KALINGA INSTITUTE OF INDUSTRIAL TECHNOLOGY (KIIT)

Deemed to be University U/S 3 of the UGC Act, 1956

LABORATORY RECORD – AUTUMN 2020

MICROWAVE ENGINEERING LAB (EC 3015)

DEBAGNIK KAR

ROLL NO: 1804373

Section: ETC-06

Index Page

Experiment Number	01
Date of Experiment	12/08/2020
Date of Submission	16/08/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC – 06

Aim of The Experiment: -

To design a quarter wave transformer for matching a 50 Ω microstrip line with a load of 173Ω

Equipment / Software Required:-

CST Studio Suite 2019 (Student Edition)

Theory:

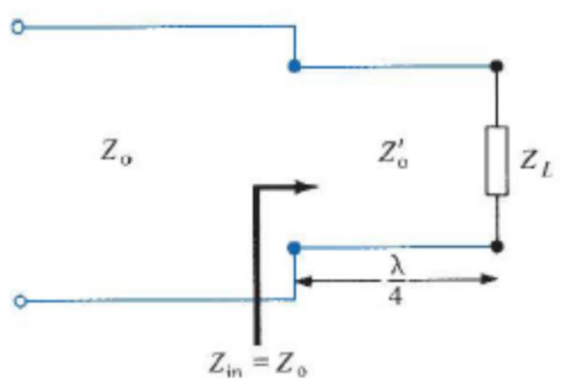


Fig 1.1: Load matching using a quarter wave transformer

When $Z_0 \neq Z_L$, the load is said to be mismatched and a reflected wave exist. So, we use quarter wave transformer for impedance matching.

When $l = \frac{\lambda}{4}$,

$$\boxed{Z_{in} = Z_0 \left[\frac{Z_L + \frac{jZ_0 \tan \pi}{2}}{Z_0 + \frac{jZ_L \tan \pi}{2}} \right] = \frac{Z_0^2}{Z_L}}$$

A mismatched load can be properly matched to a line (with characteristic impedance Z_0) by inserting prior to the transmission line λ/4 long (with characteristic impedance Z'_0) as depicted in Fig.1.

From (1), Z'_0 is selected such that ($Z_{in}=Z_0$)

Therefore,

$$Z'_0 = \sqrt{Z_0 Z_L} \tag{2}$$

Note: When microstrip line is used, then guided wavelength must be used, i.e.,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

(3)

where, λ_g= guided wavelength.

When $Z_0 \neq Z_L$, the load is said to be mismatched and a reflected wave exist. So, we use quarter wave transformer for impedance matching.

When $l = \frac{\lambda}{4}$,

$$\boxed{Z_{in} = Z_0 \left[\frac{Z_L + \frac{jZ_0 \tan \pi}{2}}{Z_0 + \frac{jZ_L \tan \pi}{2}}\right] = \frac{Z_0^2}{Z_L}}$$

A mismatched load can be properly matched to a line (with characteristic impedance Z_0) by inserting prior to the transmission line λ/4 long (with characteristic impedance Z'_0) as depicted in Fig.1.

From (1), Z'_0 is selected such that ($Z_{in}=Z_0$)

Therefore,

$$Z'_0 = \sqrt{(Z_0 Z_L)}$$

Z_0 = 50

Z_L = 173

$$Z'_0 = \sqrt{(50 \times 173)}$$

$$Z'_0 = 93.01\ \Omega \tag{2}$$

Note: When microstrip line is used, then guided wavelength must be used ,i.e.,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{3}$$

where, λ_g= guided wavelength.

Substrate: FR4 (Lossless) (ε_r = 4.3)

Width of the substrate is 50 mm and the length are 100 mm

h = 1.6 mm

t = 0.2 mm

W = 2.93 mm (determined using Analysis and synthesis of transmission lines)

ε_{eff} = 3.204

$Z_0' =$ 93.01 Ω length = 17 mm

Therefore, width of the quarter wave line is 0.87mm

Design:

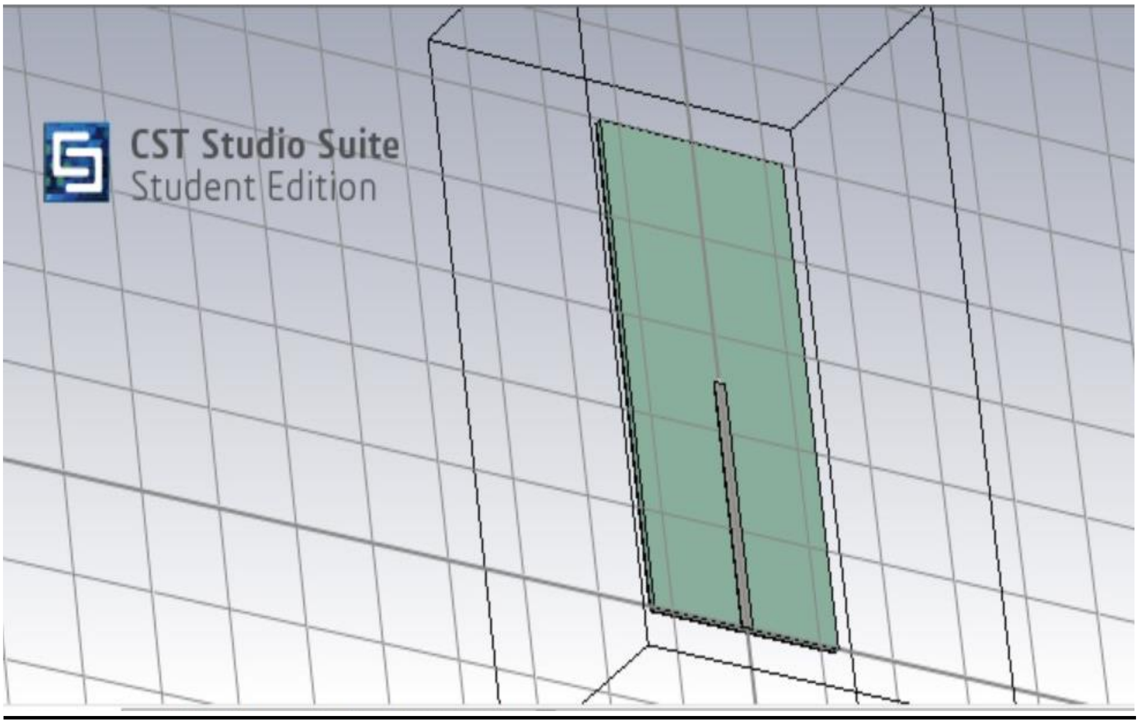


Fig 1.2: Design of microstrip line terminated with the desired load.

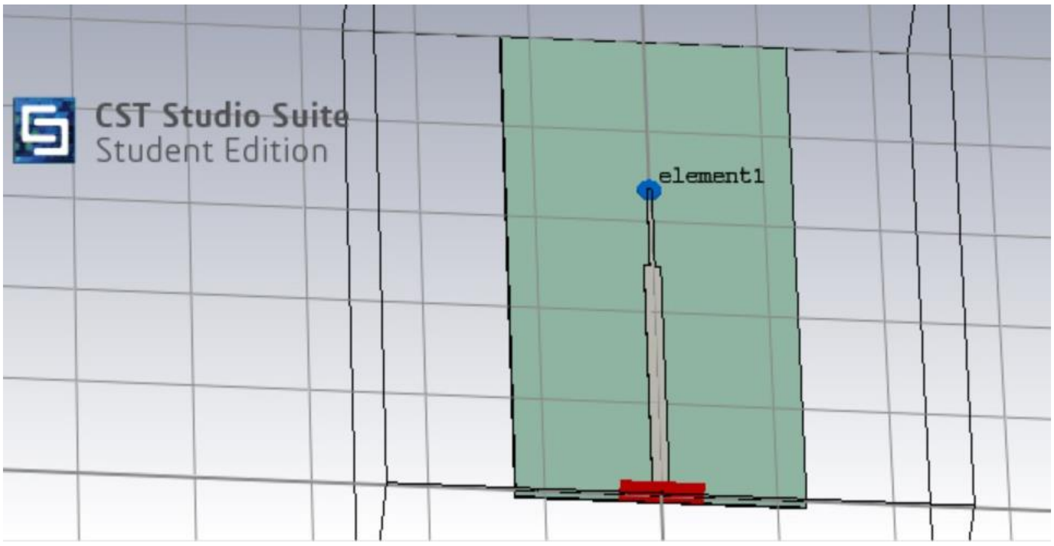


Fig 1.3: Design of microstrip line terminated with quarter wave line and desired load

Output/Graph:-

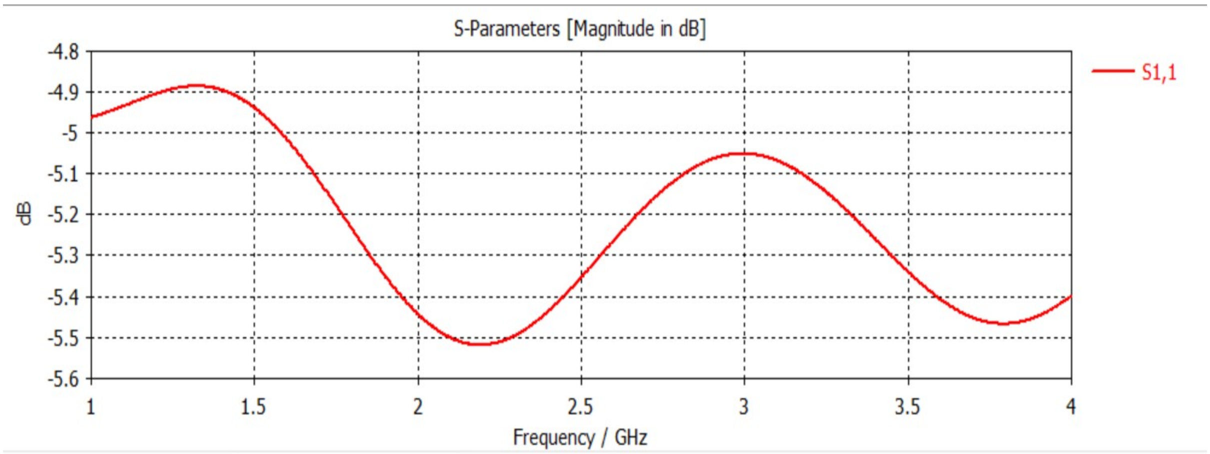


Fig 1.4: Result of the design of the microstrip line

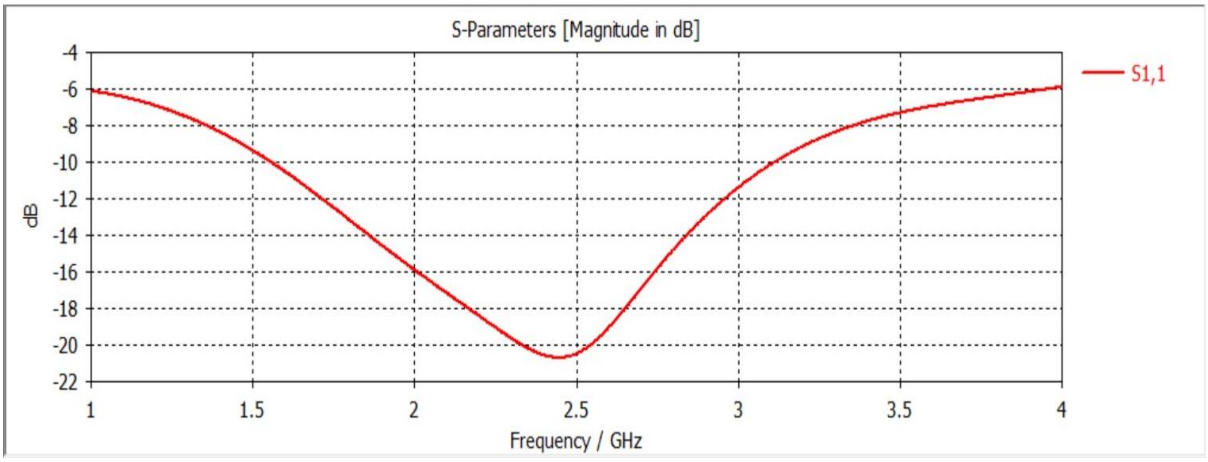


Fig 1.5: Result of the design of the microstrip line terminated by quarter wave line.

Observation of the experiment:

- For fig 4, No resonance is observed around 2.4 GHz which implies impedance mismatch.
- For fig 5, an impedance is achieved at 2.4 GHz by using a quarter wave transformer.

Conclusion:-

The designing of a quarter wave transformer for matching a 50 Ω microstrip line with a load of 173 Ω is successfully achieved.

Experiment Number	02
Date of Experiment	19/08/2020
Date of Submission	24/08/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC - 06

Aim of The Experiment :-

To design a wire dipole antenna operating at 373 MHz and to find the directive gain and half power beam width from the radiation pattern.

Software Required:-

CST Studio Suite 2019 (Student Edition)

Theory

The length of the Dipole Antenna is given by the formula:

$$\boxed{L = \frac{\lambda}{2} = \frac{c}{2f}}$$

f = 373 MHz
The length of the dipole is 0.402 m = 402 mm

For the 402 mm length, we have got, 0.373 GHz which is far from our desired result, so we can't consider it as our result.

We know, the input impedance = (73± 40j)

To cancel the complex part, we have to use a shorter length.
I am taking 360 mm to get a value which is nearly equal to the desired result 0.373 GHz

Design:-

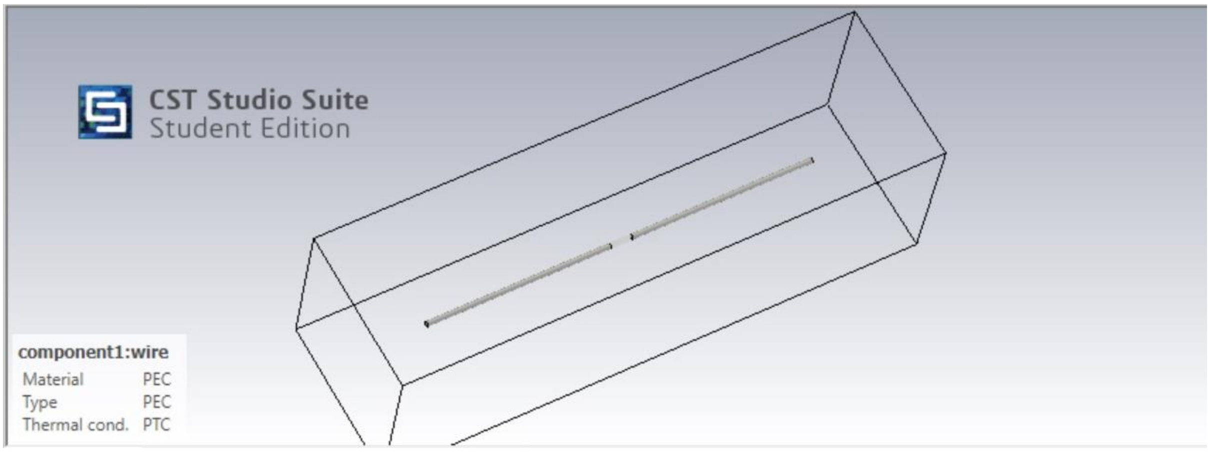


Fig 2.1: Design of wire dipole antenna

Observation:-

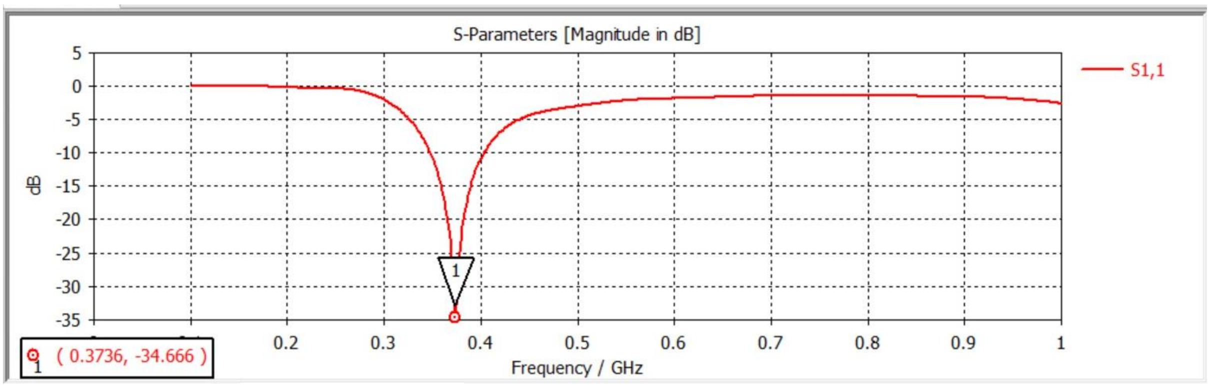


Fig 2.2: S11 Characteristics

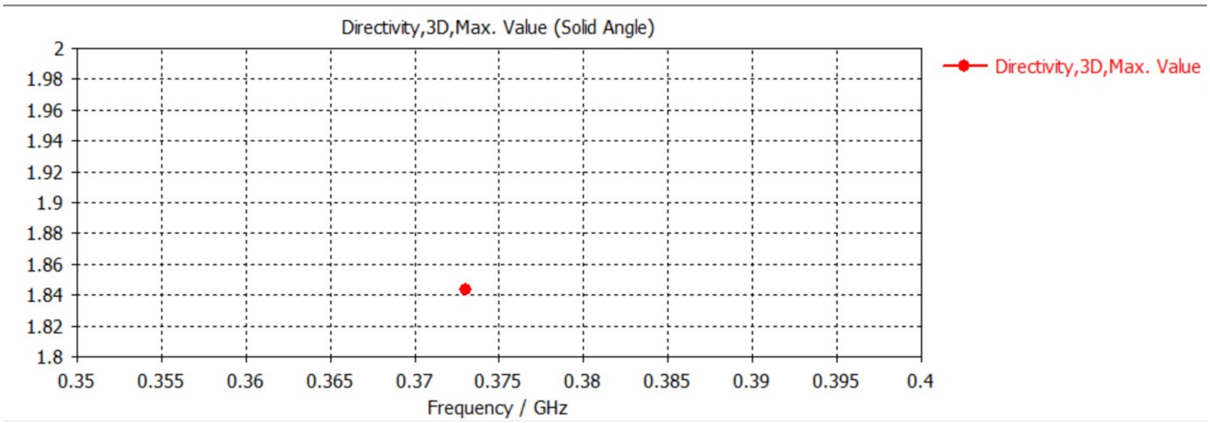


Fig 2.3: Directive Gain

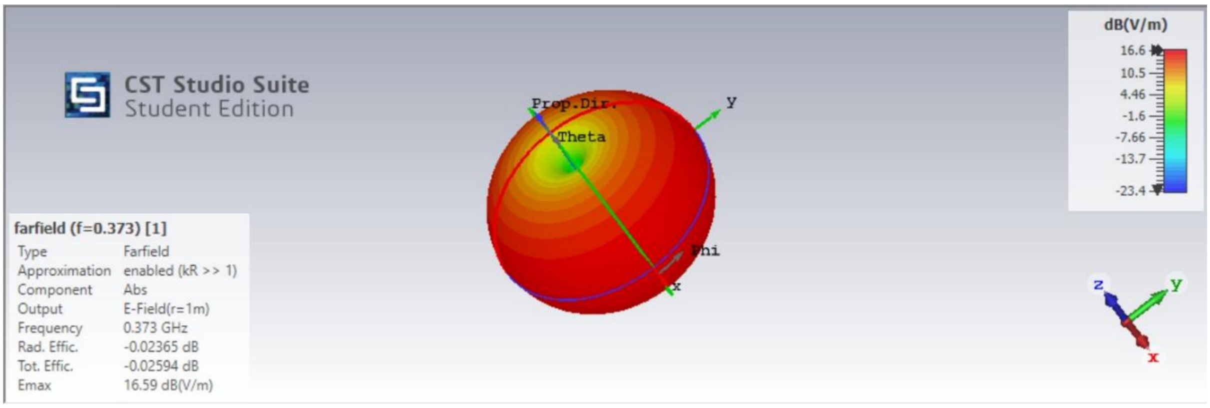


Fig 2.4: Radiation Pattern in X-Z and X-Y plane

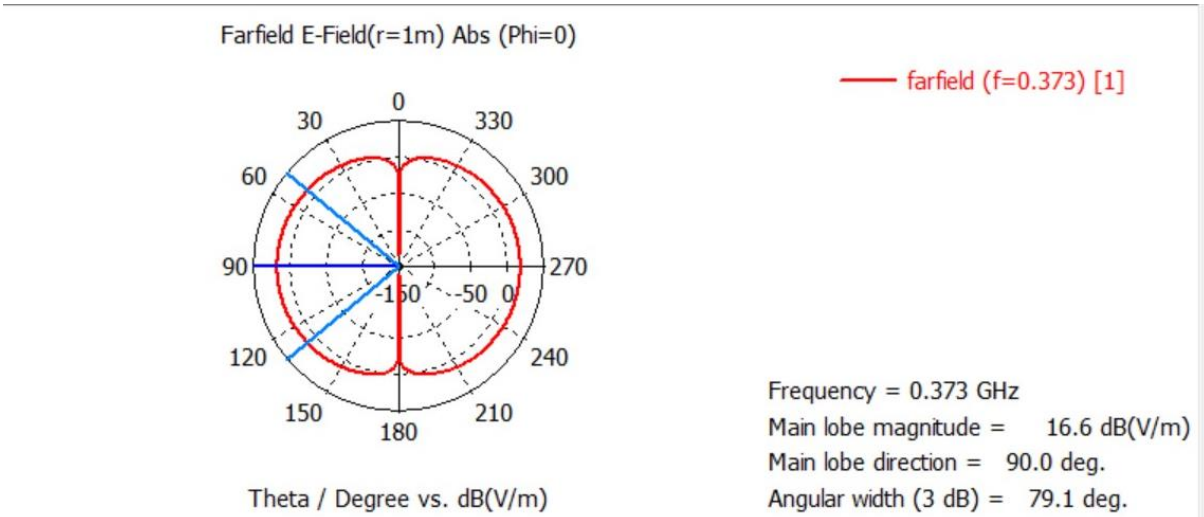


Fig 2.5: Plane radiation pattern and half powered beam width

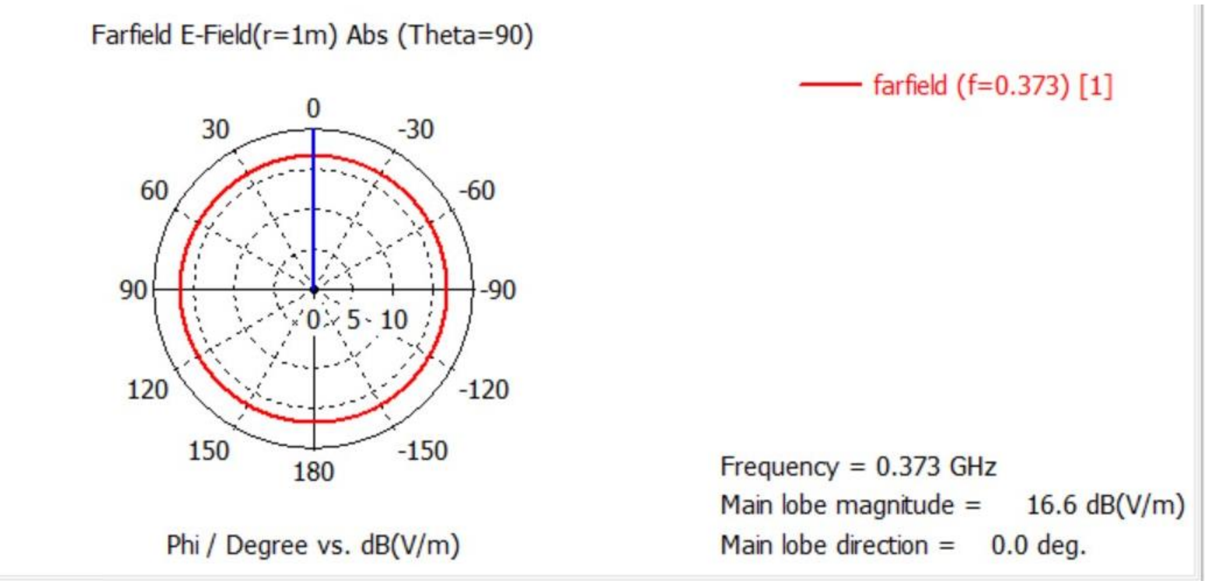


Fig 2.6: H-plane omni-directional Radiation Pattern

Inference of the experiment:

From this experiment, we learnt how to design a wire dipole antenna using CST Studio Suite. We also got to learn about the concept of radiation pattern after performing the experiment

Conclusion:-

A successful design of a wire dipole antenna operating at 373 MHz is successfully simulated on a virtual platform.

Experiment Number	03
Date of Experiment	26/08/2020
Date of Submission	30/08/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC - 06

Aim of The Experiment :-

To design Yagi-Uda Array antenna and to find the directivity and Half power beam width form the radiation patterns.

Software Required:-

CST Studio Suite 2019 (Student Edition)

Theory

The Yagi antenna consists of a single 'feed' or 'driven' element, typically a dipole or a folded dipole antenna. This is the only member of the above structure that is actually excited (a source voltage or current applied). The rest of the elements are parasitic - they reflect or help to transmit the energy in a particular direction. The length of the feed element is given as F. The feed antenna is almost always the second from the end. This feed antenna is often altered in size to make it resonant in the presence of the parasitic elements (typically, 0.45-0.48 wavelengths long for a dipole antenna).

The element to the left of the feed element is the reflector. The length of this element is given as R and the distance between the feed and the reflector is SR. The reflector element is typically slightly longer than the feed element. There is typically only one reflector; adding more reflectors improves performance very slightly. This element is important in determining the front-to-back ratio of the antenna.

Calculations:

Operating Frequency: 0.73GHz

Therefore $wavelength, \lambda = \frac{Speed\ of\ light\ (c)}{Given\ frequency(f)}$ = 410.1 meters

Length of feeder: 0.47 λ = 192.75 m

Length of reflector: 0.5 λ = 205.05 m

Length of director: 0.406 λ = 166.50 m

Spacing between the feeder and reflector: 0.25 λ = 102.53 m

Spacing between feeder and director: 0.34 λ = 139.43 m

But the calculated values may not give the desired results so I took the following values instead which is very close to the calculated values but will also give me the desired result.

Length of feeder: 167.5 m

Length of reflector: 179.5 m

Length of director: 141 m

Spacing between the feeder and reflector: 143.34 m

Spacing between feeder and director: 108.52 m

Design:-

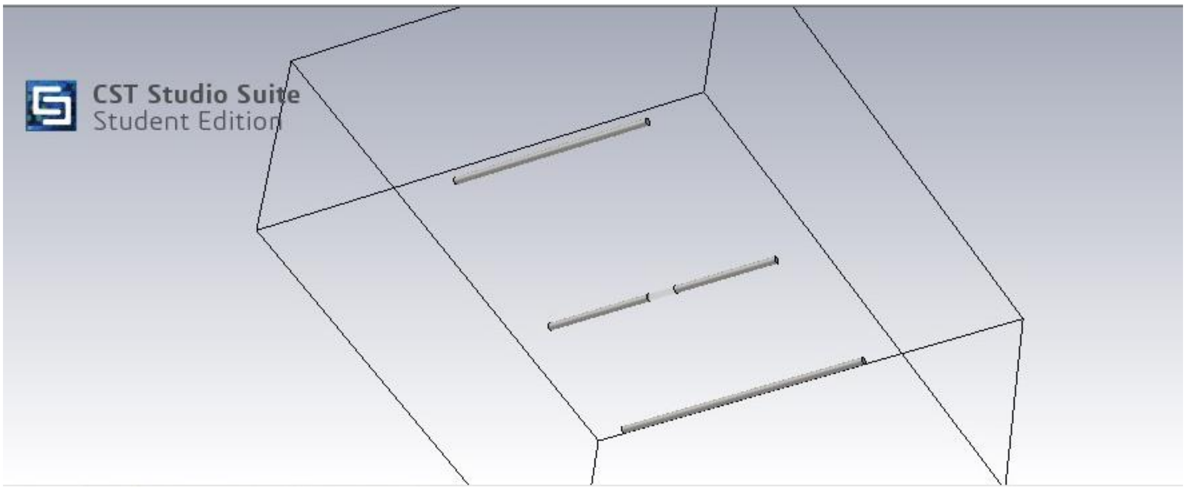


Fig 3.1: Design of the antenna

Observation:-

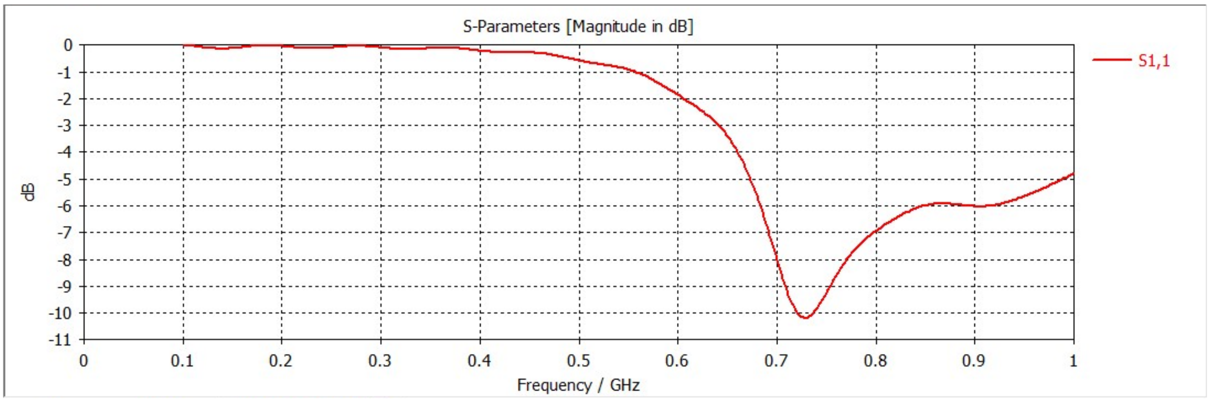


Fig 3.2: S11 Characteristics

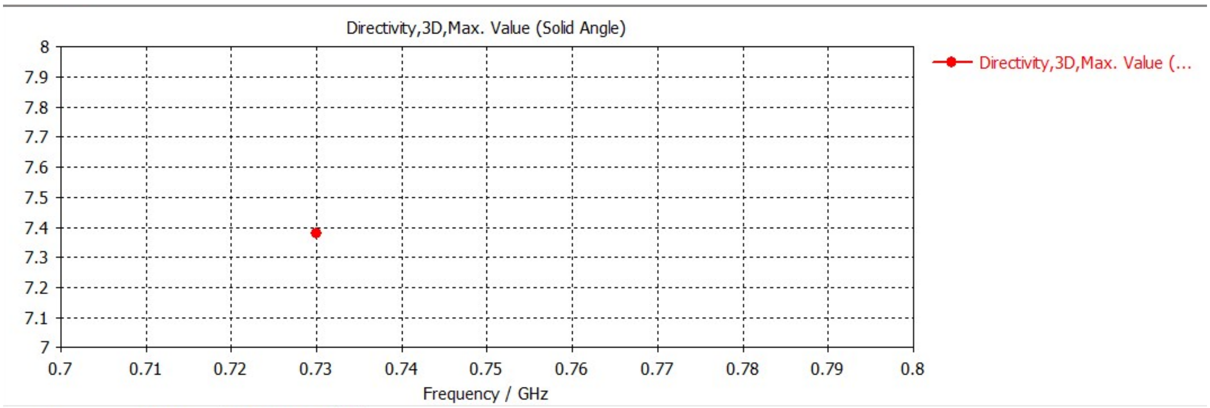


Fig 3.3: Directivity gain

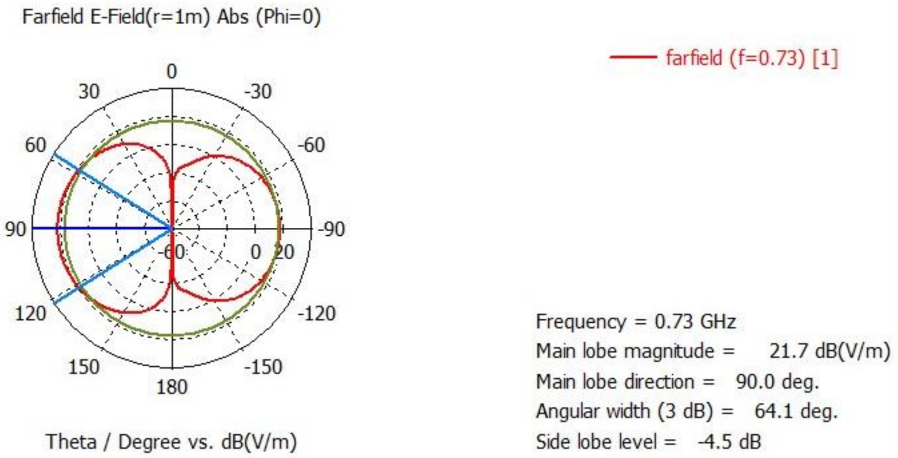


Fig 3.4: Plane radiation pattern and half powered beam width

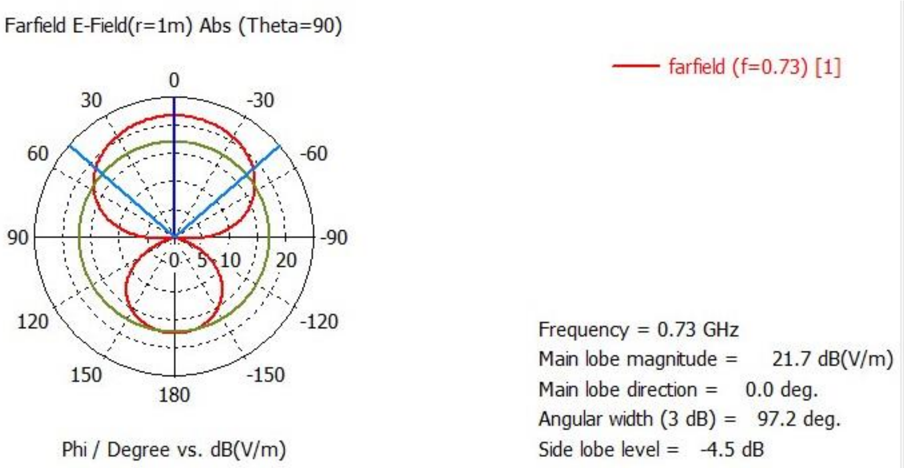


Fig 3.5: H-plane omni-directional Radiation Pattern.

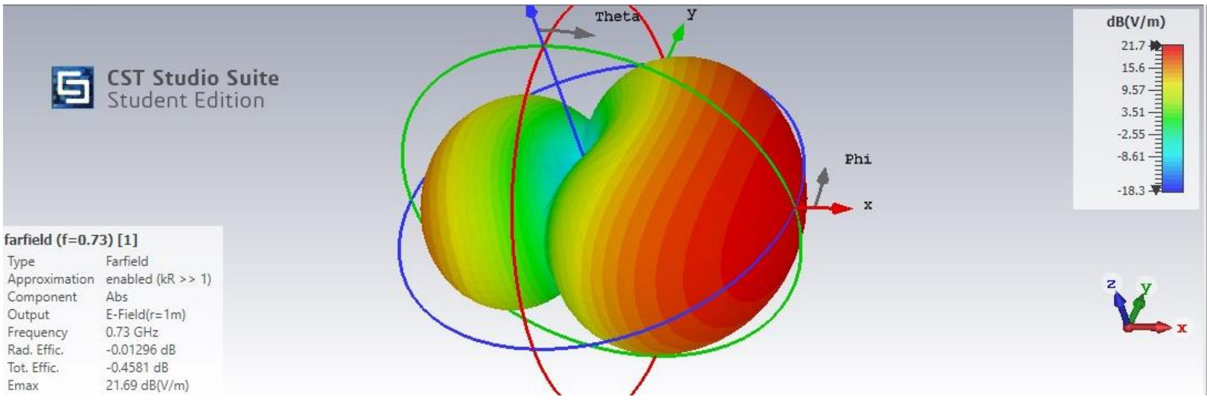


Fig 3.5: Radiation Pattern in X-Z and X-Y plane

Discussion or Inference of the experiment

From this experiment I came to know about the working of Yagi-Uda Antenna and the radiation pattern of it

Conclusion:-

Design of Yagi-Uda Array antenna is executed successfully at 0.73MHz frequency on a virtual platform and the directivity and Half power beam width form the radiation patterns is attached with the lab record.

Experiment Number	04
Date of Experiment	02/09/2020
Date of Submission	03/09/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC - 06

Aim of The Experiment :-

Design of a pyramidal Horn Antenna and study its radiation characteristics.

Software Required:-

CST Studio 2019 (Student Suite)

Theory

Design equations

$$\tan\frac{\theta}{2} = \frac{a}{2L}$$

$$L = \frac{a^2}{8\delta}$$

$$\theta = 2.\arctan\left(\frac{a}{2L}\right) = 2\cos\left(\frac{L}{L+\delta}\right)$$

where, θ= flare angle (θ_E for E plane, θ_H for H plane).

a= aperture (a_E for E plane, a_H for H plane)

L=horn length

δ= path length difference

Here We are designing a pyramidal horn antenna operating at 5.5GHz ie λ = 0.054m = 54mm. Take δ = 0.17λ = 0.0092 and L = 160mm

Form $L = \frac{a^2}{8\delta}$ we get, a = 108.5 mm for both E and H plane.

Design:-

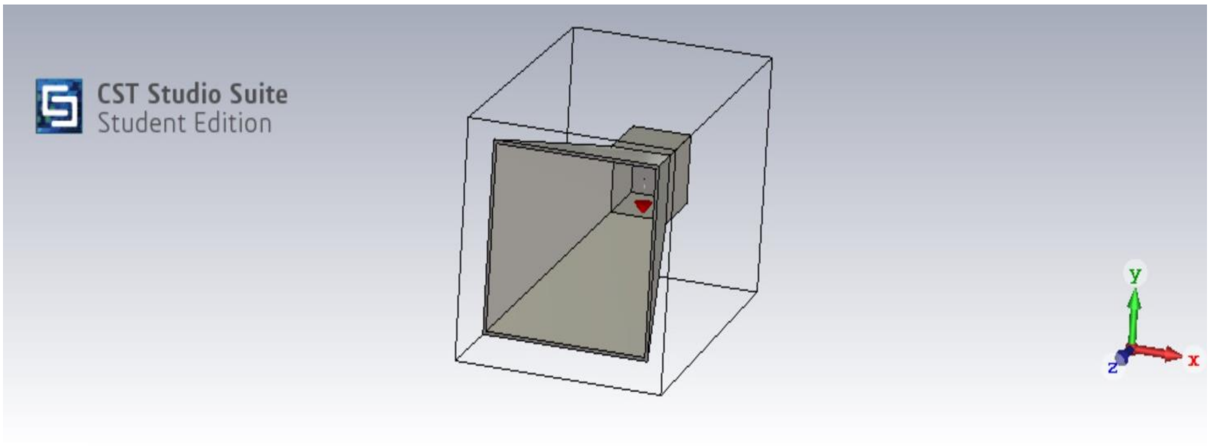


Fig 4.1: 3D model of the design

Observation:-

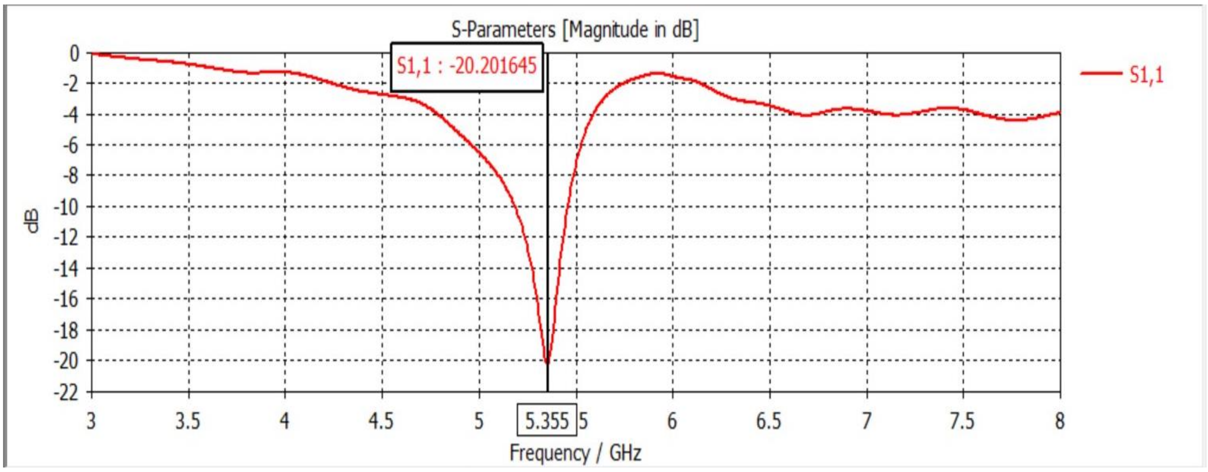
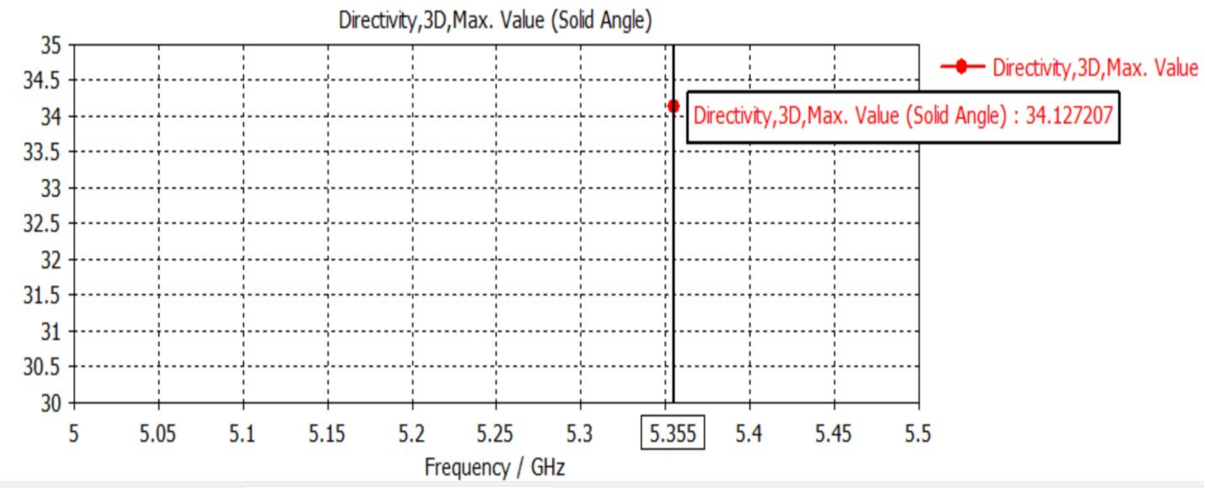


Fig 4.2: S11 Characteristics



4.3: Directivity Gain

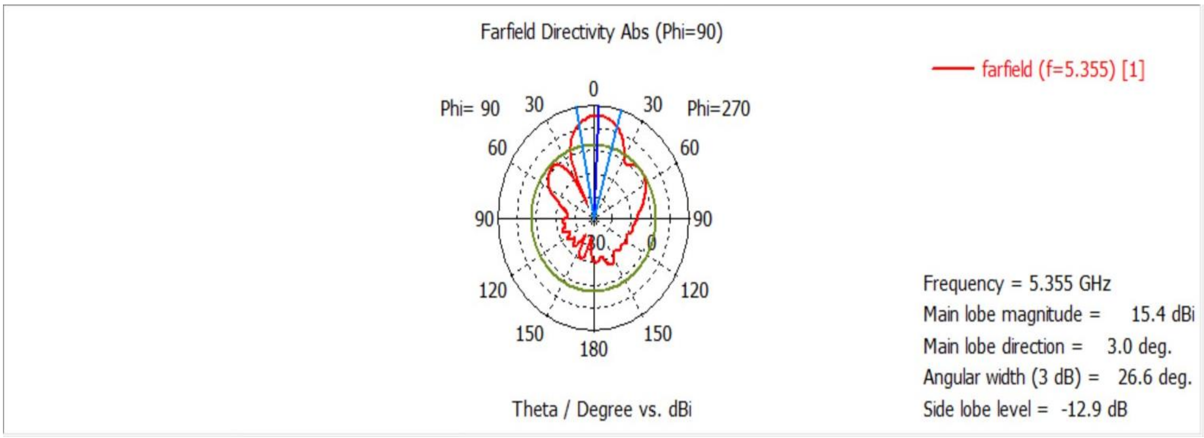


Fig 4.4: Polar Plot

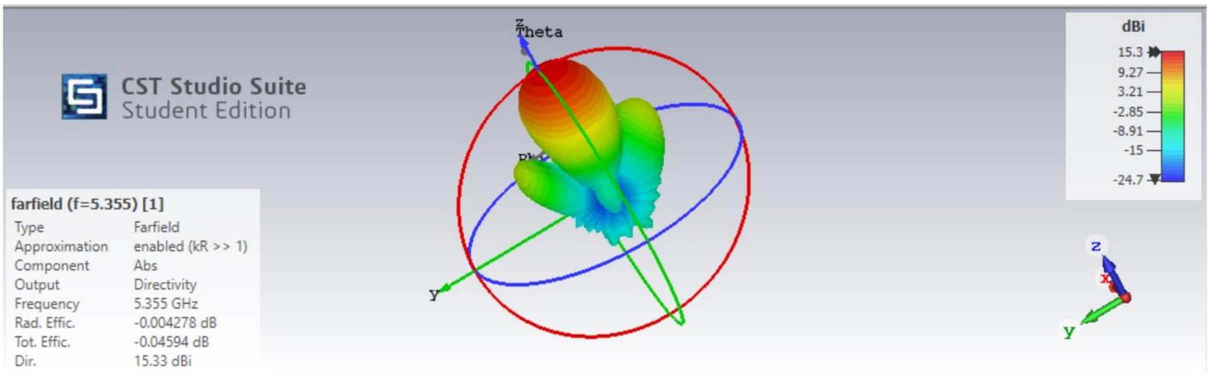


Fig 4.5: Radiation Pattern in X-Z and X-Y plane

Discussion or Inference of the experiment

From this experiment I learnt about the working principle of a horn antenna and the radiation pattern of it.

Conclusion:-

Design of horn Array antenna is executed successfully at 5.5 GHz frequency on a virtual platform and the directivity and Half power beam width form the radiation patterns is attached with the lab record.

Experiment Number	05
Date of Experiment	09/09/2020
Date of Submission	10/09/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC-06

Aim of The Experiment :-

Design a 73-element optimal isotropic antenna array with maximum side lobe level of -20 dB. Also calculate the half power beam width and beam width between 1st nulls.

Software Required:-

MATLAB 2018a

Code:-

<<<File: Exp_5_1.m comment: Plot Tchebyscheff polynomials of order 5>>>

```
%PS 5.1 Plotting Tchebyscheff Polynomials of orders 5 and 6
% Written By Debagnik Kar 1804373

clc
clear all
close all

x=linspace(-1.5,1.5,1000)

m=input('Enter the value of order(m): ')

for i=1:1000
    if abs(x(i))<=1
        y(i)=cos(m*acos(x(i)))
    else
        y(i)=cosh(m*acosh(x(i)))
    end
end

plot(x,y)
```

```
grid on

xlabel('Values of x --->')

ylabel('Tm(x)--->')

title('Plotting Tchebyscheff Polynomials')
```

<<<File: Exp_5_1.m comment: Plot Tchebyscheff polynomials of order 5>>>

```
%PS 5.1 Plotting Tchebyscheff Polynomials of orders 5 and 6
% Written By Debagnik Kar 1804373

clc
clear all
close all

x=linspace(-1.5,1.5,1000)

m=input('Enter the value of order(m): ')

for i=1:1000
    if abs(x(i))<=1
        y(i)=cos(m*acos(x(i)));
    else
        y(i)=cosh(m*acosh(x(i)));
    end
end
plot(x,y)
grid on

xlabel('Values of x --->')
ylabel('Tm(x)--->')

title('Plotting Tchebyscheff Polynomials')
```

<<<File: Exp_5_2.m Comment: Simulating an optimal isotropic antenna array and calculation of HPBW>>>

```
%PS5_2 Simulating an optimal isotropic antenna array and
calculation of HPBW

%Written by Debagnik Kar 1804373

clc
clear all
close all
```

```
N=20                    %number of isotropic antenna elements

SLL=-20                 %Desired Side lobe level

b=1/(10^(SLL/20))
order=N-1               %Order of Tchebyscheff polynomial

xo=cosh(acosh(b)/order)

k = linspace(0,0,order)
dk = linspace(0,0,order)
xk = linspace(0,0,order)
sk = linspace(0,0,order)

for index=1:order
    k(index)=index
    dk(index)=(2*index-1)*pi/(2*order)
    xk(index)=cos(dk(index))
    sk(index)=2*acos(xk(index)/xo)
end

f=3*(10^9)
lo=3*(10^8)/f
beta=2*pi/lo
d=0.5*lo
%Calculation of Array Factor
ang=linspace(0,pi,361);
AF=linspace(0,0,361);
AF2=linspace(0,0,361);
for index=1:361
    ag=ang(index);
    AF(index)=1;
    si=beta*d*cos(ag);
    for jj=1:order
        AF(index)=AF(index)*(exp(si*1i)-exp(sk(jj)*1i))
    end
    AF2(index)=abs(AF(index))
end
AF2(1:361)=AF2(1:361)/max(AF2,'g')
plot(ang*180/pi,20*log10(AF2))
grid on
xlabel('Elevation angle (degrees)')
ylabel('Array Factor (dB)')
title('Simulating the antenna array')
%Calculating HPBW
HPBW=0
for index=182:361
    if AF2(index)>0.707
        HPBW=2*(ang(index)-pi/2)*180/pi;
    end
end
```

Output/Graph:-

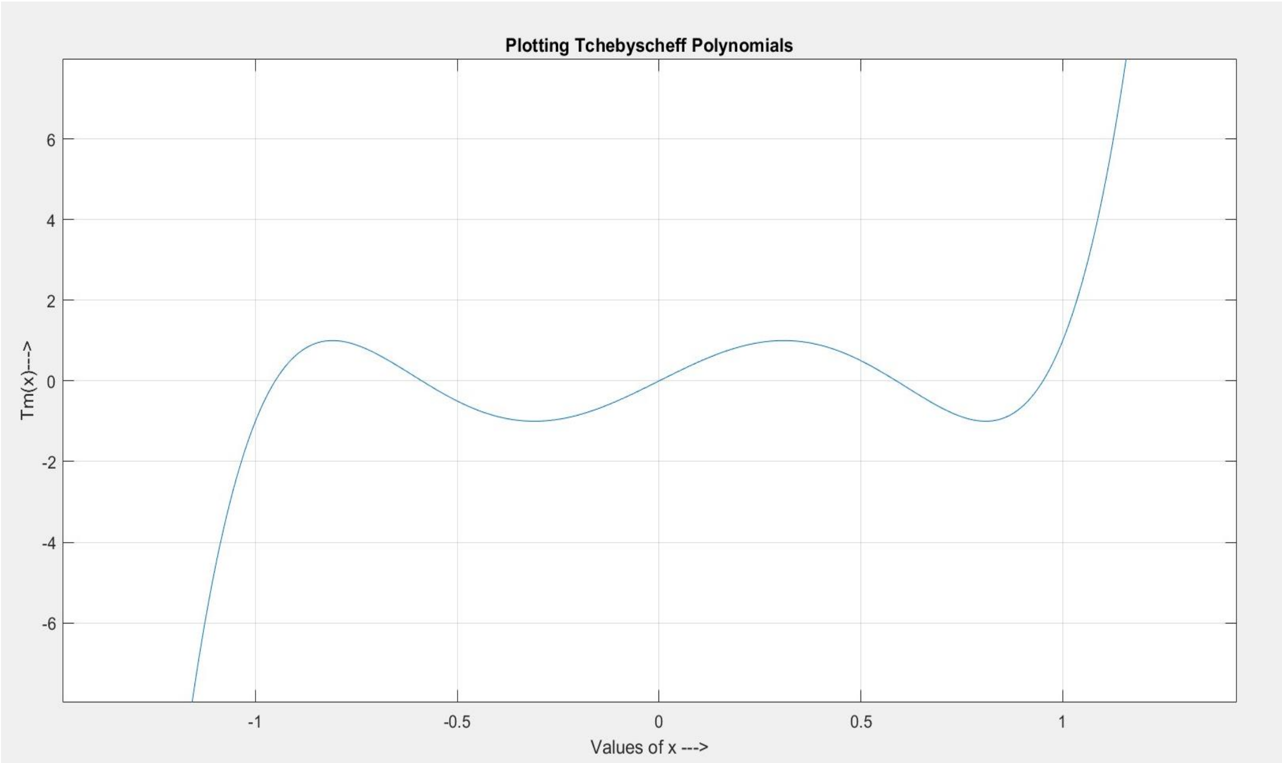


Fig 5.1: Plotting Tchebyscheff Polynomials in order 5

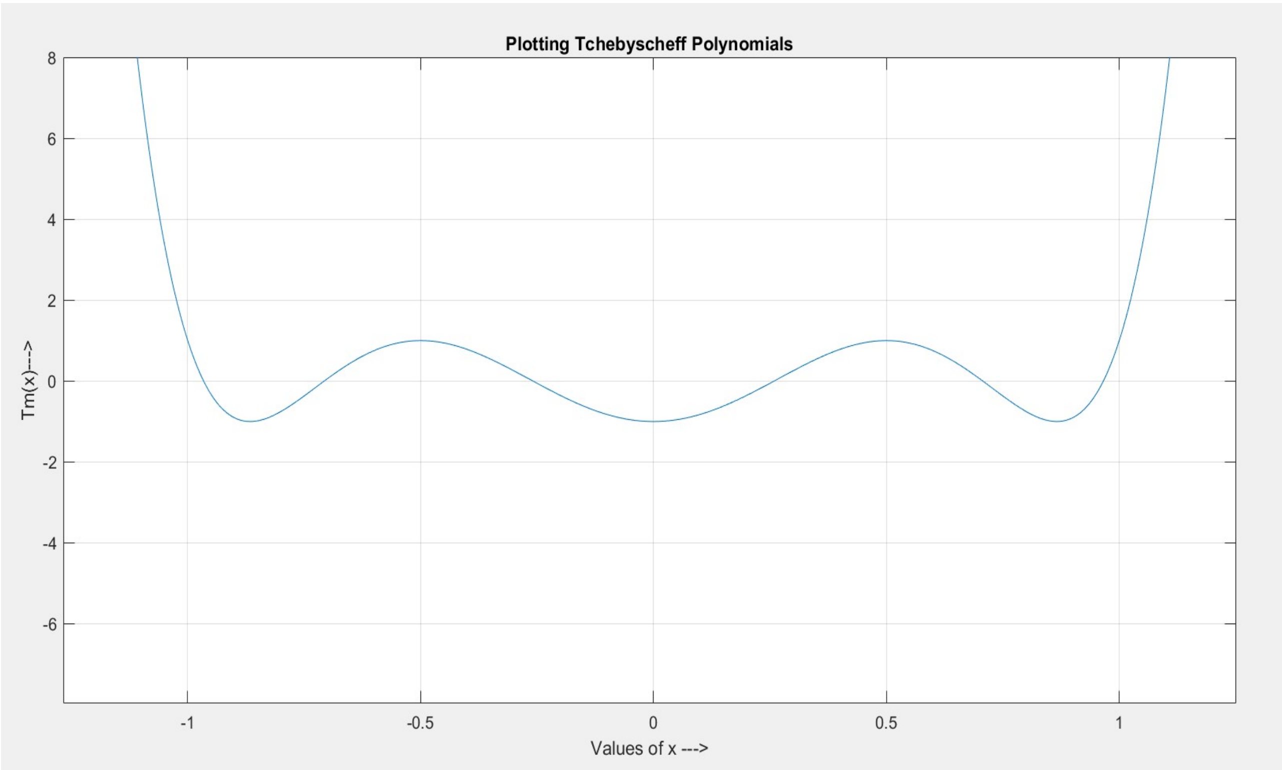


Fig 5.2: Plotting Tchebyscheff Polynomial in order 6

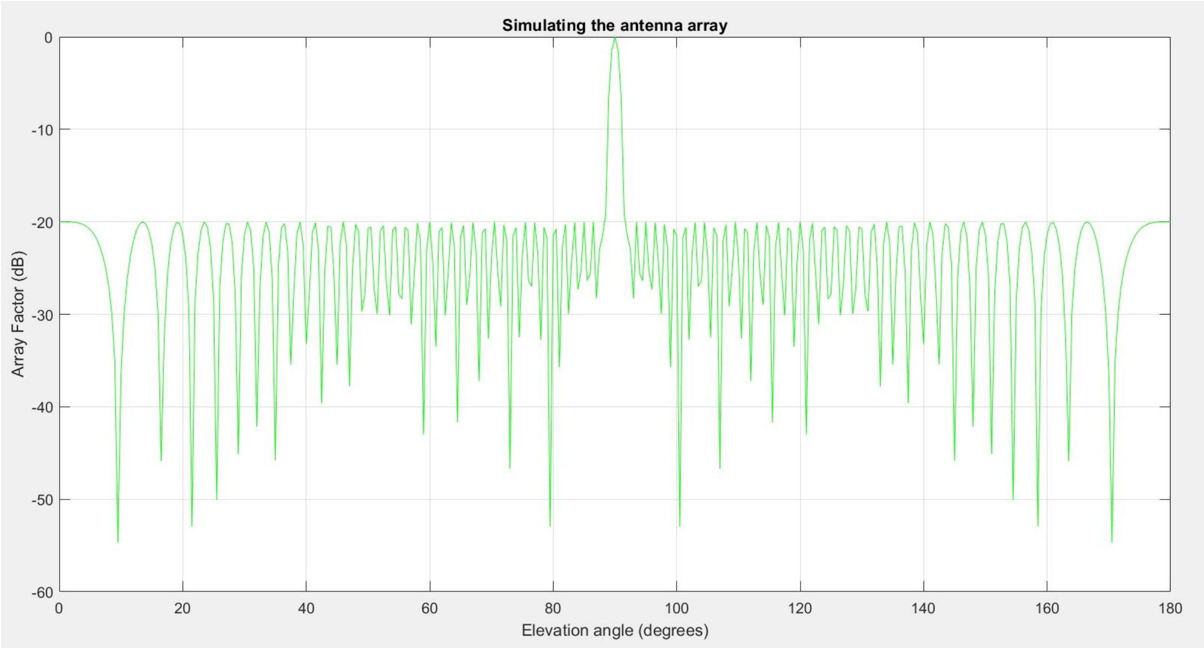


Fig 5.3: Simulation of Array Antenna

Observation:

Maximum SLL (dB)	-20
HPBW (Degrees)	1.075
BWFN (Degrees)	3.5

Table 1: Observation from the graphs

Conclusion:-

After successfully simulating the 73-element optimal isotropic antenna array we are able to observe the Tchebyshev polynomial plots for different orders and radiation pattern. We also found out the HPBW and BWFN was found out to be 1.0750 & 3.5000 respectively.

Experiment Number	06
Date of Experiment	Design of a rectangular waveguide for cut-off frequency of 6.373GHz in the dominant mode
Date of Submission	07/10/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC-06

Aim of The Experiment :-

Design of a rectangular waveguide for cut-off frequency of 6.373GHz in the dominant mode

Software Required:-

CST Studio 2019 Student Edition

Theory :

In radio-frequency engineering and communications engineering, waveguide is a hollow metal pipe used to carry radio waves. This type of waveguide is used as a transmission line mostly at microwave frequencies, for such purposes as connecting microwave transmitters and receivers to their antennas, in equipment such as microwave ovens, radar sets, satellite communications, and microwave radio links.

The electromagnetic waves in a (metal-pipe) waveguide may be imagined as travelling down the guide in a zig-zag path, being repeatedly reflected between opposite walls of the guide. For the particular case of rectangular waveguide, it is possible to base an exact analysis on this view. Propagation in a dielectric waveguide may be viewed in the same way, with the waves confined to the dielectric by total internal reflection at its surface. Some structures, such as non-radiative dielectric waveguides and the Goubau line, use both metal walls and dielectric surfaces to confine the wave.

Depending on the frequency, waveguides can be constructed from either conductive or dielectric materials. Generally, the lower the frequency to be passed the larger the waveguide is. For example, the natural waveguide the earth forms given by the dimensions between the conductive ionosphere and the ground as well as the circumference at the median altitude of the Earth is resonant at 7.83 Hz. This is known as Schumann resonance. On the other hand, waveguides used in extremely high frequency (EHF) communications can be less than a millimetres in width.

Design Problem: Design a WR90 waveguide having cut-off frequency of 6373 MHz

Solution:-

$$\boxed{f_c = \frac{Speed\ of\ light\ (c)}{2 \times a}}$$

where ‘a’ is the width of the waveguide and 4a = 9b and b is the height of the wave guide while we take 1.27mm of wall thickness

From the above equations we got,

$$a=23.56mm$$

$$b=10.45mm$$

<u>Design:-</u>

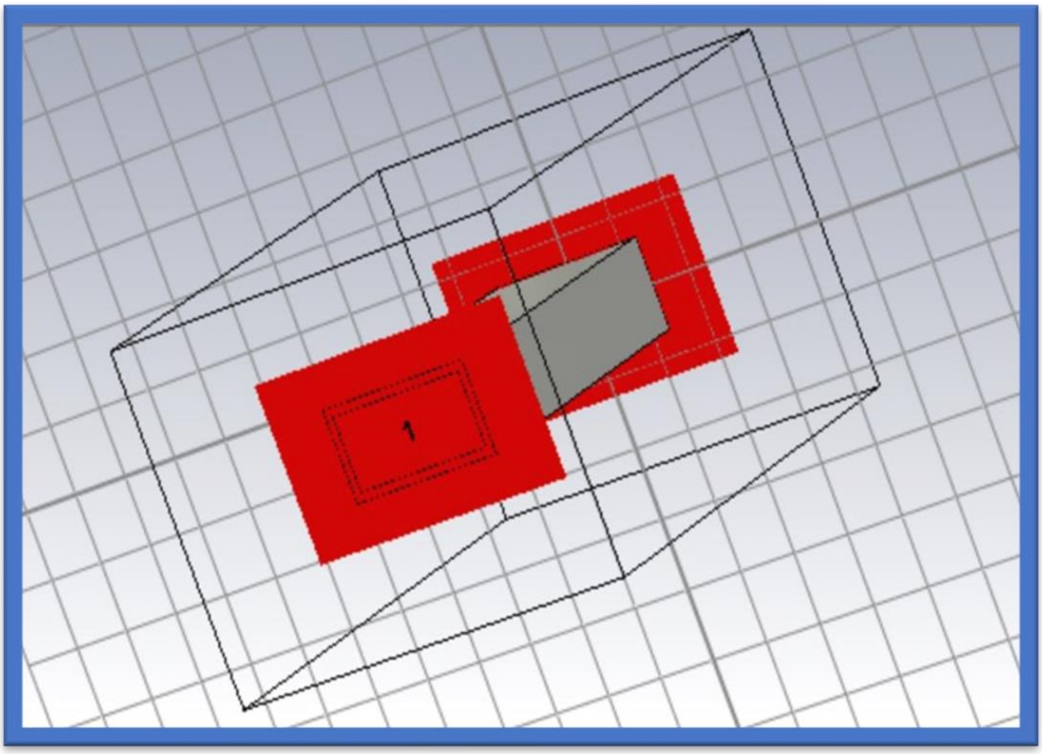


Fig 6.1: Design of the waveguide.

<u>Output/Graph:-</u>

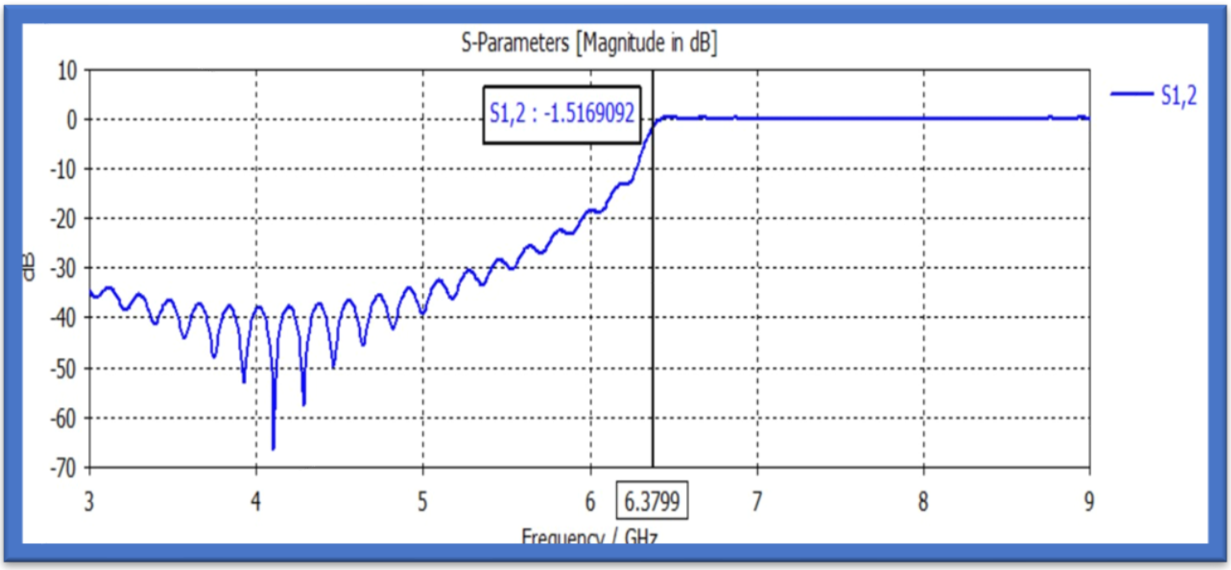


Fig 6.2: S1,2 parameter of the simulation

Inference:-

From this experiment I learnt about the working principle and importance of a waveguide in microwave communication engineering.

Conclusion:-

From the result of the simulation, the resonating frequency of the designed waveguide is 6.3799GHz which is very close to the required result. Hence we can conclude that the experiment is performed successfully

Experiment Number	07
Date of Experiment	07/10/2020
Date of Submission	14/10/2020
Name of the student	Debagnik Kar
Roll Number	1804373
Section	ETC-06

Aim of The Experiment :-

Design and analysis of E plane Tee and H plane Tee.

Equipment / Software Required:-

CST Studio 2019 Student Edition

Theory

- An E-Plane Tee junction is formed by attaching a simple waveguide to the broader dimension of a rectangular waveguide, which already has two ports. The arms of rectangular waveguides make two ports called collinear ports i.e., Port1 and Port2, while the new one, Port3 is called as Side arm or E-arm. T his E-plane Tee is also called as Series Tee.
  As the axis of the side arm is parallel to the electric field, this junction is called E-Plane Tee junction. This is also called as Voltage or Series junction. The ports 1 and 2 are 180° out of phase with each other. The cross-sectional details of E-plane tee can be understood by the following figure.

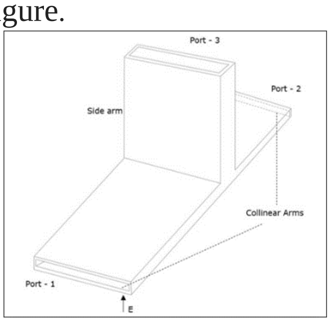


Fig 7.1: A E-plane Tee Junction

- An H-Plane Tee junction is formed by attaching a simple waveguide to a rectangular waveguide which already has two ports. The arms of rectangular waveguides make two ports called collinear ports i.e., Port1 and Port2, while the new one, Port3 is called as Side arm or H-arm. This H-plane Tee is also called as Shunt Tee.
  As the axis of the side arm is parallel to the magnetic field, this junction is called H-Plane Tee junction. This is also called as Current junction, as the magnetic field divides

itself into arms. The cross-sectional details of H-plane tee can be understood by the following figure.

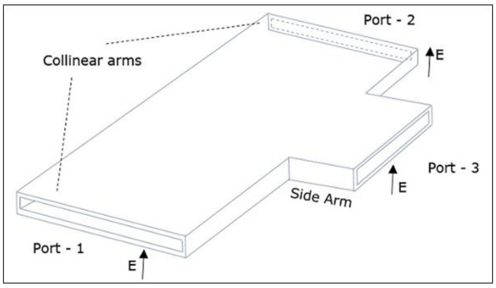


Fig 7.2: A H-plane Tee

Design Problem:-

Designing a E-plane Tee and a H-plane Tee of 6.373GHz.

Solution:

$$\boxed{f_c = \frac{Speed\ of\ light\ (c)}{2\times a}}$$

where ‘a’ is the width of the waveguide and 4a = 9b and b is the height of the wave guide while we take 1.27mm of wall thickness

From the above equations we got,

a=23.56mm

b=10.45mm

Design:

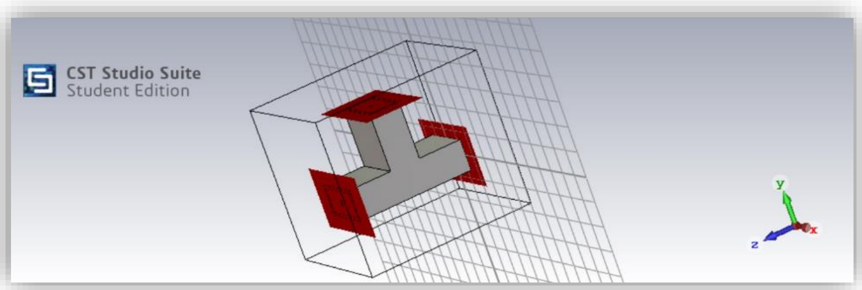


Fig 7.3: Design of E-plane Tee

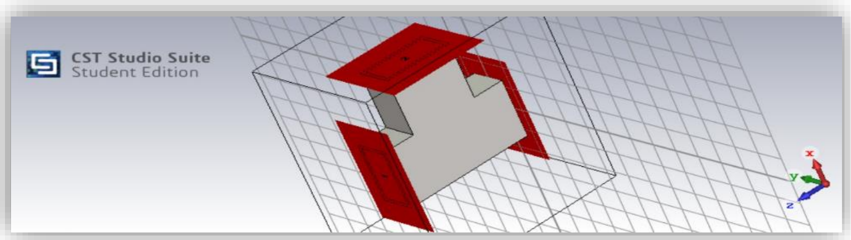


Fig 7.4: Design of H-plane Tee

Output/Graph:-

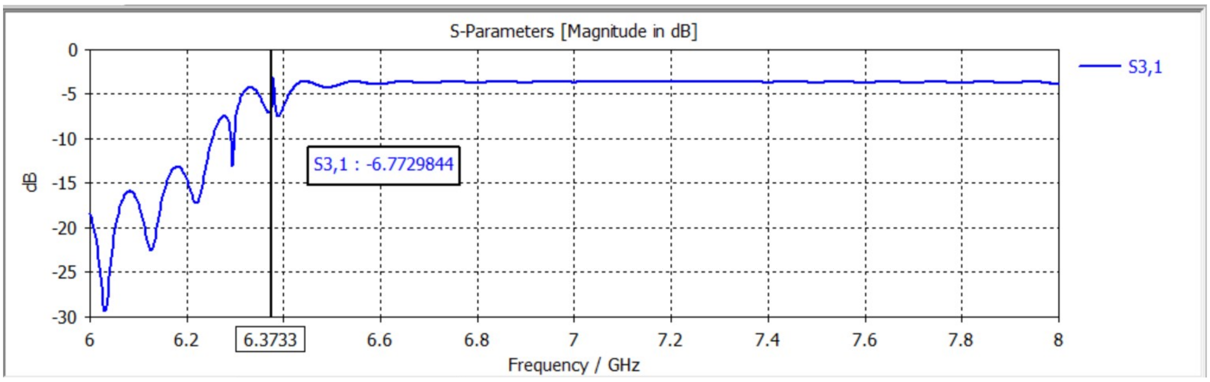


Fig 7.5: Magnitude Plot of S3,1 of E-plane Tee

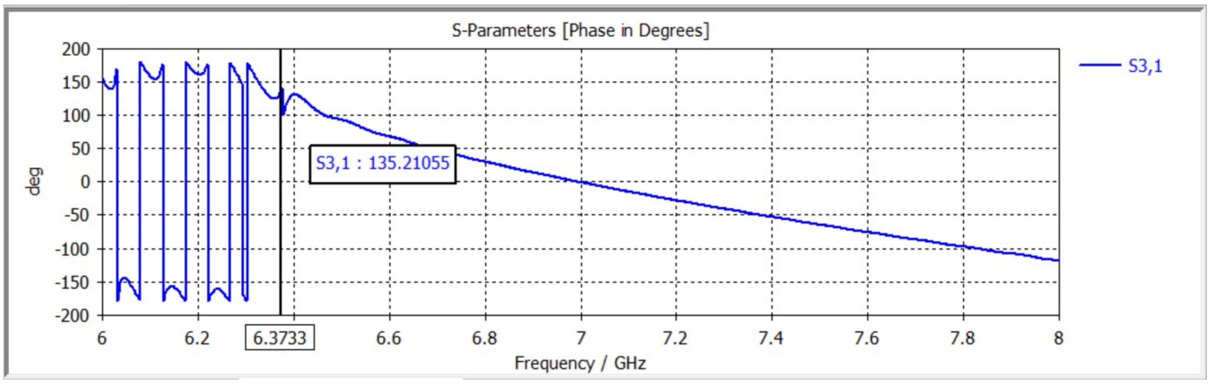


Fig 7.6: Phase Plot of S3,1 of E-plane Tee

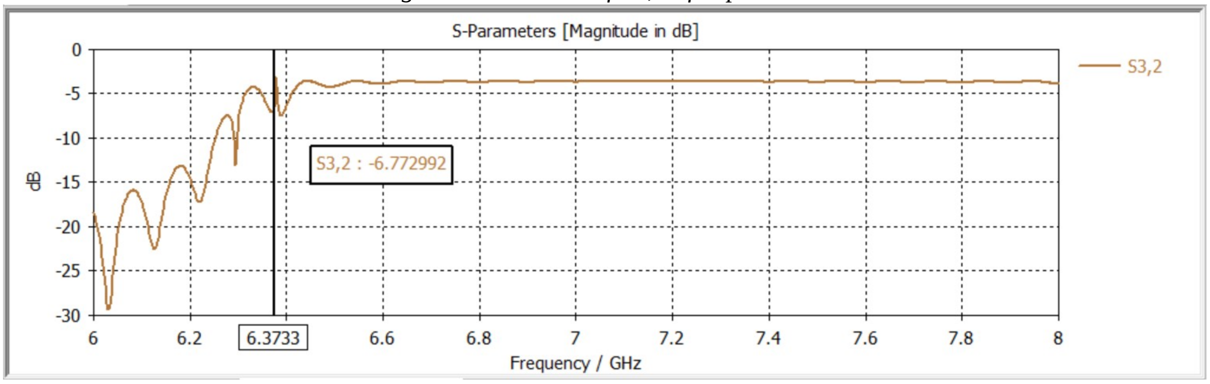


Fig 7.7: Magnitude Plot of S3,2 of E-plane Tee

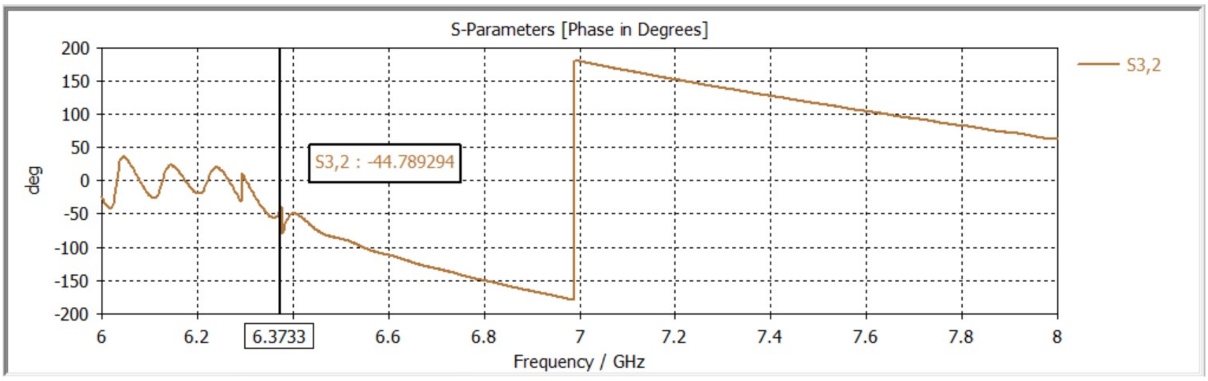


Fig 7.8: Phase Plot of S3,2 of E-plane Tee

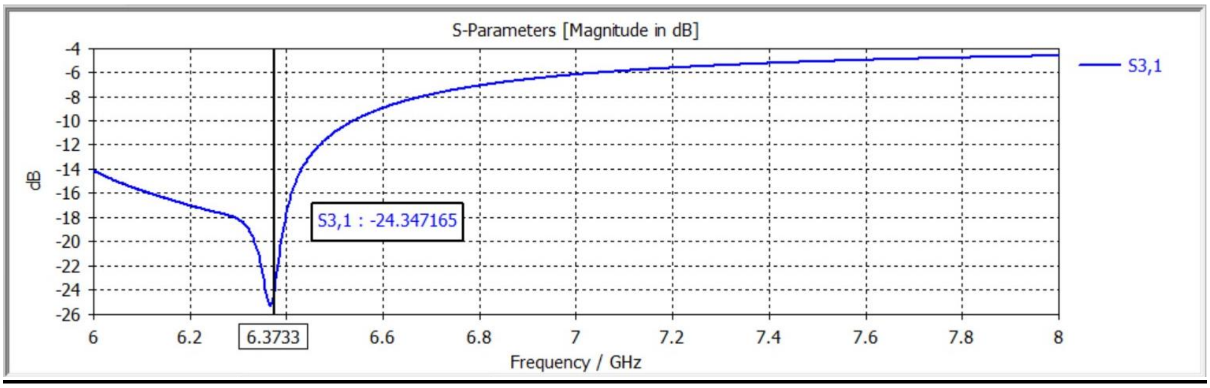


Fig 7.9: Magnitude plot of S3,1 of H-plane

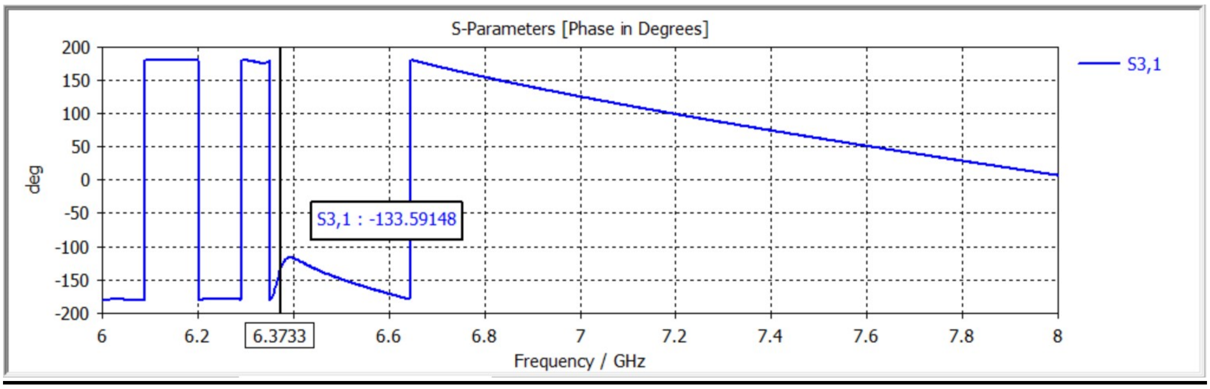


Fig 7.10: Phase plot of S3,1 of H-plane

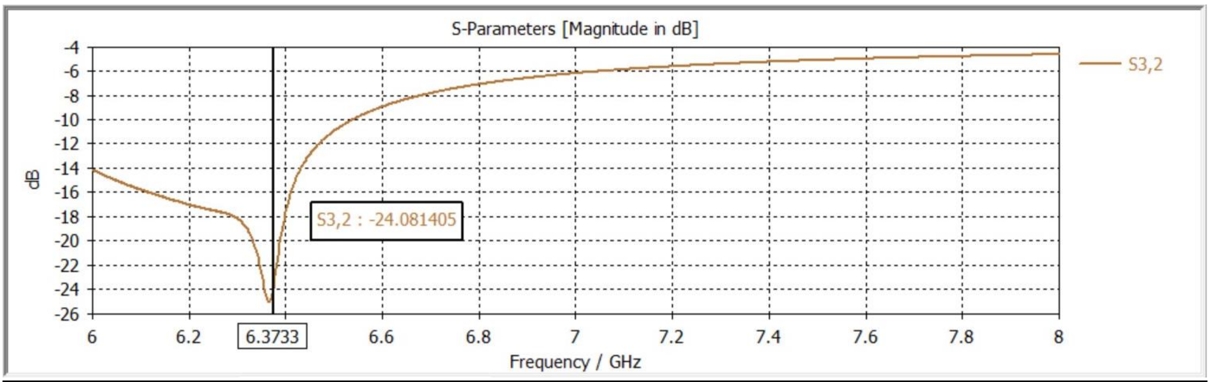


Fig 7.11: Magnitude plot of S3,2 of H-plane

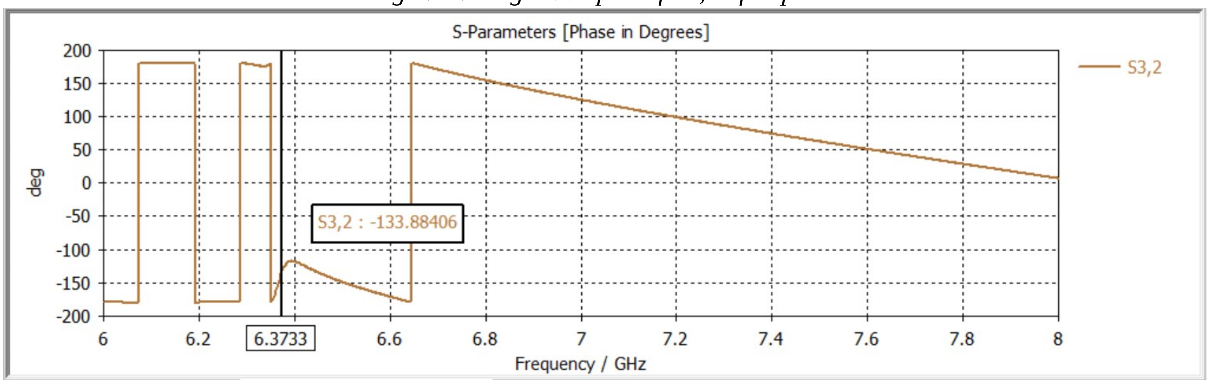


Fig 7.12: Phase plot of S3,2 of H-plane

Observation:

E-Plane Tee				H-Plane Tee			
S3,1		**S3,2**		**S3,1**		**S3,2**	
Magnitude	**Phase**	**Magnitude**	**Phase**	**Magnitude**	**Phase**	**Magnitude**	**Phase**
-6.773	*135.211*	*-6.773*	*-44.784*	*-24.347*	*-133.591*	*-24.081*	*-133.884*

Table 2: Observation of from the results of the above simulation.

E-Plane		H-Plane	
Magnitude Difference	**Phase Difference**	**Magnitude Difference**	**Phase Difference**
0	*179.995*	*0.266*	*0.293*

Table 3: Results from the above observations

Discussion or Inference of the experiment

From this experiment I learnt that the prime difference between a E-Plane and a H-Plane Tee is that the phase difference between the two collinear arms if sourced from the perpendicular arm is 180^o for E-Plane and 0^o for H-Plane. I also learnt that the working principle of tees.

Conclusion:-

The phase difference of the two collinear arms of E-planes and H-planes is $179.99^o \approx 180^o$ and $0.293^o \approx 0^o$ respectively, which matches with our theoretical concepts, and hence we can say that the simulation is done successfully

Experiment Number	07
Date of Experiment	14/10/2020
Date of Submission	21/10/2020
Name of the student	Debagnik Kar
Roll Number	184373
Section	ETC-06

Aim of The Experiment :-

Design and Analysis of Magic Tee

Equipment / Software Required:-

- CST Studio Suite 2019 (Student Edition)

Theory

An E-H Plane Tee junction is formed by attaching two simple waveguides one parallel and the other series, to a rectangular waveguide which already has two ports. This is also called as Magic Tee, or Hybrid or 3dB coupler.

The arms of rectangular waveguides make two ports called collinear ports i.e., Port 1 and Port 2, while the Port 3 is called as H-Arm or Sum port or Parallel port. Port 4 is called as E-Arm or Difference port or Series port.

The cross-sectional details of Magic Tee can be understood by the following figure.

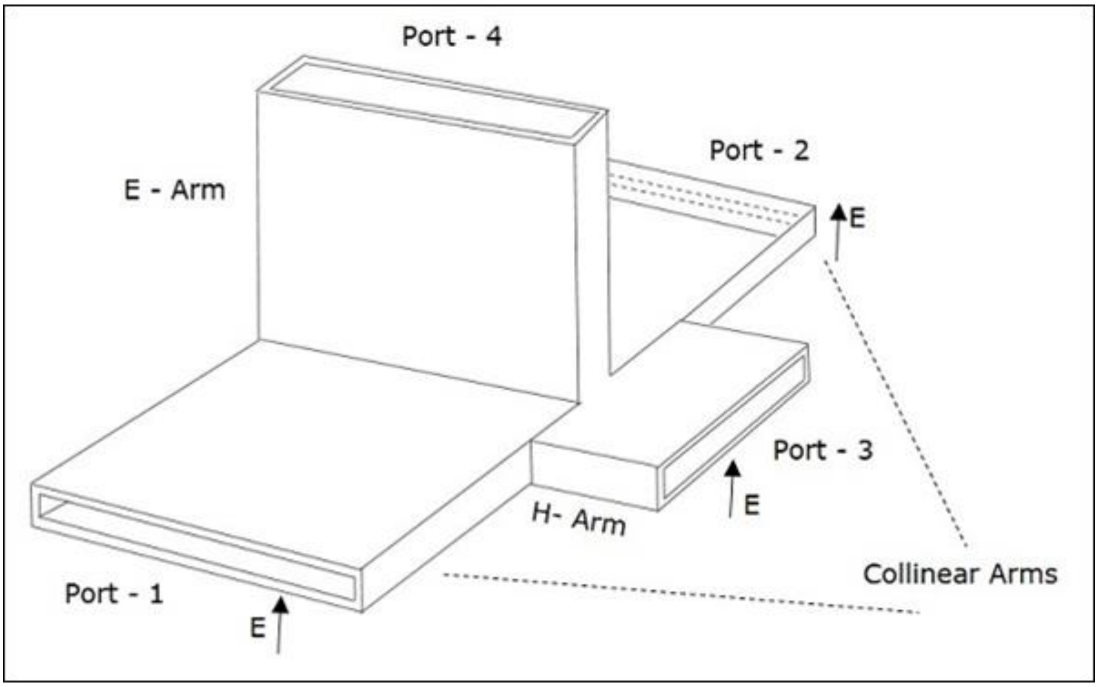


Fig 8.1: A diagram of magic tee

Design Problem:-

Design a magic tee wave guide having cut-off frequency 6.373 GHz in dominant mode

Solution:-

$$f_c = \frac{Speed\ of\ light\ (c)}{2 \times a}$$

where ‘a’ is the width of the waveguide and 4a = 9b and b is the height of the wave guide while we take 1.27mm of wall thickness

From the above equations we got,

a=23.56mm

b=10.45mm

Design:

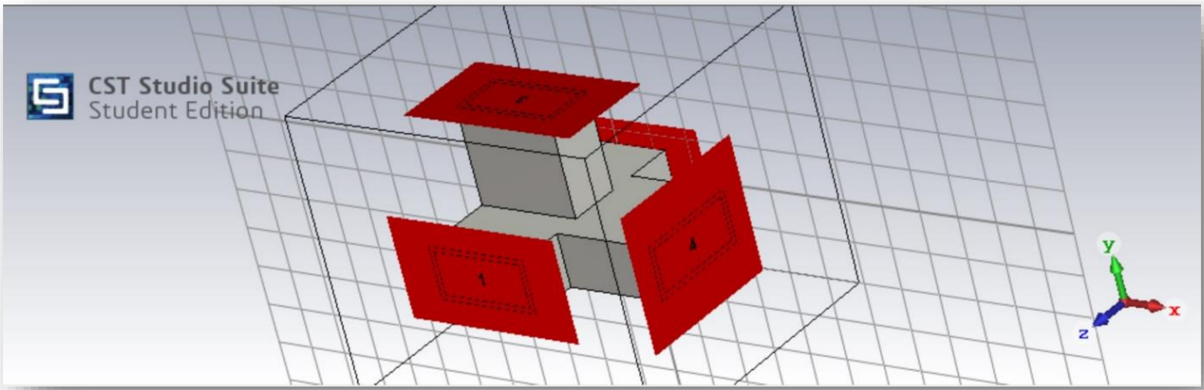


Fig 8.2: Magic Tee design View

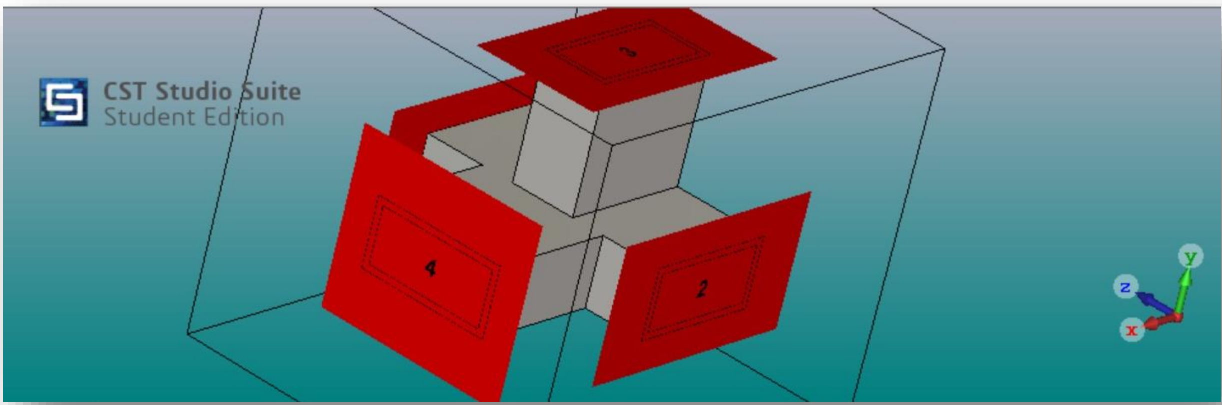


Fig 8.3: Another Magic Tee design view

Output/Graph:-

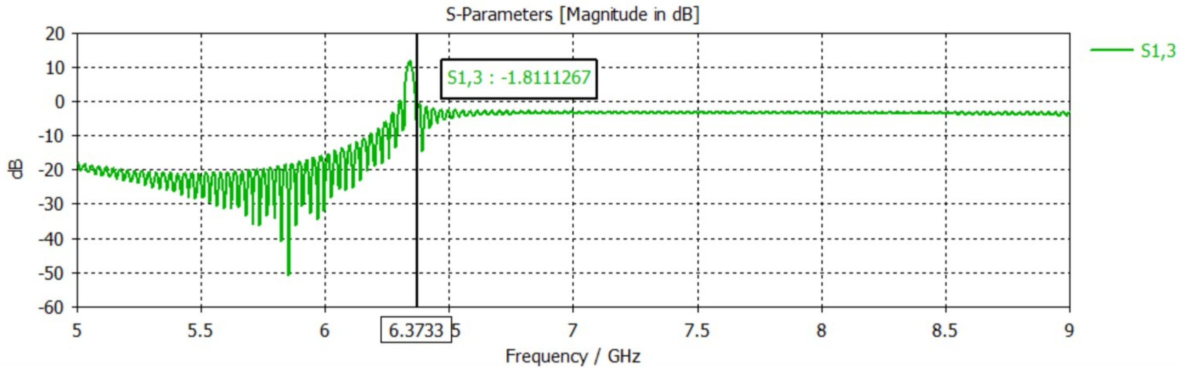


Fig 8.4: Magnitude plot of S13

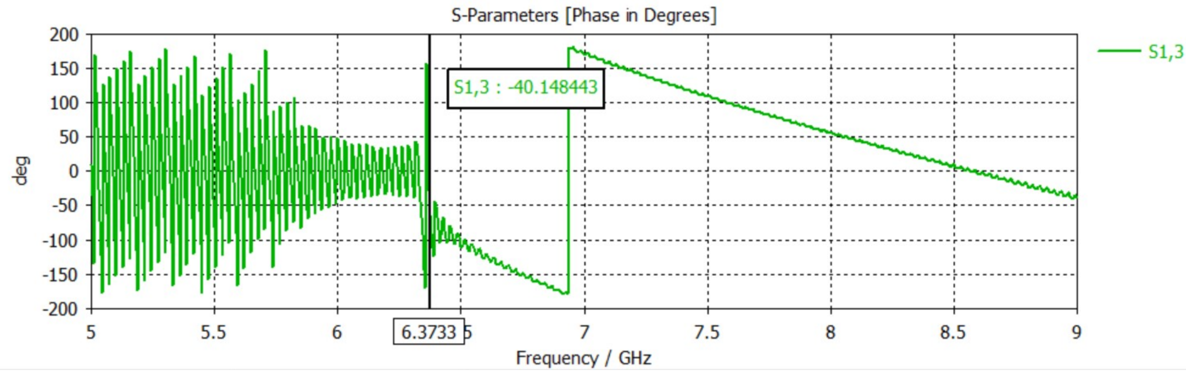


Fig 8.5: Phase plot of S13

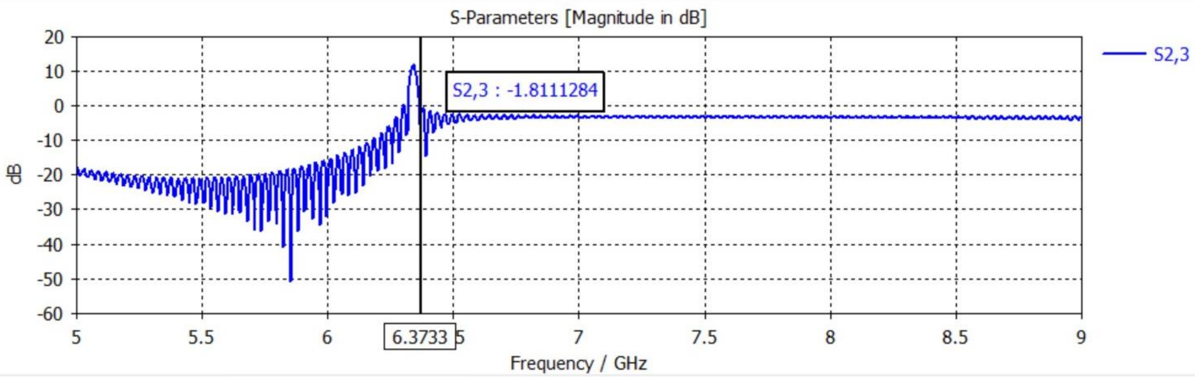


Fig 8.6: Magnitude plot of S23

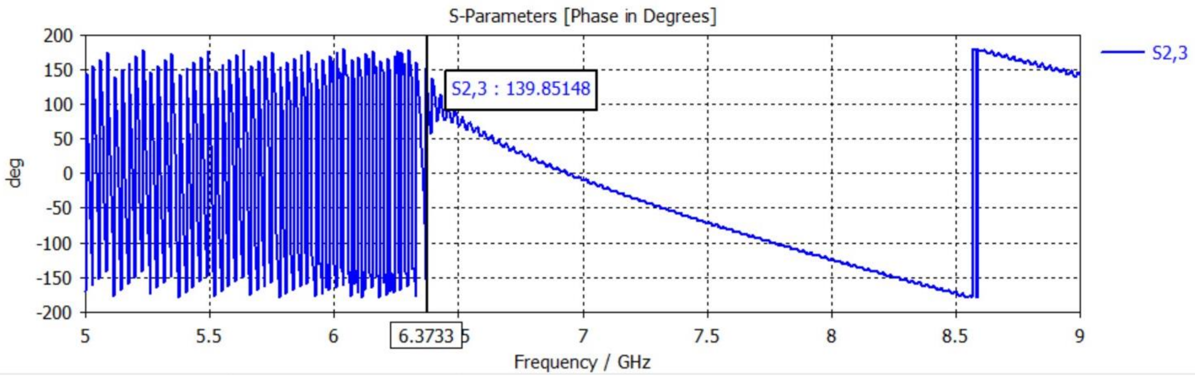


Fig 8.7: Phase plot of S23

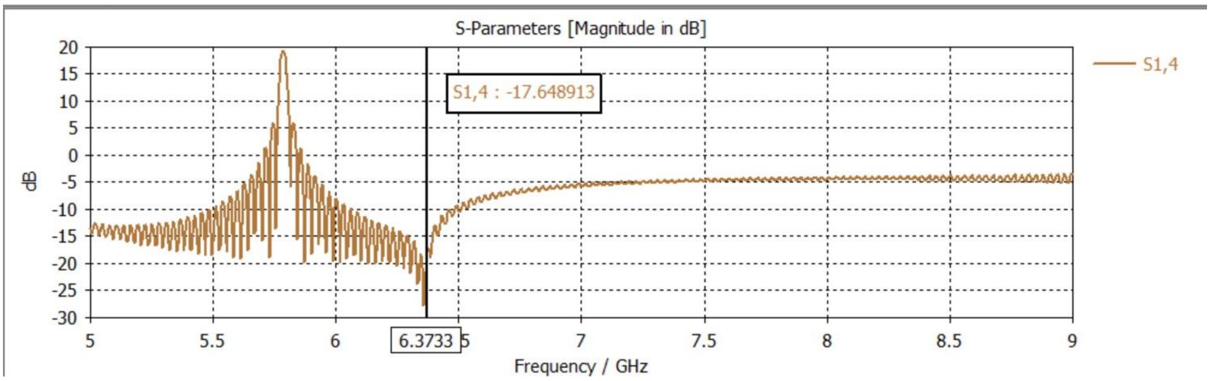


Fig 8.8: Magnitude plot of S14

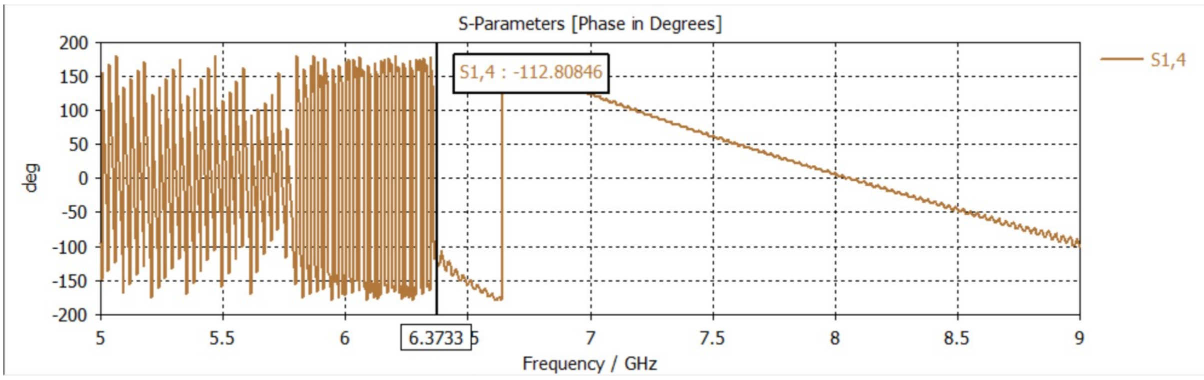


Fig 8.9: Phase plot of S14

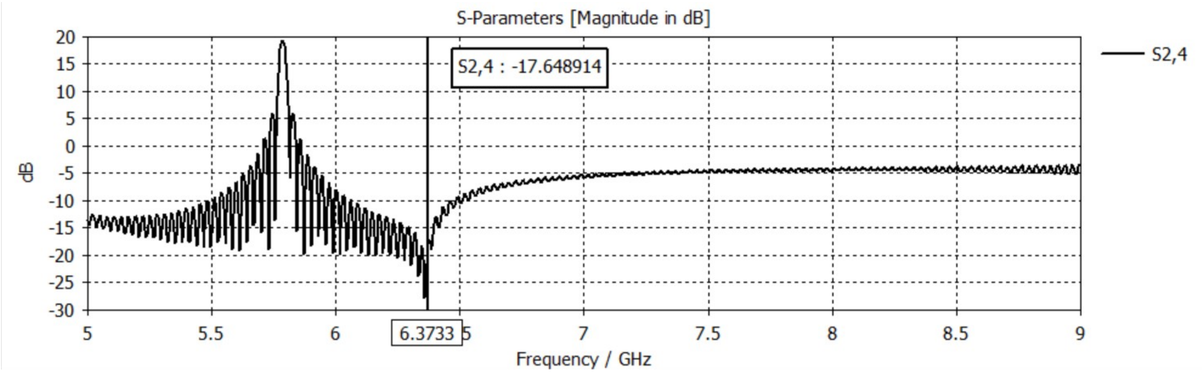


Fig 8.10: Magnitude plot of S24

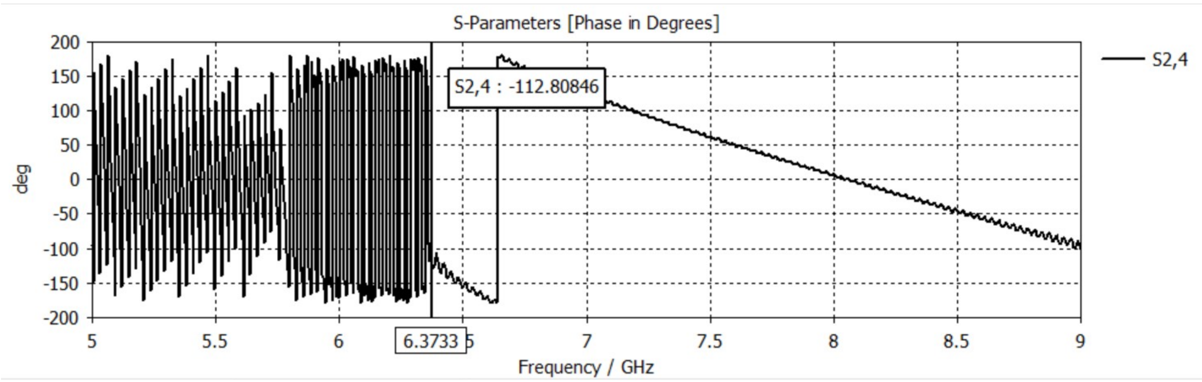


Fig 8.11: Phase plot of S24

Observation:

E-Plane Tee				H-Plane Tee			
S1,3		S2,3		S1,4		S2,4	
Magnitude	**Phase**	**Magnitude**	**Phase**	**Magnitude**	**Phase**	**Magnitude**	**Phase**
-1.811	*-40.148*	*-1.811*	*139.851*	*-17.649*	*-112.808*	*-17.649*	*-112.808*

Table 2: Observation of from the results of the above simulation.

E-Plane		H-Plane	
Magnitude Difference	**Phase Difference**	**Magnitude Difference**	**Phase Difference**
0	*179.999*	*0*	*0*

Table 3: Results from the above observations

Discussion or Inference of the experiment

From this experiment I learnt that Magic Tee is an extension of the working principle of the E-Plane Tee and H-plane Tee, the junction of the E-lane and H-plane Tee is the magic Tee. The prime difference between a E-Plane and a H-Plane Tee is that the phase difference between the two collinear arms if sourced from the perpendicular arm is 180^o for E-Plane and 0^o for H-Plane which is also true for the magic Tee. I also learnt that the working principle of tees.

Conclusion:-

The phase difference of the two collinear arms of E-planes and H-planes in the magic Tee is $179.99^o \approx 180^o$ and $0.293^o \approx 0^o$ respectively, which matches with our theoretical concepts, and hence we can say that the simulation and analysis is done successfully