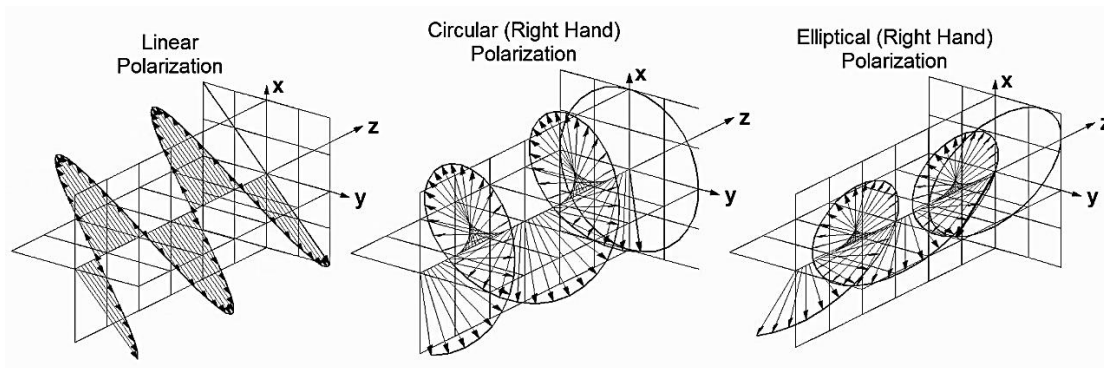


Fig 2.9: Linear, circular & circular polarization.

2.11 Radiation Efficiency:

Radiation efficiency is the ratio of the radiated power of the antenna to the input power accepted by the antenna. The efficiency of an antenna explains how much an antenna is able to deliver its output effectively with minimum losses in the transmission line. It is sometimes called *radiation efficiency*. One nice property of antennas is that the efficiency is the same whether we are using the antenna as a transmit or receive antenna. [3] the mathematical expression can be given as,

$$\eta_e = \frac{P_{\text{radiated}}}{P_{\text{input}}} \quad (2.05)$$

2.12 Antenna Efficiency:

To measure the total efficiency of an antenna we need to take into account losses at the input terminals which is caused by impedance mismatch, conductive and dielectric materials.

$$e_o = e_r e_c e_d \quad (2.06)$$

Where e_o = total efficiency, e_r = reflection mismatch efficiency, e_c = conduction efficiency, e_d = dielectric efficiency. [1]

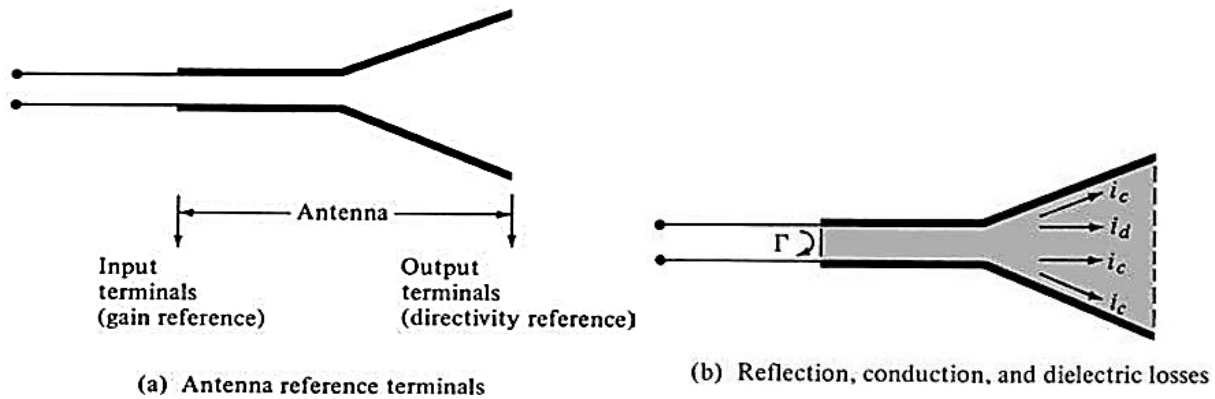


Fig 2.10: Reference terminals and losses of an antenna.

2.13 Beam Efficiency:

The beam efficiency can be defined as the ratio of the beam area of the main beam to the total beam area radiated. It is another parameter that is frequently used to judge the quality of transmitting and receiving antenna.

The energy when radiated from an antenna, is projected according to the antenna's directivity. The direction in which an antenna radiates more power has maximum efficiency, while some of the energy is lost in side lobes. The maximum energy radiated by the beam, with minimum losses can be termed as beam efficiency. [3] mathematically it can be expressed as,

$$\eta_B = \frac{\Omega_{MA}}{\Omega_A} \quad (2.01)$$

Where, Ω_{MA} is beam area of the main beam and Ω_A is total solid beam angle (beam area).

Chapter 3: Transmission Line Theories

3.1 Introduction to transmission Line:

A transmission line basically consists of two or more parallel conductors used to connect a source to a load. The source may be a hydroelectric generator, a transmitter, or an oscillator; the load may be a factory, an antenna, or an oscilloscope, respectively. Typical transmission lines include coaxial cable, a two-wire line, a parallel-plate or planar line, a wire above the conducting plane, and a microstrip line.

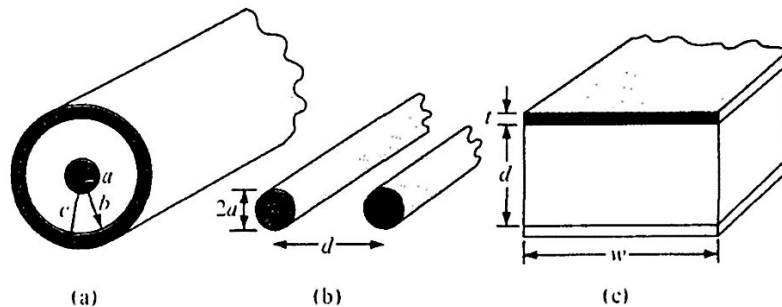


Fig 3.1: Common transmission lines: (a) coaxial line, (b) two-wire line, (c) planar line.

3.2 Transmission Line Elements:

It is customary and convenient to describe a transmission line in terms of its line parameters, which are its resistance per unit length R , inductance per unit length L , conductance per unit length G , and capacitance per unit length C . [5]

- 1) The line parameters R , L , G , and C are not discrete or lumped but distributed. By this we mean that the parameters are uniformly distributed along the entire length of the line.
- 2) For each line, the conductors are characterized by $\sigma_c, \mu_c, \epsilon_c = \epsilon_0$ and the homogeneous dielectric separating the conductors is characterized by σ, μ, ϵ .
- 3) $G \neq \frac{1}{R}$, R is the ac resistance per unit length of the conductors comprising the line and G is the conductance per unit length due to the dielectric medium separating the conductors.
- 4) The value of L is the external inductance per unit length; that is $L = L_{ext}$. The effects of internal inductance L_{in} are negligible as high frequencies at which most communication systems operate.
- 5) For each line, $LC = \mu\epsilon$ and $\frac{G}{C} = \frac{\sigma}{\epsilon}$

Table 1: Distributed Line Parameters at High Frequencies

Parameters	Coaxial Line	Two-Wire Line	Planar Line
R (Ω/m)	$\frac{1}{2\pi\delta\sigma_c} \left[\frac{1}{a} + \frac{1}{b} \right]$ ($\delta \ll a, c - b$)	$\frac{1}{\pi i \delta \sigma_c}$ ($\delta \ll a$)	$\frac{2}{w\delta\sigma_c}$ ($\delta \ll t$)
L (H/m)	$\frac{\mu}{2\pi} \ln \frac{b}{a}$	$\frac{\mu}{\pi} \cosh^{-1} \frac{d}{2a}$	$\frac{\mu d}{w}$
G (S/m)	$\frac{2\pi\sigma}{\ln \frac{b}{a}}$	$\frac{\pi\sigma}{\cosh^{-1} \frac{d}{2a}}$	$\frac{\sigma w}{d}$
C (F/m)	$\frac{2\pi\epsilon}{\ln \frac{b}{a}}$	$\frac{\pi\epsilon}{\cosh^{-1} \frac{d}{2a}}$	$\frac{\epsilon w}{d}$ ($w \gg d$)

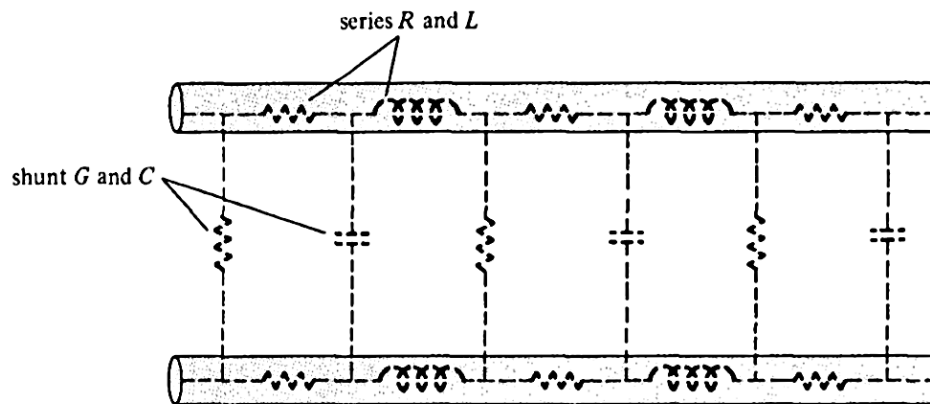


Fig 3.2: Distributed parameters of a two-conductor transmission line.

3.3 Transmission Line parameters:

3.3.1 Wave propagation on a transmission line:

The wavelength of the travelling waves is defined as the distance between two successive points of equal phase on the line at a fixed instant of time.

$$\lambda = \frac{2\pi}{\beta} \quad (3.01)$$

Here λ is the wavelength and β is propagation phase constant.

3.3.2 Phase and group velocity:

Phase velocity (V_p) is the velocity at which the phase of any one frequency component of a wave travel, where group velocity (V_g) is the overall velocity with which the overall shape wave amplitude known as envelop propagate through space.

$$V_p = \frac{\omega}{\beta} \quad (3.02)$$

$$V_g = \frac{1}{d\omega/d\beta} \quad (3.03)$$

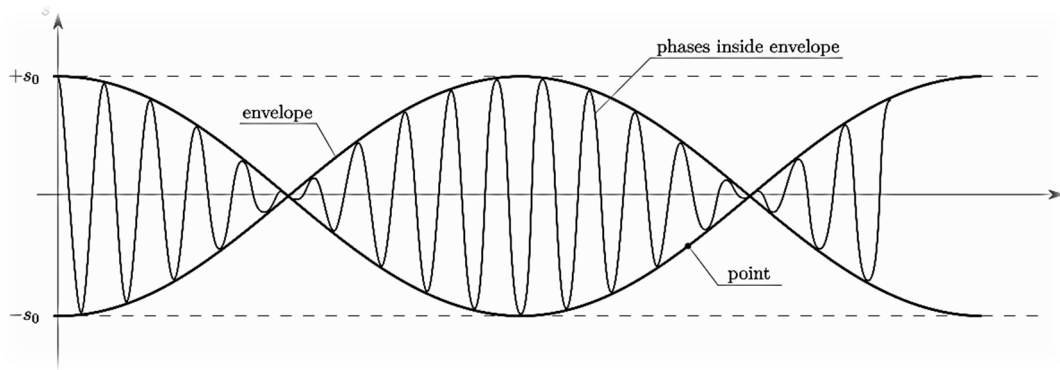


Fig 3.3: Phase & group velocity in x direction

3.3.3 Characteristic Impedance:

The characteristic impedance for a specific type of line is a function of the conductor size, the conductor spacing, the conductor geometry and the dielectric constant of the insulating material used between the conductors. It can be defined as the positively traveling voltage wave to the current wave at any point on the line. [6] The mathematical expression of characteristic impedance,

$$Z_o = \sqrt{\frac{R+j\omega L}{G+j\omega C}} = R + jX \quad (3.04)$$

R is the resistive component of the impedance and X is the reactive component of the impedance.

3.3.4 Voltage reflection coefficient (Γ):

The amplitude of the reflected voltage wave, normalized to the amplitude of the incident voltage wave, is defined as the voltage reflection coefficient. The average power flow is constant along the line and the total power delivered to the load is the difference between incident power and the reflected power. If $\Gamma = 0$, maximum power is delivered to the load while no power is delivered for $\Gamma = 1$ (all the incident power is reflected back from the load) [1]

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o} \quad (3.05)$$

3.4 Transmission Line Characteristics:

3.4.1 Attenuation:

Attenuation describes how energy is lost or dissipated. Energy dissipation occurs as a transformation from one type of energy to another. The factors that induce attenuation to cable are conductor size, material, insulation, frequency, speed and distance. A signal that attenuates too much become unintelligible which is why most networks requires repeaters at a regular interval.

Attenuation increases with both frequency and length. Attenuation is usually expressed as decibels. Attenuation for a cable of length L , and attenuation coefficient α is, [5]

$$A = 8.686L\alpha \text{ dB} \quad (3.06)$$

It us usually expressed as a negative value. Thus -12 dB is weaker signal than -10 dB.

3.4.2 Return Loss (RL):

Return loss is the measure of reflected energy caused by the dissimilarity between impedances in metallic transmission lines and loads. It also can be regarded as the ratio, at the junction of a transmission line and a terminating impedance or other discontinuity, of the amplitude of reflected wave to the amplitude of the incident wave. Possible cause of excessive return loss include fluctuation in characteristic impedance, cable kinks, excessive bends, heating issue, cable jacket etc. [5]

Return loss is defined as the ratio of the reflected power to incident power. Mathematical expression of return loss is given below,

$$RL = 10\log_{10}\left(\frac{P^+}{P^-}\right) = -20\log_{10}(|\Gamma|) \text{ dB} \quad (3.07)$$

3.4.3 Voltage Standing Wave Ratio (VSWR):

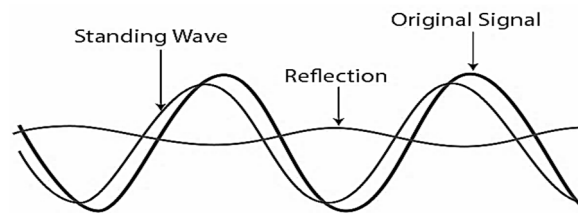


Fig 3.4: Representation of original, reflected and standing wave.

When a transmission line is not matched to its load some of the energy is absorbed by the load and some is reflected back down the line towards the source. The interference of the incident and reflected wave creates standing waves on the transmission line. As the magnitude of the reflection coefficient Γ increases, the ratio of V_{max} to V_{min} also increases. [6] A measure of the mismatch of the line is called the standing wave ration (SWR), also known as VSRW. It can be expressed as,

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (3.08)$$

3.5 Microstrip Transmission Line:

A microstrip line consists of a single ground plane and an open strip conductor separated by dielectric substrate. Apart from being the most commonly used form of transmission lines for microwave integrated circuits, microstrips are used for circuit components such as filters, couplers, resonators, antennas, and so on. In comparison with the coaxial line, the microstrip line allows for greater flexibility and compactness of design.

Due to the open structure of the microstrip line, the EM field is not confined to the dielectric, but is partly in the surrounding air. Provided the frequency is not too high, the microstrip line will propagate a wave that, for all practical purposes, is a TEM wave. Because of the fringing, the effective relative permittivity ϵ_{eff} is less than the relative permittivity ϵ_r of the substrate. [5]

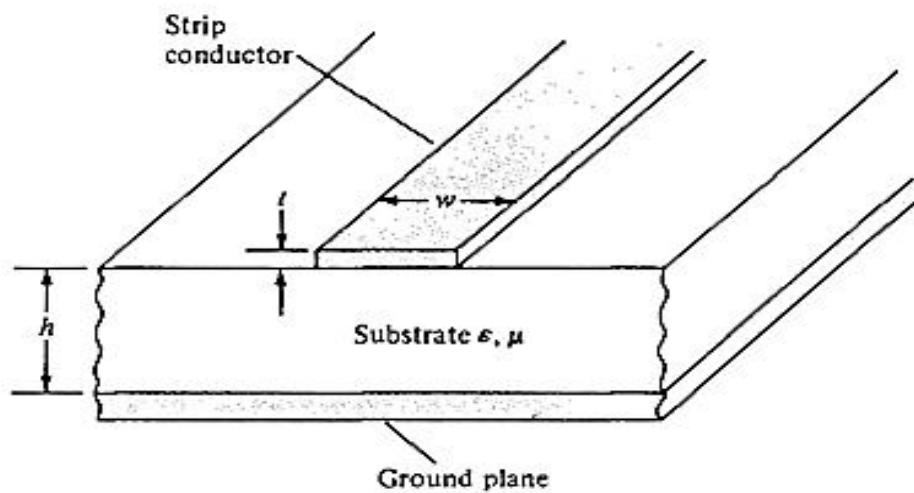


Fig 3.5: Schematic diagram of a microstrip line.

- If w is the line width and h is the substrate thickness, an approximate value of ϵ_{eff} is given by,

$$\epsilon_{eff} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2\sqrt{1 + 12(h/w)}} \quad (3.09)$$

- The characteristic impedance is given by the following approximate formulas,

$$Z_o = \begin{cases} \frac{60}{\sqrt{\epsilon_{eff}}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right), & w/h \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_{eff}} [w/h + 1.393 + 0.667 \ln(w/h + 1.444)]}, & w/h \geq 1 \end{cases} \quad (3.10)$$

- The characteristic impedance of a wide strip is often low while that of a narrow strip is high. If ϵ_r and Z_o are known, the ratio w/h necessary to achieve Z_o is given by,

$$\frac{w}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2}, & w/h < 2 \\ \frac{2}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{(\epsilon_r - 1)}{2\epsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right] \right\}, & w/h > 2 \end{cases} \quad (3.11)$$

Where **A** and **B** have separate equation,

$$A = \frac{Z_o}{60} \sqrt{\frac{(\epsilon_r - 1)}{2}} + \frac{(\epsilon_r - 1)}{(\epsilon_r + 1)} \left(0.23 + \frac{0.11}{\epsilon_r} \right) \quad (3.12)$$

$$\text{and, } B = \frac{60\pi^2}{Z_o\sqrt{\epsilon_r}} \quad (3.13)$$

- ➔ From the values of ϵ_{eff} and Z_o , the phase constant and the phase velocity of a wave propagating on the microstrip are given by,

$$\beta = \frac{\omega \epsilon_{eff}}{c} \quad (3.14)$$

$$u = \frac{c}{\epsilon_{eff}} \quad (3.15)$$

- ➔ The total attenuation constant is the sum of the ohmic attenuation constant α_c and the dielectric attenuation constant α_d , that is,

$$\alpha = \alpha_c + \alpha_d \quad (3.16)$$

Where,

$$\text{Ohmic attenuation, } \alpha_c = 8.686 \frac{R_s}{wZ_o} \text{ dBm} \quad (3.17)$$

$$\text{Dielectric attenuation, } \alpha_d = 27.3 \frac{(\epsilon_{eff} - 1)\epsilon_r}{(\epsilon_r - 1)\sqrt{\epsilon_{eff}}} \frac{\tan\theta}{\lambda} \text{ dBm} \quad (3.18)$$

3.6 MATLAB code for Microstrip Transmission Line:

```

clc
clear all
format long

er=input('Enter the dielectric constant:');
h=input('Enter substrate thickness(in mm):');
f=input('Enter the Frequency(in Ghz):');
z=input('Enter the input impedance(in Ohm):');
f=f*1e9;

W=(3e8/(sqrt((er+1)/2)*2*f))*1000;
e_eff=((er+1)/2)+((er-1)/2)*(1+(12*(h/W))^-0.5);
del_l=(0.412*h*((e_eff+0.3)*((W/h)+0.264)/(e_eff-0.258)*((W/h)+0.8)));%fringing length
l_eff=(3e8/(2*f*sqrt(e_eff)))*1000; %effective length
L=l_eff-(2*del_l); %actual length

Lg_min=6*h+L;
Wg_min=6*h+W;

la=(3e8/f)*1000; %wavelength in mm
k=(2*pi)/la; %wave number
x=k*W;
i1=-2+cos(x)+(x*sinint(x))+sin(x)/x;
g1=i1/(12*pi*pi); %conductance

a=@(th)((sin((x./2).*cos(th))./cos(th)).^2.*(besselj(0,(k.*L.*sin(th))))).*(sin(th)).^3);
a1=integral(a,0,pi);
g12=a1/(120*pi*pi); %in siemens
r_in=1/(2*(g1+g12)); %in Ohm
inset=(L/pi)*(acos(sqrt(z/r_in))); %in mm

B=60*pi*pi/(z.sqrt(er));
m1=2*B-1;
m=log(m1);
n1=B-1;
n=log(n1);

wf=(2*h/pi)*(B-1-m+(((er-1)/(2*er))^(n+(0.39*0.61)/er)));
g=(3e8*4.65e-9)/(sqrt(2*e_eff)*f*10^-9);

disp('Rectrangular Patch:');
disp(['The width of the patch (Wp) is:',num2str(W),'mm'])
disp(['The length of the patch (Lp) is:',num2str(L),'mm'])
disp(['The min. width of ground plane (Wg) is:',num2str(Wg_min),'mm'])
disp(['The min. length of ground plane (Lg) is:',num2str(Lg_min),'mm'])
disp(['The inset feed point (Fi) is:',num2str(inset),'mm'])
disp(['The width of the feed line (Wf) is:',num2str(wf),'mm'])
disp(['The gap of the feed line (Gpf) is:',num2str(g),'mm'])

```

3.7 The Smith Chart:

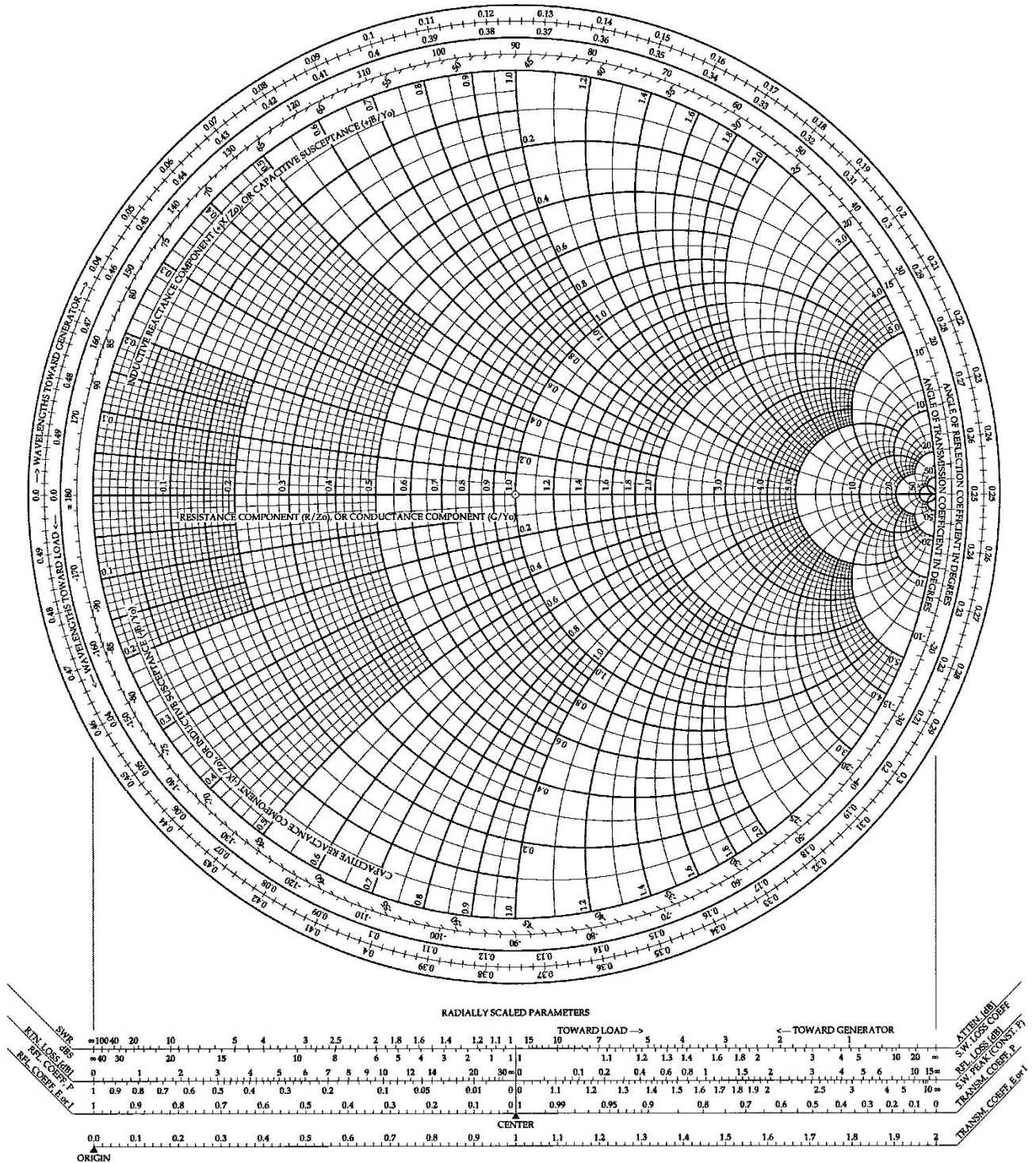


Fig 3.6: The complete Smith Chart.

The Smith Chart is a useful tool for visualizing the impedance of a transmission line and antenna system as a function of frequency. It consists of a series of overlapping orthogonal circles that intersect each other at right angles. These sets of orthogonal circles make up the basic structure of the Smith chart. Smith Charts can be used to increase understanding of transmission lines and how they behave from an impedance viewpoint. Smith Charts are also extremely helpful for impedance matching. It is used to display an actual (physical) antenna's impedance when measured on a Vector Network Analyzer (VNA).

Smith Charts were originally developed around 1940 by Phillip Smith as a useful tool for making the equations involved in transmission lines easier to manipulate. With modern computers, the Smith Chart is no longer used to simplify the calculation of transmission line equations; however, their value in visualizing the impedance of an antenna or a transmission line has not decreased.

3.7.1 The Normalized Impedance Line:

A baseline bisects the Smith chart outer circle and forms the reference of measurements made on the chart. The Complex impedance contains both resistance and reactance and is expressed mathematically as, $Z = R + jX$

The pure resistance circle represents the situation where $X=0$, and the impedance is therefore equal to the resistive component only. To make the Smith chart universal, the impedances along the pure resistance line are normalized with reference to system impedance (Z_o). The actual impedance it is divided by the system impedance. The pure resistance line is structured such that the system standard impedance is at the center of the chart and has a normalized value of 1.0. [6]

3.7.2 The constant resistance circles:

The isoresistance circles, also called the constant resistance circles represent points of equal resistance. These circles are all tangent to the point at the right hand extreme of the pure resistance line and are bisected by that line.

3.7.3 The constant reactance circles:

The circles above the pure resistance line represent the inductive reactance (+X) while the circles below the pure resistance line represent capacitive reactance (-X). The outermost circle is called the pure reactance circle. Points along this circle represent reactance only.

3.7.4 S-parameter:

The scattering matrix is a mathematical construct that quantifies how RF energy propagates through a multi-port network. The S-matrix is what allows us to accurately describe the properties of incredibly complicated networks as simple "black boxes". For an RF signal incident on one port, some fraction of that signal gets reflected back out of the incident port, some of it enters into the incident port and then exits at (or scatters to) some or all of the other ports. What's left of that incident power disappears as heat or even electromagnetic radiation. The S-matrix for an N-port contains N^2 coefficients (S-parameters), each one representing a possible input-output path.

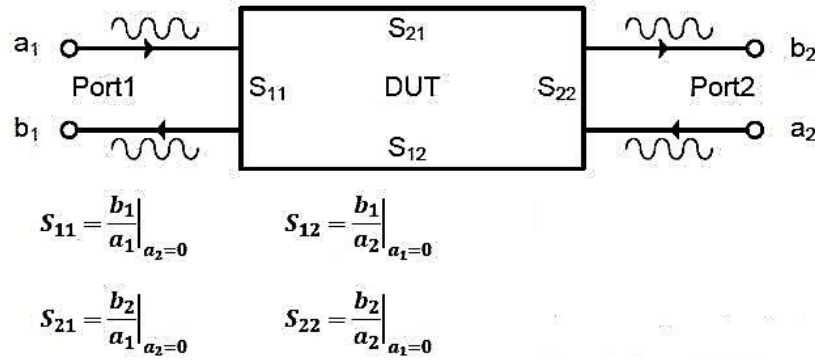


Fig 3.7: A 2-port S-parameter model

S-parameters are usually displayed in a matrix format, with the number of rows and columns equal to the number of ports. For the S-parameter S_{ij} the j subscript stands for the input port, and the i subscript is for the output port. Thus S_{11} refers to the ratio of the amplitude of the signal that reflects from port one to the amplitude of the signal incident on port one. Parameters along the diagonal of the S-matrix are referred to as reflection coefficients because they only refer to what happens at a single port, while off-diagonal S-parameters are referred to as transmission coefficients, because they refer to what happens at one port when it is excited by a signal incident at another port.

Chapter 4: Microstrip Patch Antenna

4.1 Introduction

A microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in fig 4.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

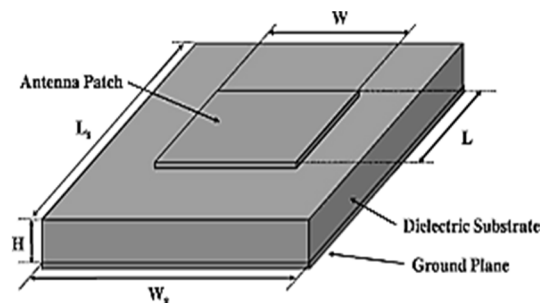


Fig 4.1: a cross sectional view of a microstrip patch antenna.

The following figure shows a patch antenna in its basic architecture. The patch and the ground plane are separated by a dielectric material. A flat plate over a ground plane and then the dielectric substrate at the center and the patch is at the top. The patch and the ground plane are generally conducting materials such as gold, copper and the patch can be any shape as the design specification. The feed line is used to feed the patch. There are many different types of feeding techniques. Usually, the patch and the feed line are photo etched to the substrate. The radiating patch can be square, rectangular, circular, triangular, elliptical, circular ring and dipole and so on. [8]

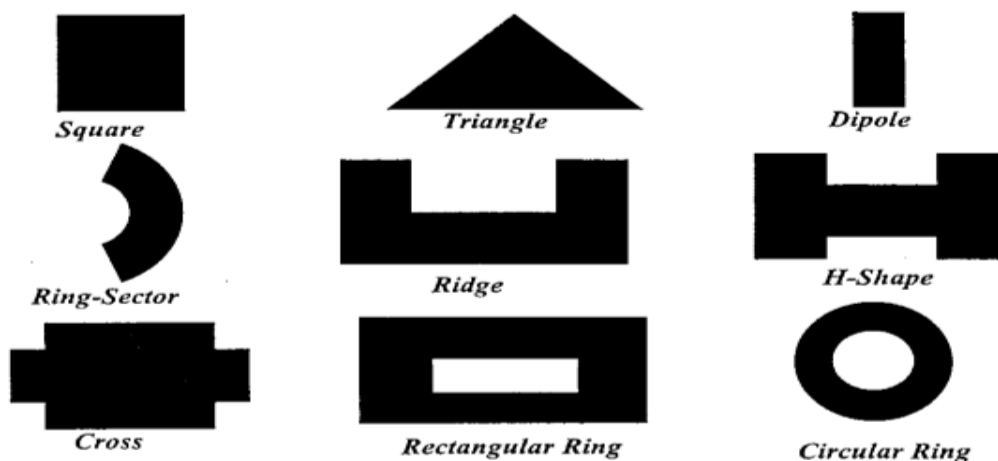


Fig 4.2: Common shapes of microstrip patch elements.

4.2 Feeding Methods

There are many methods used for feeding a microstrip antenna. The most commonly used ones are:

4.2.1 Coaxial Feed

Coupling power to a patch antenna through a coaxial connector is very cheap, simple and an effective way. The coaxial connector is connected to the ground plane of the microstrip antenna and it is passed across the substrate at the center and soldered to the patch, as shown in the figure below. [4]

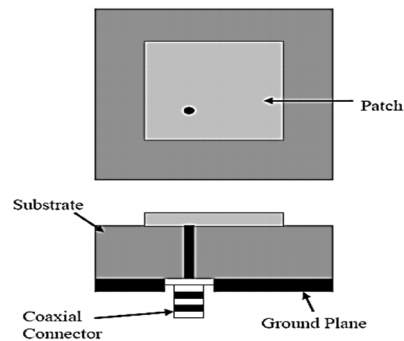


Fig 4.3: Coaxial line feed

4.2.2 Microstrip Line

This method of feeding is more commonly used because it is very simple to design and analyze, and very easy to manufacture. The Figure 4.4 shows a patch with microstrip line feed. Also, this type of feeding is mostly used in the case of multipatches (patch array). [8]

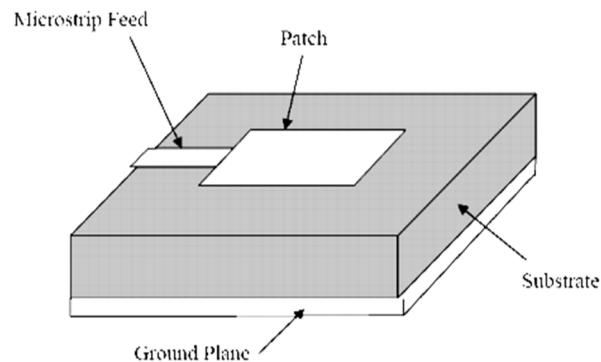


Fig 4.4: Microstrip patch antenna with feed line

4.2.3 Proximity Coupling

Two substrates are used in a proximity coupling feeding method with permittivity 1.2. The patch is placed on the top, the ground plane in the bottom and a feed line is connected to the source with a placing between the two substrates as shown in the fig 4.5. [8]

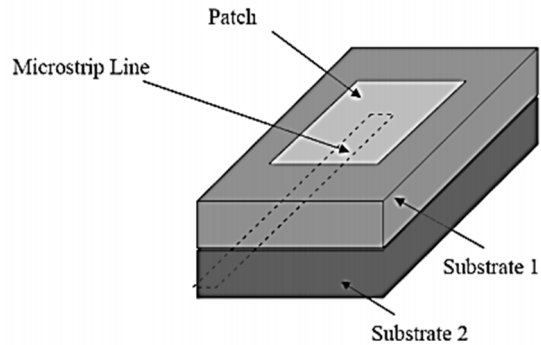


Fig 4.5: Proximity coupling feed method

4.2.4: Aperture Coupling

The microstrip patch antenna uses the aperture mechanism in the type of feeding as shown in Fig 4.6. The ground plane has an aperture in different shapes, and it placed between two substrates: the upper substrate 1 with the patch over it, and the lower substrate 2 with the microstrip feed line below it. This type of feeding gives wider bandwidth. [8]

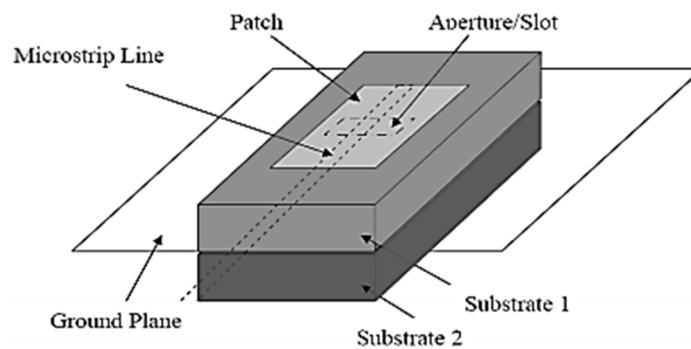


Fig 4.6: Aperture coupling feed method

4.2.6: Patch Array:

The radiation pattern of a single element is relatively wide, and each element gives low values of directivity and gain. In most applications, it is necessary to design antennas with high gain for long distance communications. This can only be achieved by increasing the electrical size of the antenna. This new antenna, is formed by multi-elements, which is referred to as an array. [9]

Table 2: Comparison of the different feed techniques-

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture coupled Feed	Proximity coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

4.2.7 Microstrip Slot Antenna:

Microstrip slot antenna consists of a slot in the ground plane fed by a microstrip feed line. They have the advantages of being able to produce bi-directional and unidirectional radiation patterns. Patch and slot combinations offer an additional degree of freedom in the design of microstrip antennas. This design criterion facilitates the design of antennas with desired polarization and they are less sensitive to manufacturing tolerances than are microstrip patch antennas. The slot can have the shape of a rectangle (narrow or wide), a circle or a ring slot as shown in fig 4.7. Microstrip slot antennas are generating wide interest owing to its characteristic features like compactness and dual-frequency operation. [9]

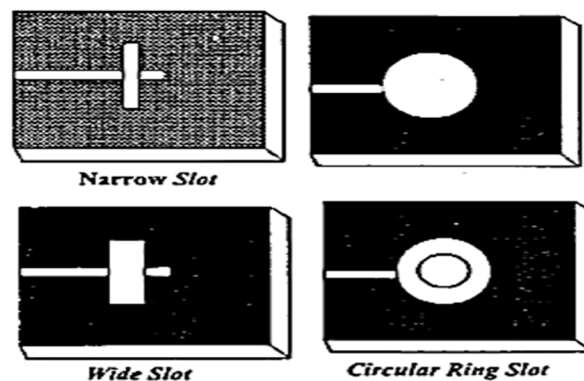


Fig 4.7: Microstrip Slot Antennas

Table 3: Comparison of microstrip patch and microstrip feed slot antenna [9]

Characteristics	Patch	Microstrip feed Slot
Analysis and design	Easy	Easy
Fabrication	Very easy	Very easy
Tolerance in fabrication	Critical	Not very critical
Profile	Thin	Thin
Shape Flexibility	Any shape	Limited
Radiation fields	Unidirectional	Unidirectional and bidirectional
Polarization	Linear and circular	Linear and circular
Bandwidth	Narrow (2-50%)	Wide (5-30%)
Dual frequency operation	Possible	Possible
Spurious Radiation	Moderate	Low
Isolation between radiating elements	Fair	Good
Frequency scanning	Easily possible	Possible
Cross-polarization level	low	Very low
End-fire antenna	Not possible	Possible

4.3 Advantages and limitations of microstrip patch antennas:

4.3.1 The advantages of microstrip patch antenna are-

Microstrip patch antennas and arrays are of tremendous commercial interest because of their numerous advantages.

- ↳ Light weight, low volume and conformal configurations.
- ↳ Low fabrication cost.
- ↳ Linear and circular polarizations possible with simple feeds.
- ↳ Dual-frequency and dual-polarization designs possible.
- ↳ No cavity backing required.
- ↳ Compatible with integrated circuits.
- ↳ Feed lines and matching networks can be fabricated simultaneously with the antenna structure.

These advantages that make microstrip patch antennas highly suitable for commercial mobile, high-speed communication applications also make them ideal for the aperiodic and opportunistic array concepts. [9]

4.3.2 The limitations of microstrip antennas and arrays, as compared with conventional antennas, are:

- ↳ Narrow bandwidth and associated tolerance problems.
- ↳ Lower gain.
- ↳ Most microstrip antennas radiate into half-space only.
- ↳ Complex feed structures required for typical high-performance arrays.
- ↳ Polarization purity hard to achieve.
- ↳ Extraneous radiation from feeds and junctions.
- ↳ Lower power handling capability (approximately 100 W).

Nonetheless, some of these limitations can be overcome through specialized techniques. This thesis, for example, investigates incorporating a U-slot into the design to achieve broad-band characteristics as well as using an array configuration to achieve desired gain levels.

4.4 Applications:

The Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this Microstrip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the Microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. Some of the advantages of using microstrip antenna are discussed below [9]

- **Mobile and satellite communication application:** Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems. In case of satellite communication circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed points.
- **Radio Frequency Identification (RFID):** RFID uses in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically, RFID system is a tag or transponder and a transceiver or reader.
- **Radar Application:** Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas.
- **Worldwide Interoperability for Microwave Access (WiMAX):** The IEEE 802.16 standard is known as WiMAX. It can reach up to 30-mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMAX compliant communication equipment.
- **Global positioning system applications:** Nowadays microstrip patch antennas with substrate providing high permittivity sintered material are being used for global positioning systems. These antennas are circularly polarized, compact and very expensive due to their positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicles, maritime vessels and aircraft to find their position accurately.

Chapter 5: Antenna Design with CST Microwave Studio

5.1 Introduction to CST Microwave Studio:

CST Microwave Studio (MWS) is part Of CST Studio Suite and a fully featured software package for electromagnetic analysis and design in the high frequency range. It simplifies the process of creating the structure by providing a powerful graphical solid modeling front end which is based on the ACIS modeling kernel. After the model has been constructed, a fully automatic meshing procedure is applied before a simulation engine is started.

Since no one method works equally well for all applications, the software contains several different simulation techniques such as transient solver, frequency domain solver, integral equation solver, multilayer solver, asymptotic solver, and eigenmode solver to best suit various applications. The frequency domain solver also contains specialized methods for analyzing highly resonant structures such as filters.

Each method in turn supports meshing types best suited for its simulation technique. Hexahedral grids are available in combination with the Perfect Boundary Approximation (PBA) feature and some solvers which use the hexahedral mesh also support the Thin Sheet Technique (TST) extension. Applying these highly advanced techniques usually increases the accuracy of the simulation substantially in comparison to conventional simulators. In addition to the hexahedral mesh the frequency domain solver also supports a tetrahedral mesh. Surface or multilayer meshes are available for the integral equation and multilayer solver, respectively.

Each solver's simulation results can be visualized with a variety of different options. Again, a strongly interactive interface will help user to achieve the desired insight into their device quickly. So, the outstanding feature is the full parameterization of the structure modeler, which enables the use of variables in the definition of your component. In combination with the built-in optimizer and parameter sweep tools, CST MWS is capable of both the analysis and design of electromagnetic devices. [10]

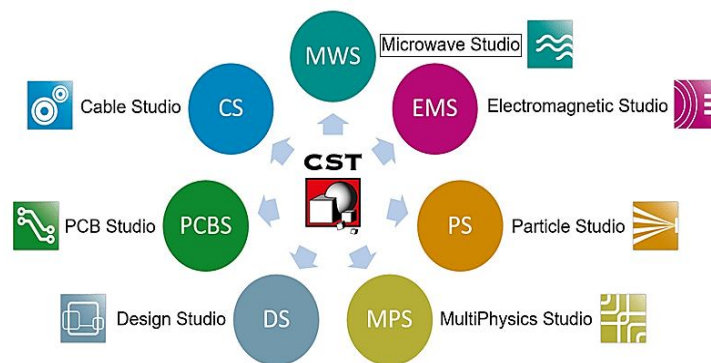


Fig 5.1: CST MWS as a part of CST Studio Suit.

5.2 Some Key features of CST MWS:

5.2.1 General Features

- ↳ Native graphical user interface based on Windows XP, Windows Vista, Windows 7, Windows 8, Windows 10 and Linux.
- ↳ Fast and memory efficient Finite Integration Technique
- ↳ Extremely good performance due to Perfect Boundary Approximation (PBA) feature for solvers using a hexahedral grid. The transient and eigenmode solvers also support the Thin Sheet Technique (TST).
- ↳ The structure can be viewed either as a 3D model or as a schematic. The latter allows for easy coupling of EM simulation with circuit simulation.

5.2.2 Structure Modeling

- ↳ Advanced ACIS1-based, parametric solid modeling front end with excellent structure visualization
- ↳ Feature-based hybrid modeler allows quick structural changes
- ↳ Import of 3D CAD data by SAT, Autodesk Inventor, IGES, VDA-FS, STEP, ProE, CATIA 4, CATIA 5, CoventorWare, Mecadtron, Nastran, STL or OBJ files
- ↳ Import of 2D CAD data by DXF, GDSII and Gerber RS274X, RS274D files
- ↳ Import of EDA data from design flows including Cadence Allegro / APD / SiP, Mentor Graphics Expedition®, Mentor Graphics PADS® and ODB++
- ↳ Import of PCB designs originating from Simlab PCBMod / CST PCBStudio
- ↳ Import of 2D and 3D sub models
- ↳ Import of Agilent ADS® layouts
- ↳ Import of Sonnet® EM models (8.5x)
- ↳ Import of a visible human model dataset or other voxel datasets
- ↳ Export of CAD data by SAT, IGES, STEP, NASTRAN, STL, DXF, Gerber, DRC or POV files
- ↳ Parameterization for imported CAD files
- ↳ Material database
- ↳ Structure templates for simplified problem description

5.2.3 CST DESIGN STUDIO View

- ↳ Represents a schematic view that shows the circuit level description of the current CST MWS project.
- ↳ Allows additional wiring, including active and passive circuit elements as well as more complex circuit models coming from measured data such as Touchstone or IBIS files, analytical or semi analytical descriptions like microstrip or stripline models or from simulated results.
- ↳ Offers many different circuit simulation methods, including transient EM/circuit co-simulations.
- ↳ All schematic elements as well as all defined parameters of the connected CST MWS project can be parameterized and are ready for optimization runs.

5.2.4 Visualization and Secondary Result Calculation

- ↳ Multiple 1D result view support
- ↳ Displays S-parameters in xy-plots (linear or logarithmic scale)
- ↳ Displays S-parameters in Smith charts and polar charts
- ↳ Online visualization of intermediate results during simulation

- ↳ Import and visualization of external xy-data
- ↳ Copy / paste of xy-datasets
- ↳ Fast access to parametric data via interactive tuning sliders
- ↳ Displays port modes (with propagation constant, impedance, etc.)
- ↳ Various field visualization options in 2D and 3D for electric fields, magnetic fields, power flows, surface currents, etc.
- ↳ Animation of field distributions
- ↳ Calculation and display of farfields (fields, gain, directivity, RCS) in xy-plots, polar plots, scattering maps and radiation plots (3D)
- ↳ Calculation of Specific Absorption Rate (SAR) including averaging over specified mass
- ↳ Calculation of surface losses by perturbation method and Q factor
- ↳ Display and integration of 2D and 3D fields along arbitrary curves
- ↳ Integration of 3D fields across arbitrary faces
- ↳ Automatic extraction of SPICE network models for arbitrary topologies ensuring the passivity of the extracted circuits
- ↳ Combination of results from different port excitations
- ↳ Hierarchical result templates for automated extraction and visualization of arbitrary results from various simulation runs. These data can also be used for the definition of optimization goals.

5.2.5 Result Export

- ↳ Export of S-parameter data as TOUCHSTONE files
- ↳ Export of result data such as fields, curves, etc. as ASCII files
- ↳ Export screen shots of result field plots
- ↳ Export of farfield data as excitation for integral equation solver
- ↳ Export of nearfield data from transient or frequency domain solver as excitation in transient solver

5.2.6 Automation

- ↳ Powerful VBA (Visual Basic for Applications) compatible macro language including editor and macro debugger
- ↳ OLE automation for seamless integration into the Windows environment like Microsoft Office, MATLAB, AutoCAD, MathCAD, Windows Scripting Host, etc.

5.3 Solver technology:

A. High frequency:

- ↳ Transient solver – general purpose
- ↳ Frequency domain solver – general purpose
- ↳ Integral equation solver – electrically large structures, RCS
- ↳ Asymptotic solver – installed performance, RCS
- ↳ Eigen mode solver – resonant cavities
- ↳ Multilayer solver – planar structures
- ↳ Filter Designer 2D – RF filter analysis and synthesis
- ↳ Filter Designer 3D – cross-coupled cavity filter synthesis

B. Low Frequency:

- ↳ Electrostatic / Magneto static – fast static simulation
- ↳ Stationary current solver – DC applications
- ↳ Time domain solver – non-linear materials, transient effects
- ↳ Frequency domain solver – eddy currents, displacement current

C. EDA:

- ↳ PEEC solver – boards without reference planes
- ↳ Transmission line solver – signal integrity
- ↳ 3D FEFD solver – power integrity
- ↳ Rule Check – EMC and SI on PCB

D. Practical Dynamics:

- ↳ Particle tracking solver – low energy particles, electron guns
- ↳ PIC solver – high energy particles, RF devices
- ↳ Wake field solver – accelerator components

E. Multiphysics:

- ↳ Thermal solvers – electromagnetic heating, bio heat
- ↳ Structural mechanics solver – thermal expansion, deformation

F. EMC:

- ↳ Transmission line matrix (TLM) solver – general purpose, EMC
- ↳ Cable solver – cable harness simulation
- ↳ Rule Check – EMC and SI on PCBs.

(turn to next page)

5.4 Antenna Designing Procedures:

5.4.1 Rectangular microstrip patch Antenna:

First of all, open the CST STUDIO SUITE and then click on new project>MW, RF & Optics>Antenna. There will be various types of antenna, from options we chose planer antenna. After that, we'll choose time domain solver for workflow. And by clicking next a new will window which shows parameters with their units. In this part we have to make sure that the frequency is in 'GHz', Lengths in 'mm' and others parameters will be left unchanged. Now it is time to set the frequency range and select what we want to monitor. Let the frequency range from 3.1 to 4.1GHz and define the operating frequency at 3.5 GHz. We'll mainly monitor electric field, magnetic field and far-field for the defined frequency. Now it's time to give a name to the project and let it 'Antenna MP1'. After clicking okay a hexahedral grid will appear on working plane.

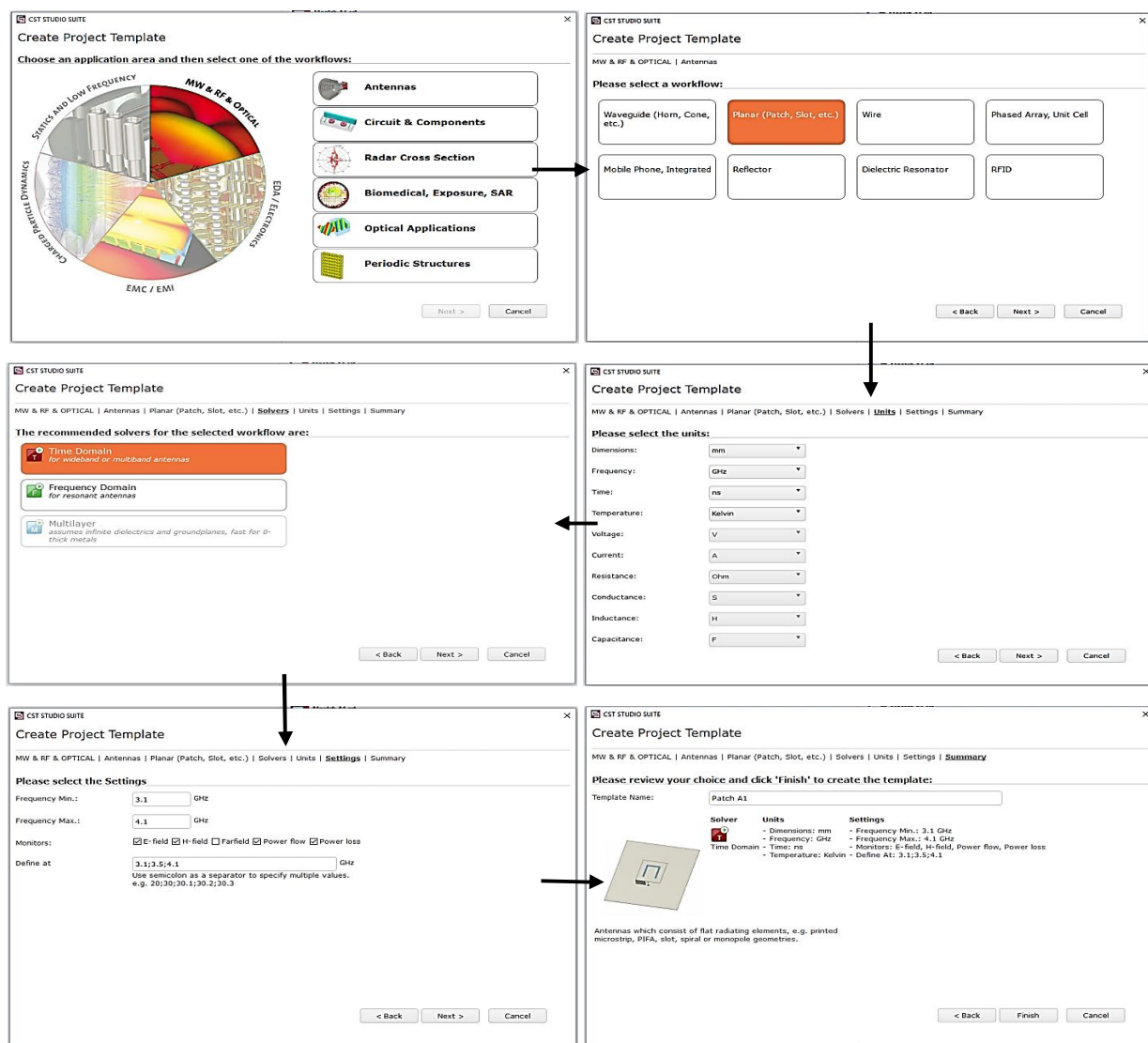


Fig 5.2: Steps to Create project template.

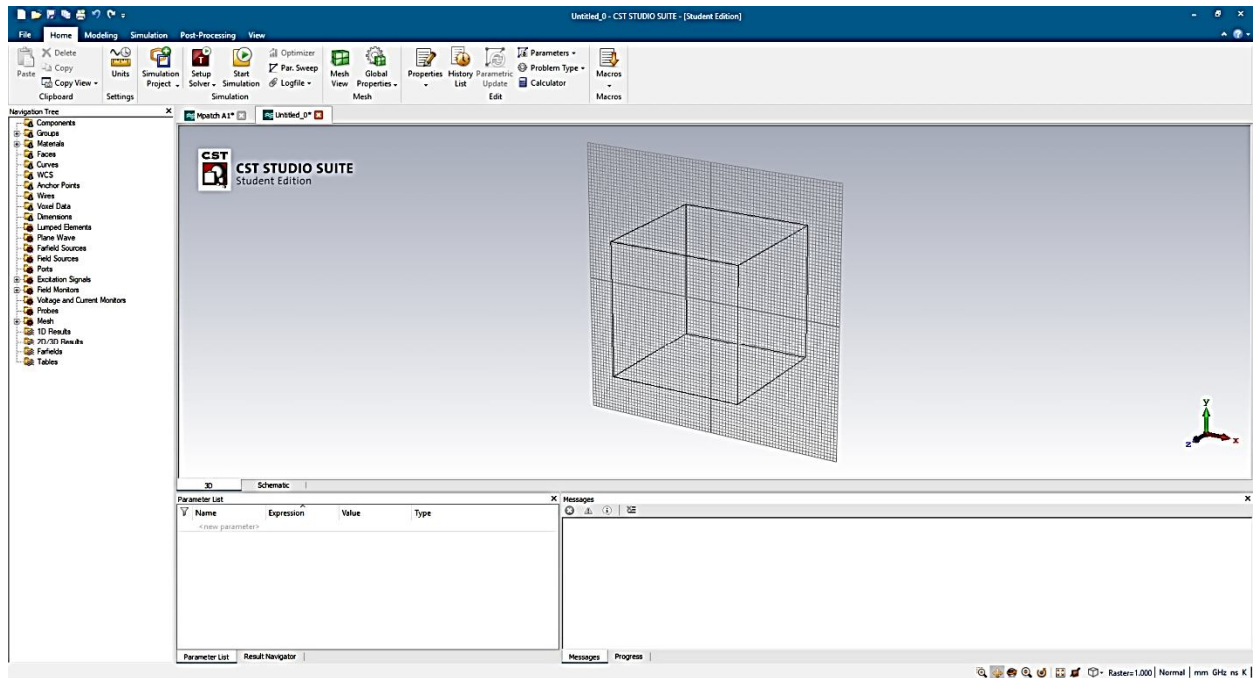


Fig 5.3: CST MWS's working plane.

Now it is time to design a rectangular patch antenna. The values we needed for component's length can be found in the MATLAB program we've stated in chapter 4. So first we have to design a ground plane, steps are going to the modeling window> click on the brick>press Esc key on keyboard thus provide the desired values for dimension and select Copper (pure) as the material. After that, we've to put a substrate on the ground where the dimension would be the same but the material would be FR-4(lossy). Using the similar we've put a patch on the substrate using the calculated values for the dimension and used pure Copper as the material. And it's the turn to create an empty space for feed line where a material is nickel and cut the specific portion of part for it. The next step is to add the feed line which is also made of pure copper add it with the patch using the Boolean method. At this stage, we have to create a waveguide port accordingly and set a pick point on it. After ensuring all the terms we started stimulation.

Table 4: Parameter list with values to design 'Antenna MP1'

Parameter	Length (in mm)
Ground Length (Lg)	30
Ground Width (Wg)	36
Patch Length (Lp)	19.1
Patch Width (Wp)	26
Feed line Length (Fi)	7
Feed line Width (Wf)	3
Gap- Patch & Feed (gpf)	0.5
Height- conductor (ht)	0.03
Height- Substrate (hs)	1.6

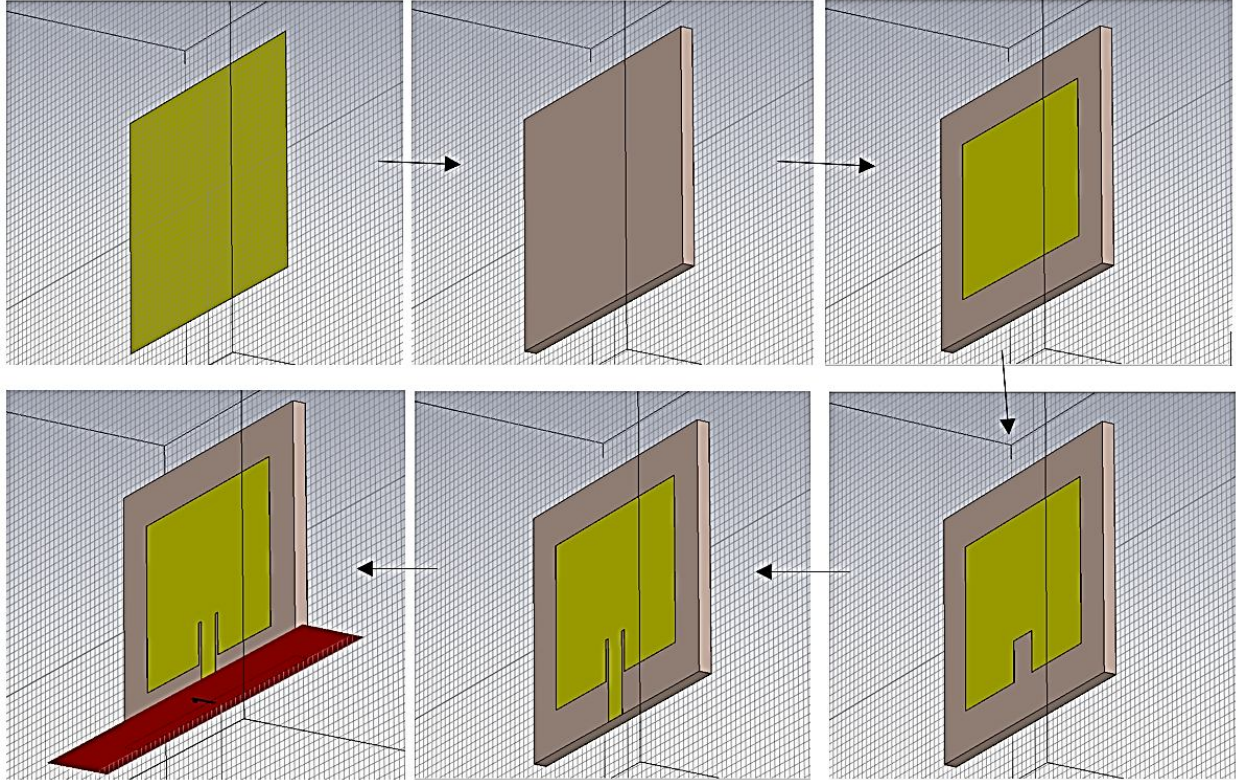


Fig 5.4: Sequence of designing patch antenna 'Antenna-A'

5.4.2 Slotted microstrip Patch Antennas:

In this case we've used the slightly changed data as what we did for designing '**Antenna MP1**' and the steps also was the same. But on the patch, we've used three parallel slots at '**Antenna MP2**' and seven slots at "**Antenna MP3**' to improve the performance like gain and directivity of the antenna.

Table 5: Parameter list with values to design 'Antenna MP2'

Parameter	Length (in mm)
Ground Length (Lg)	30
Ground Width (Wg)	36
Patch Length (Lp)	19
Patch Width (Wp)	26
Feed line Length (Fi)	7.1
Feed line Width (Wf)	3
Gap- Patch & Feed (gpf)	0.4
Height- conductor (ht)	0.04
Height- Substrate (hs)	1.6

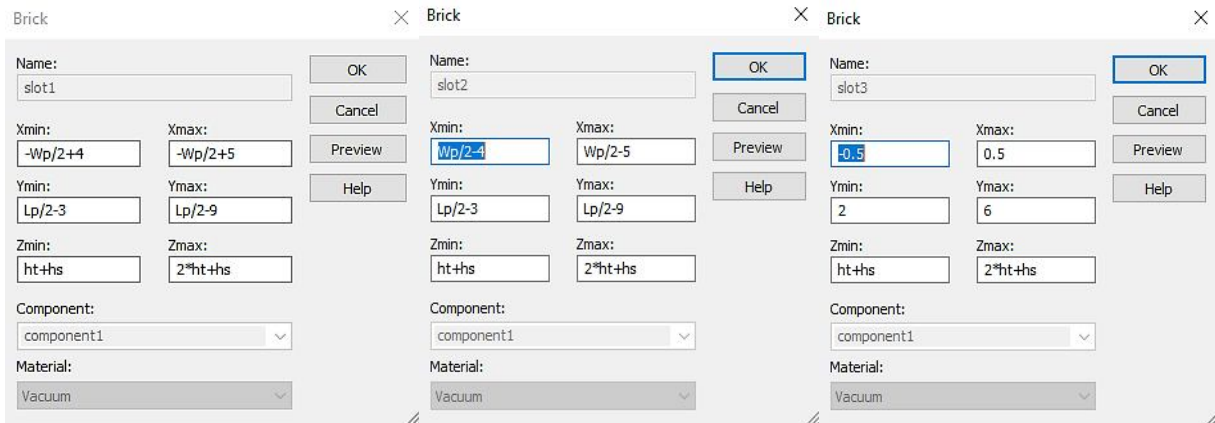
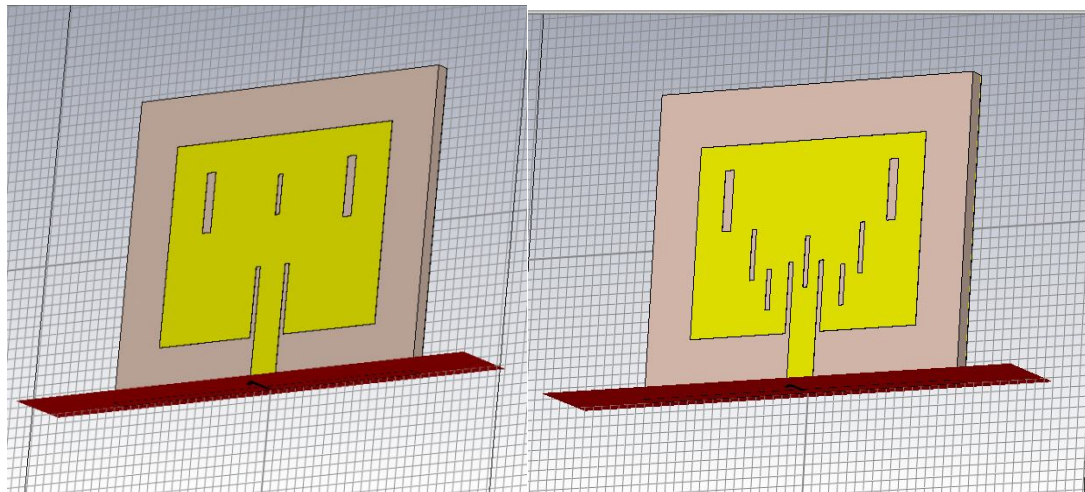


Fig 5.5: Slot value assignation for our desired antenna MP2

Table 6: Parameter list with values to design 'Antenna MP3'

Parameter	Length (in mm)
Ground Length (Lg)	30
Ground Width (Wg)	36
Patch Length (Lp)	18.9
Patch Width (Wp)	26
Feed line Length (Fi)	7.0
Feed line Width (Wf)	3
Gap- Patch & Feed (gpf)	0.5
Height- conductor (ht)	0.03
Height- Substrate (hs)	1.7



5.6: Diagram of 'Antenna-MP2' and 'Antenna-MP3'

Fig

Chapter 6: Results and Discussion

6.1 Antenna Stimulation:

We've designed three microstrip patch antennas after trying several combinations, changing the parameters and inserting slots on the patch. After that we've applied our desired frequency point to measure the field patterns. In our next step, we've used time domain solver to stimulate the antennas at '-30 dB' accuracy point. It took a while to complete the stimulation and there it showed a completion message at the end at the down right corner. Now we've got return loss, standing wave ratio, surface current, power flow, E-field, H-field, Bandwidth, gain, realized gain, efficiency etc. In our next steps we've synchronized those results and compared the performances antennas.

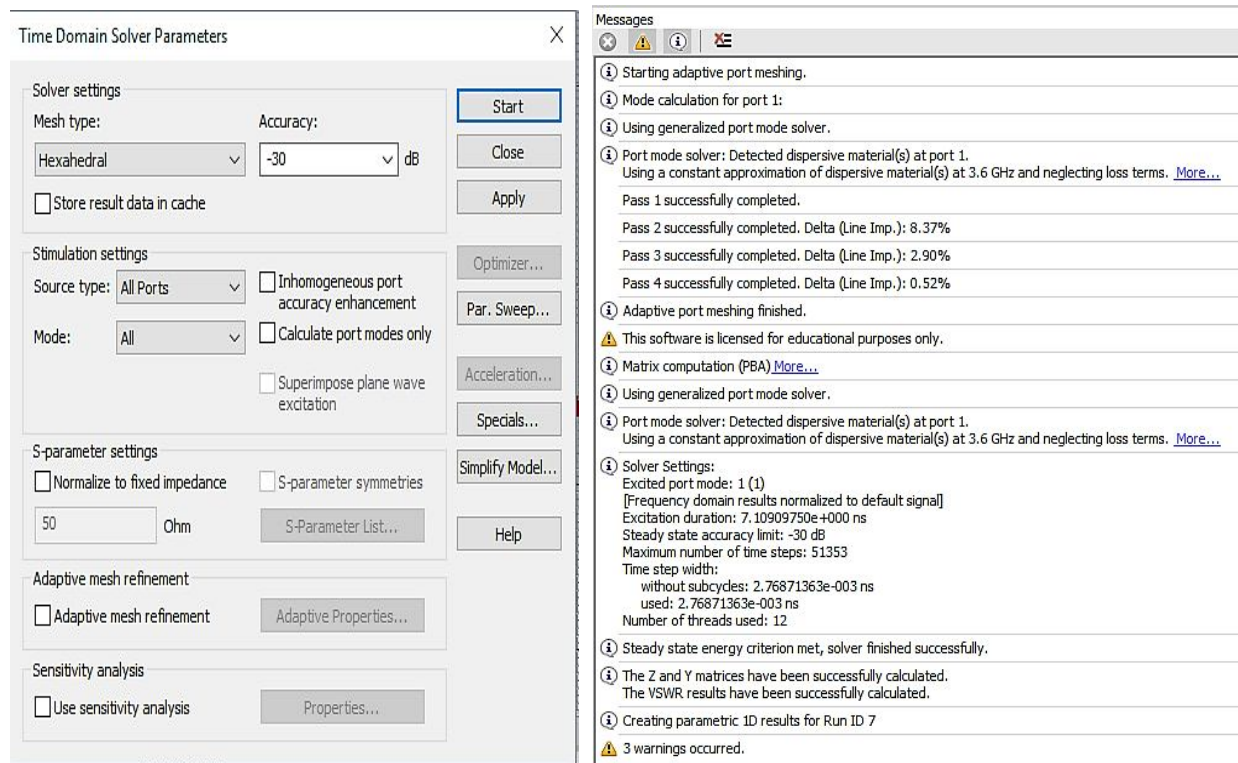


Fig 6.1: Time domain solver (left) and stimulation message log(right).

6.2 Result Parameter of Our Designed antennas:

Antenna-MP1:

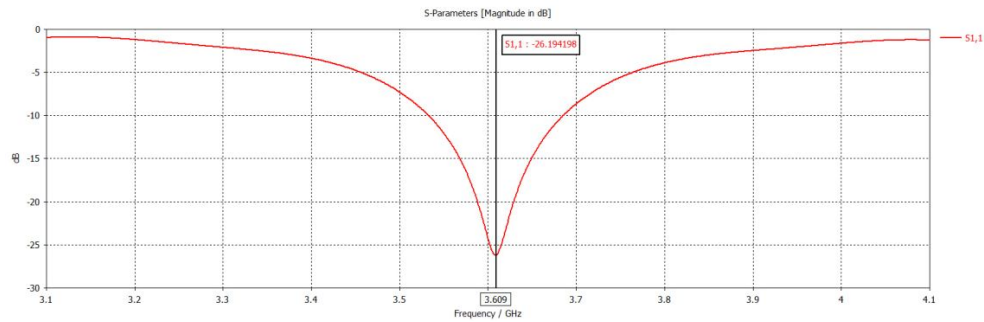


Fig 6.2: Return loss of 'Antenna-MP1'

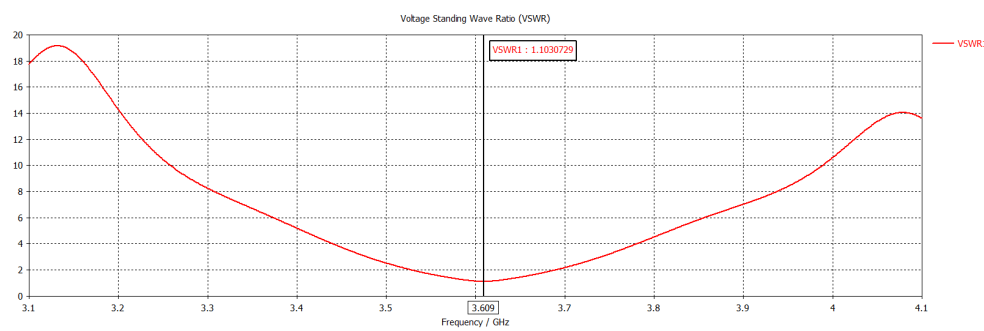


Fig 6.3: Standing wave ratio for 'Antenna-MP1'

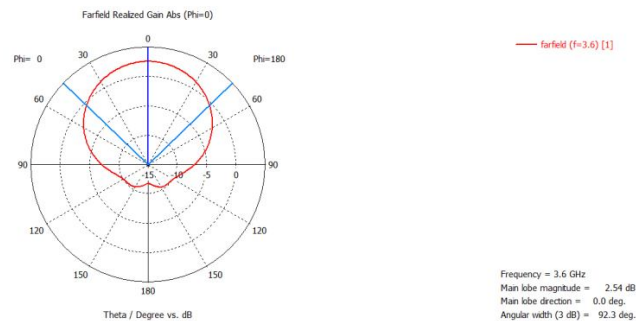


Fig 6.4: Far field radiation pattern (gain) in polar from for 'Antenna-MP1'

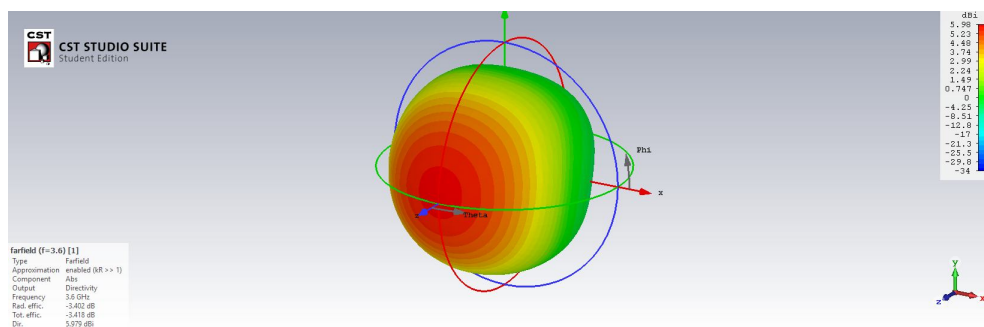


Fig 6.5: Far field radiation pattern (directivity) in 3D from for 'Antenna-MP1'

► **Antenna-MP2:**

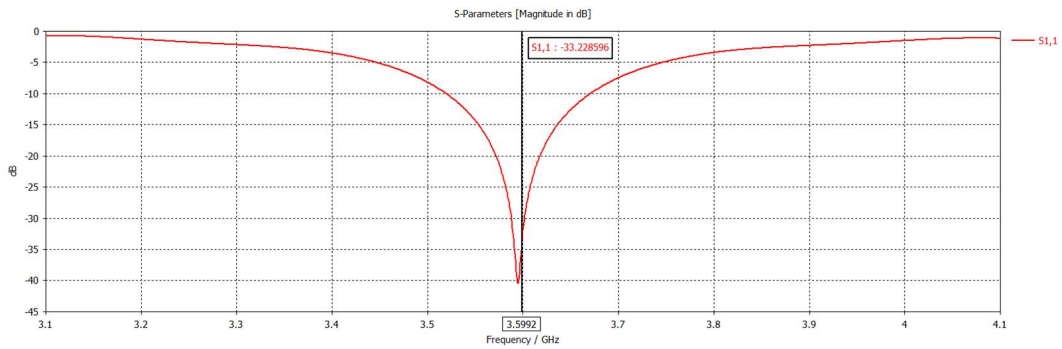


Fig 6.6: Return loss of 'Antenna-MP2'

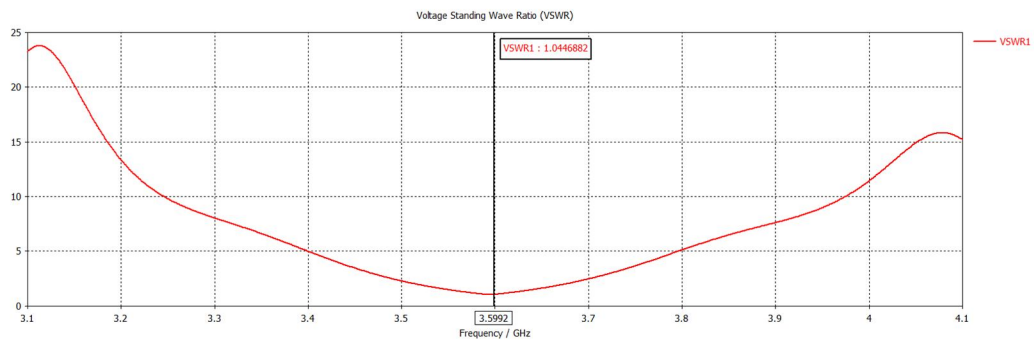


Fig 6.7: Standing wave ratio for 'Antenna-MP2'

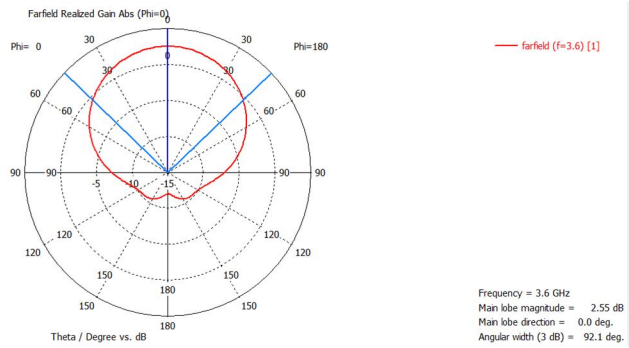


Fig 6.8: Far field radiation pattern (gain) in polar from for 'Antenna-MP2'

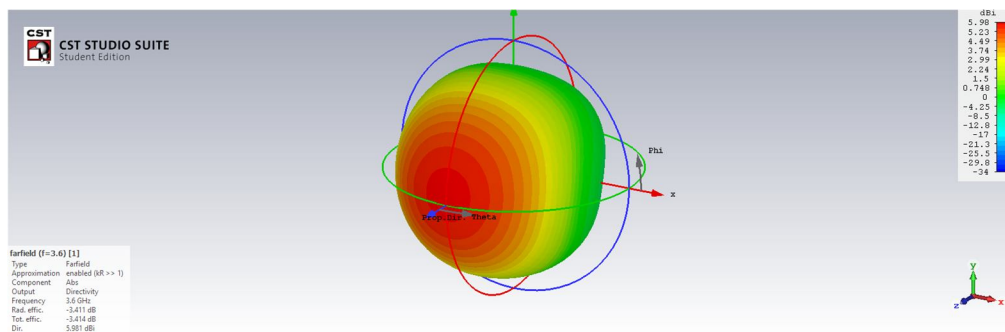


Fig 6.9: Far field radiation pattern (directivity) in 3D from for 'Antenna-MP2'

➔ **Antenna-MP3:**

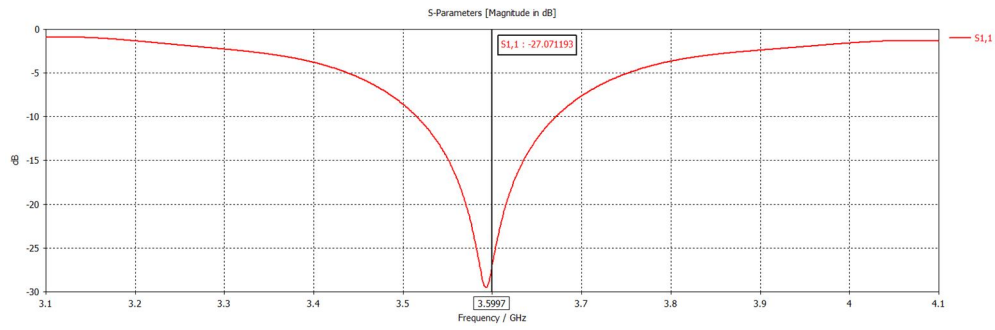


Fig 6.10: Return loss of 'Antenna-MP3'

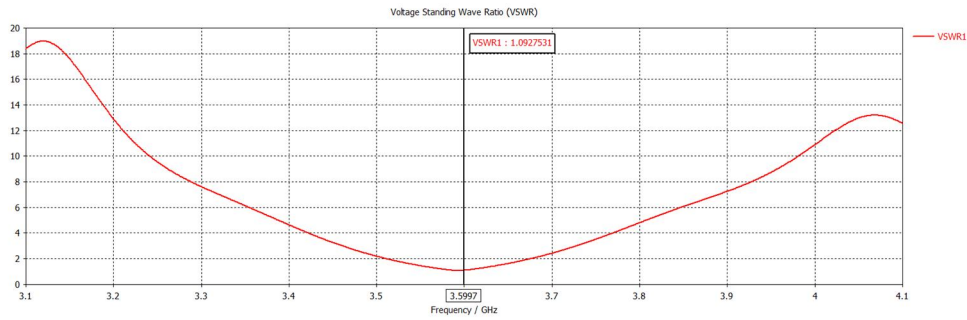


Fig 6.11: Standing wave ratio for 'Antenna-MP3'

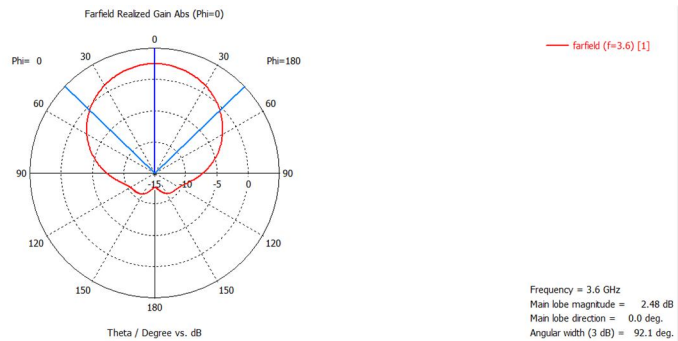


Fig 6.12: Far field radiation pattern in polar from for 'Antenna-MP3'

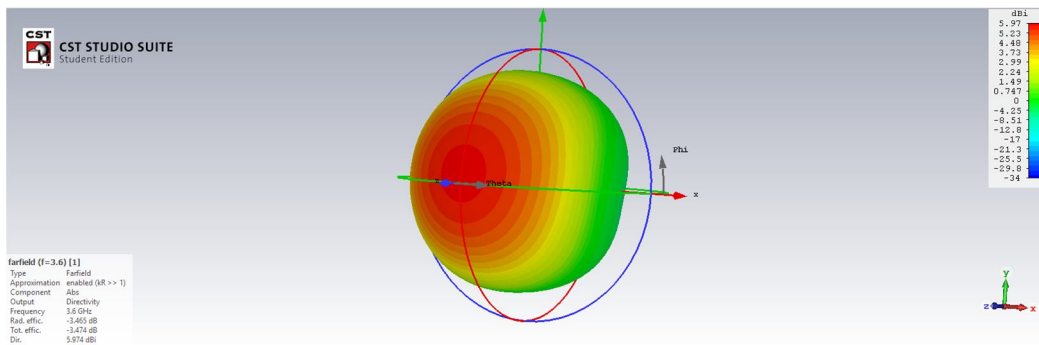


Fig 6.13: Far field radiation pattern (directivity) in 3D from for 'Antenna-MP2'

6.3 Comparison of Designed antennas:

So far, we've designed and arranged the result parameters of each antenna in a sequential order, and now we'll make a comparison among the three designed antennas to find out the most suitable one.

Table 7: Comparison among three designed antennas (for 3.6Ghz)

Antenna	Volume (Lp.Wp.hs) (mm ³)	Return Loss (dB)	VSWR	BW(%) (-10dB)	BW (MHz)	Directivity (dBi)	Realized Gain (dB)
MP1	19.1 × 26 × 1.6 = 794.56	-24.3	1.13	4.25	153	5.97	2.56
MP2	19 × 26 × 1.6 = 790.4	-32.1	1.05	4.27	154	5.98	2.57
MP3	18.9 × 26 × 1.7 = 835.4	-26.7	1.10	4.30	155	5.97	2.50

After comparing the antennas we've found that their performance is quite similar but yet there are some slight differences. Firstly, if we talk about the size the volume of the antenna MP3 is a bit higher where MP2 and MP1 are almost identical. The return loss of MP2 is -32.1 dB which indicates that it can radiate power more efficiently than two others. Now from the VSWR graph, it is obvious that all the antennas are matched well with the transmission line as their standing wave ratio values are around 1. And again, the MP2 shows a bit better value 1.05, thus this standing wave ratio value is almost ideal.

We've also calculated the bandwidth (BW) of the antennas from the return loss graph. All the three antenna's bandwidth is almost same where MP3 stays at the top with percentage BW 4.3 with linear BW 155Mhz. The directivity of the antennas is around 5.98 dBi which means that accuracy of the all antenna's radiation pattern in a given direction is also similar. There is also no noticeable difference in realized gain of the antennas, only the MP2's gain is 2.57 which is a bit high compared to others.

So, the overall performance of the antenna MP2 is better compared to our other designed antennas. It is compact as it just 790.4mm³ in size, have high return loss, broad bandwidth, good directivity and gain compared to other low gain antennas. For those reasons, we've chosen MP2 as our proposed antenna.

Table 8: Comparison among other's designed antenna with proposed antenna

SL	Volume (Lp.Wp.hs) (mm ³)	Return Loss (dB)	BW(%) (-10dB)	Operating freq. (Ghz)	Reference
1	19 × 26 × 1.6 = 790.4	-32.1	4.27	3.6	proposed antenna
2	46 × 56 × 1.6 = 4121.6	-19	2.26	2.44	Hrucha R. Kharat, et al [11]
3	40 × 47 × 1.2 = 2256	-30	1.87	3.23	Md. Amirul Islam et al [12]
4	37 × 24 × 1.6 = 1420.8	-16.3	3.9	5.9	Navpreet Kaur et al [13]
5	25 × 24.9 × 3.2 = 1992	-26.5	3.94	3.55	Ali El Alami et al [14]
6	26 × 20 × 1.6 = 832	-25	3.4	3.5	Nurul, Jahid, Pappu [15]

We've compared MP2 with similar profile antenna designing published in international journals. After reanalyzing the parametric data of MP2 with them we've found that it is the most compact sized antenna among them yet a solid performer. It can radiate quite efficiently at 3.6 GHz band as it has a good flexibility in bandwidth. One drawback is that the gain of the antenna could be a bit more to increase the area of radiation.

Chapter 7: Conclusion & Future Work

7.1 Conclusion:

We've designed, analyzed and compared the performance of our proposed antenna to make it acceptable for small range ultrawideband devices which can operate well at any frequency ranging from 3.55 to 3.64 GHz. As we know that 5G is on the way to consumer level and there is a possibility to make 3600 MHz as a carrier band, so we can hope that our proposed antenna could be used in compact devices to interact at the band.

In our analysis, we've noticed that a properly slotted microstrip patch antenna can perform better than a plain microstrip patch antenna. The bandwidth (154MHz) and return loss (-32.2dB) of the proposed antenna are quite good at a compact and lightweight design. We've used a low cost but a good performer FR-04 as our substrate and pure copper for ground and patch. We've also used a predefined MATLAB code to calculate the rough values of parameters like width, length, height, feed size etc. and altered those values a bit to have a good result at the as the output. Our value assignation was near perfect and our antenna matched with the 50 Ohm transmission line as the VSWR was 1.05. Now we are hoping to develop similar types of antennas with more accuracy at a more compact size.

7.2 Future work:

Antenna engineering is a vast field, new types of antennas have been developed for every specific need considering the range and area to cover. In designing a compact ultra-wideband antenna further improvement can be made in the following segments stated below.

- The radiation pattern, directivity, gain and efficiency and be improved by using array element in microstrip phase array antennas.
- We can use circular, elliptical beam or any shaped slots to change the directivity and others parameters.
- Different materials like (RT Duroid 6002, RO 4730, RO 3200) can be used as substrate as per need or to check the performance variations.
- Microstrip and ground can be made with copper, gold, silver. Silver has higher conductivity then gold and copper but not hard enough. Gold is excellent conductor but expensive, so overall copper is used at it is more available, low cost and hard enough to use in compact antennas as well.
- Various tools like CST, MATLAB, ADS Momentum and other online tools to make the working easy and time efficient.

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