19ECE381 RF AND SIMULATION LAB

REPORT

ELECTRONICS AND COMMUNICATION ENGINEERING

AMRITA SCHOOL OF ENGINEERING

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July- 2021

Certified that this is the bonafide record of work done by Mr/Ms………………………… **NIGIL M R** ………………………….

RollNo…… **CB.EN.U4ECE19136** ……of………… **ECE B** …………………Semester…… **V** ……...

(Branch)…… **B.TECH ELECTRONICS AND COMMUNICATION ENGINEERING** ……in the

…………………………… **RF AND SIMULATION** ……………………………Lab

oratory of this institute during the academic year…… **2019-2023** ………

Faculty-in-Charge

Chairman of the Department

The candidate is examined by me/us.

on…………………………………
(Date)

Examiner 1

Name:

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Experiment-1 Part A

Rectangular Waveguide WR284

Batch B23

Nigil M R

CB.EN.U4ECE19136

ECE B

Experiment-1A – Rectangular Waveguide WR284

Aim of Experiment:

Study of field patterns of various modes inside a rectangular waveguide – **WR284**

Specification:

Dimentions – **2.84 Inches (72.136 mm) x 1.34 Inches (34.036 mm)**

Cut-off frequenies of lowest order mode- **2.078 Ghz**

Cut-off frequencies of upper order mode- **4.156 Ghz**

Recommended Frequency Band- **2.60 to 3.95 Ghz**

Software Requirement:

- Ansys HFSS

Theory:

Rectangular Waveguides

A Rectangular waveguide is used Is hollow metallic tube with a rectangular cross section. As we know the conducting walls on the rectangular waveguide confine the electromagnetic waves (mainly used in high frequencies) and transport / guide the EM waves.

The modes of operation for a rectangular waveguide is different from the normal Plane wave model were the dominant mode is TEM. Where as in Waveguide there are two dominant modes TE Mode (Transverse Electric) and TM Mode (Transverse Magnetic).

TE Mode has no electric field in the direction of propagation and TM Mode has no magnetic field in the direction of propagation

Mode of Operation Calculations of Waveguide WR284 and Field Variation

$$f_{mn} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{a}\right)^2}$$

Modes	Calculation	Cut-Off Frequency

$\boldsymbol{TE_{10}}$	$\boldsymbol{f_{C10} = \frac{c}{2a}}$	**2.0794 GHz (Dominant Mode)**
TE_{01}	$f_{C01} = \frac{c}{2b}$	4.4070 GHz
TE_{20}	$f_{C01} = \frac{c}{a}$	4.1588 GHz
TE_{11} or TM_{11}	$f_{C11} = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$	4.8725 GHz

Procedure:

1. Construct a solid box/cuboid for the given specification
2. Define the inner wall of the waveguide
3. Define the outer wall of the waveguide with thickness appx. 0.2 mm
4. Use the Boolean subtraction to obtain Hollow waveguide
5. For the inside of the waveguide set the environment as Air
6. Define the outside waveguide by assigning Radiation Boundary
7. Define the wave ports for the waveguide
8. Add the Solution setup and Choose network analysis
9. Validate the waveguide structure using the tool
10. Simulate the waveguide and plot the following using the project manager pane
    a. Port Field Display
    b. Field Overlay (Electric Field)
        i. Magnitude of Electric Field
        ii. Vector of the Electric Field
        iii. Propagation Constant vs Frequency Graph
        iv. Scattering Parameter Graph

Results:

1. **Electric Field Magnitude and Vector Plots**

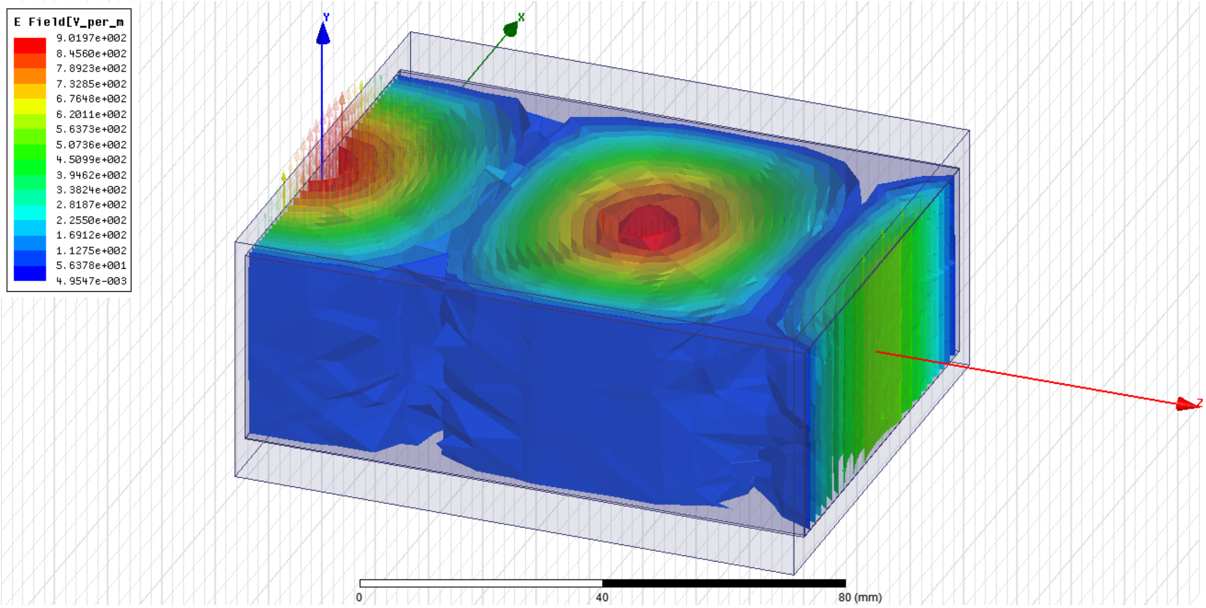


Fig 1(a) Magnitude of Electric Field

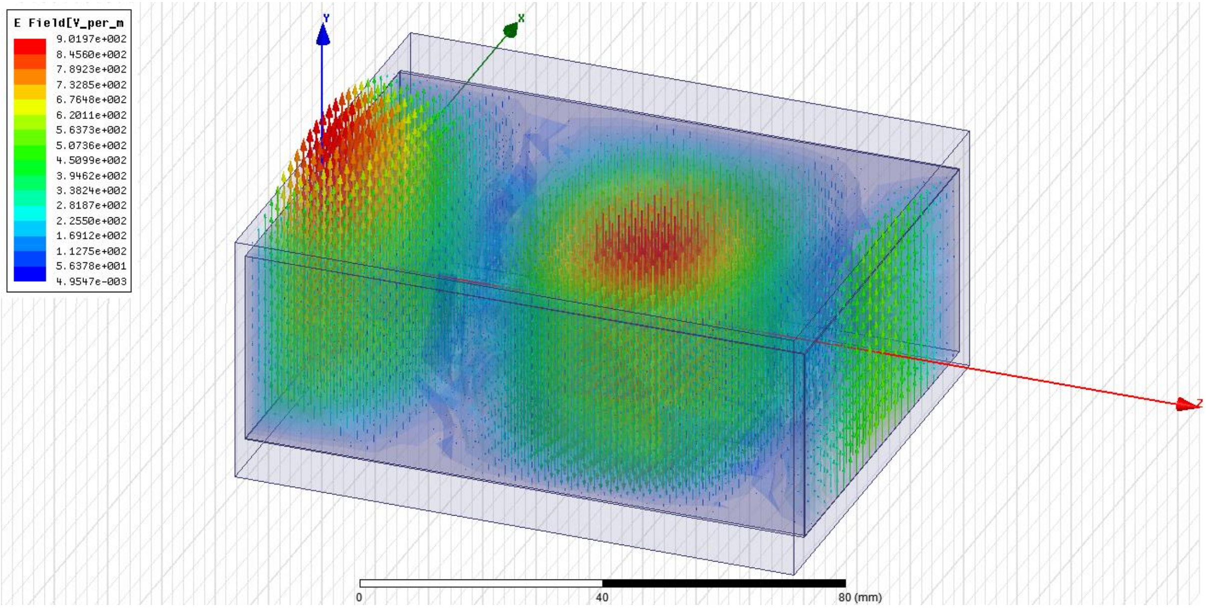


Fig 1(b) Vector of Electric Field

2. Dominant Mode (TE_{10})

Port Field Display

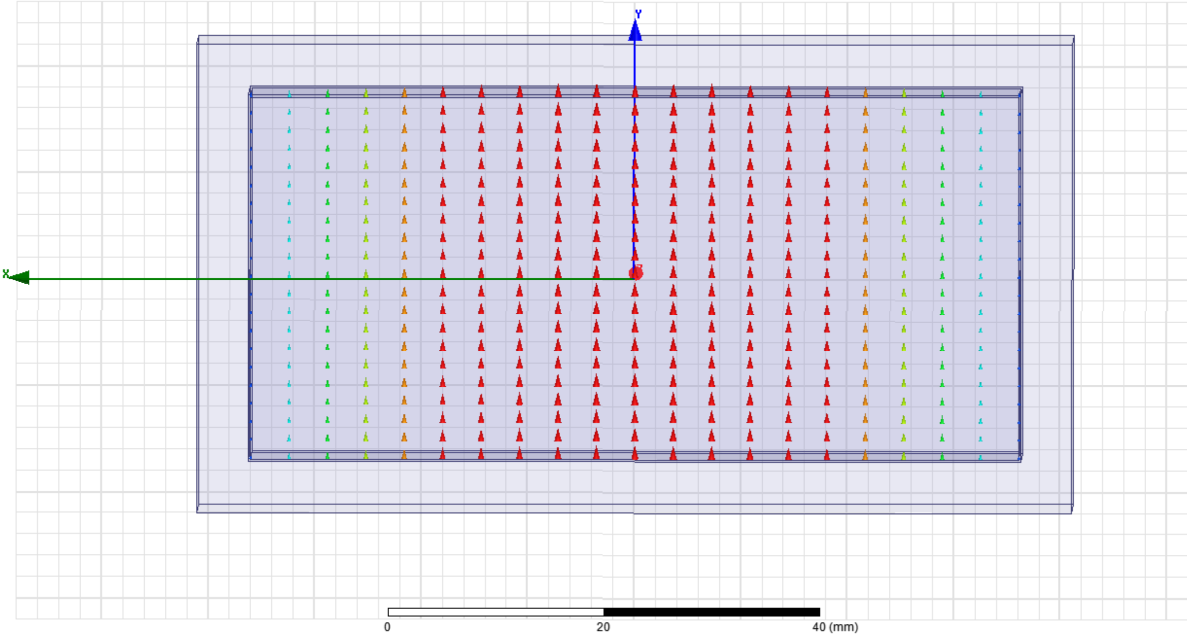


Fig 2(a) Port Field Display of TE_{10} Mode

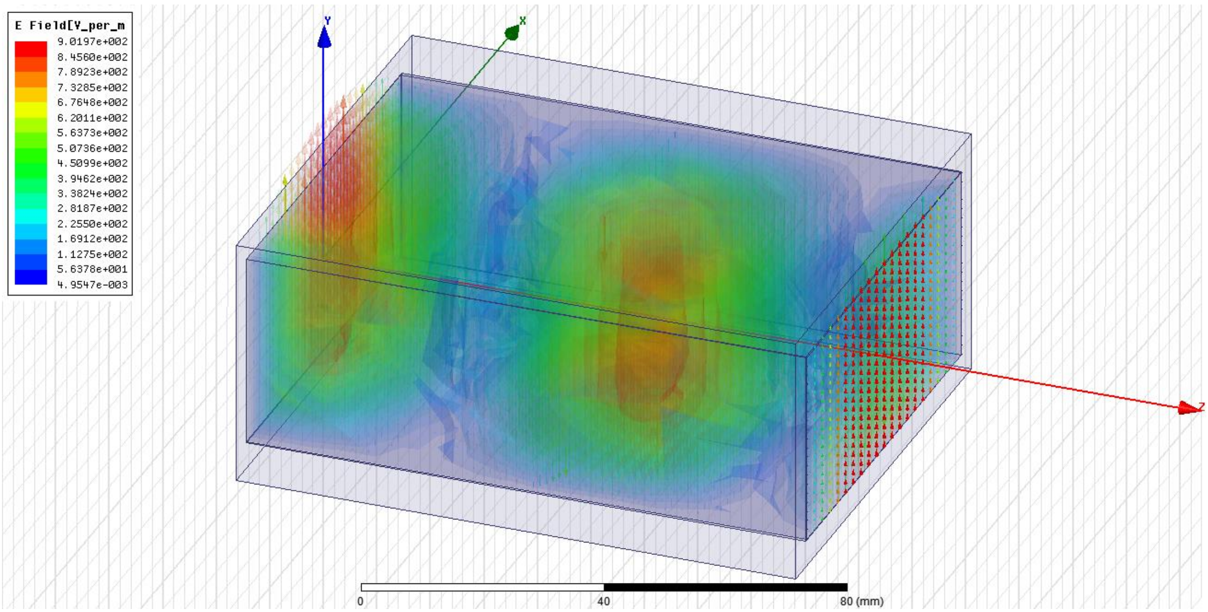


Fig 2(b) Port Field Display of TE_{10} Mode

Propagation Constant vs Frequency Graph

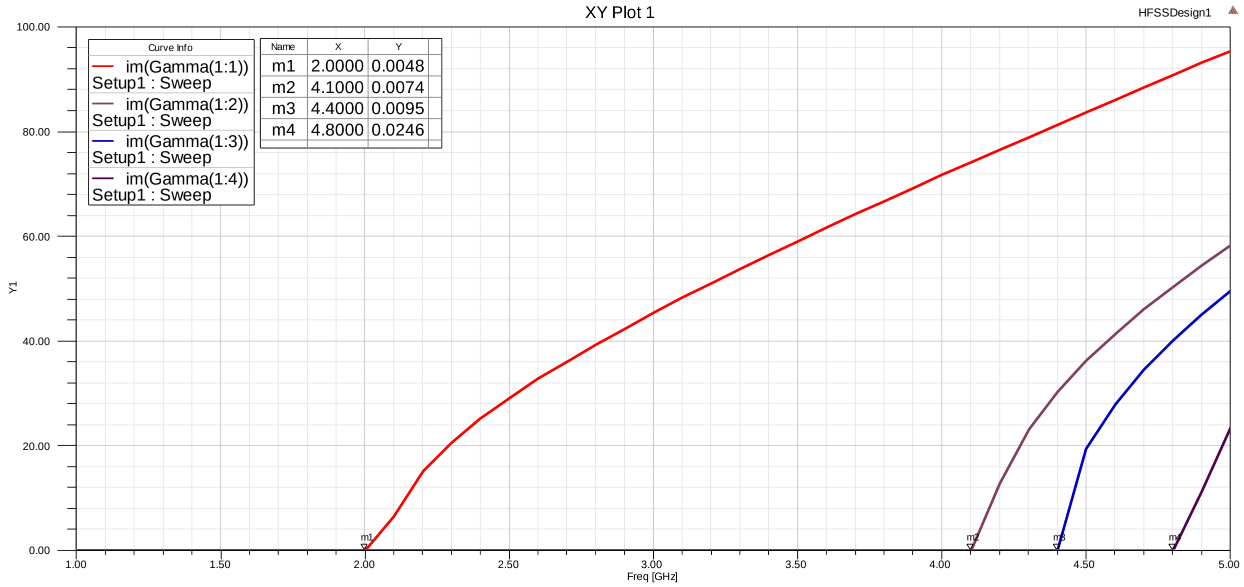


Fig 2(b) Propagation Constant vs Frequency Graph

Note the calculated values and the simulated values are almost same and matching

Scattering Parameter

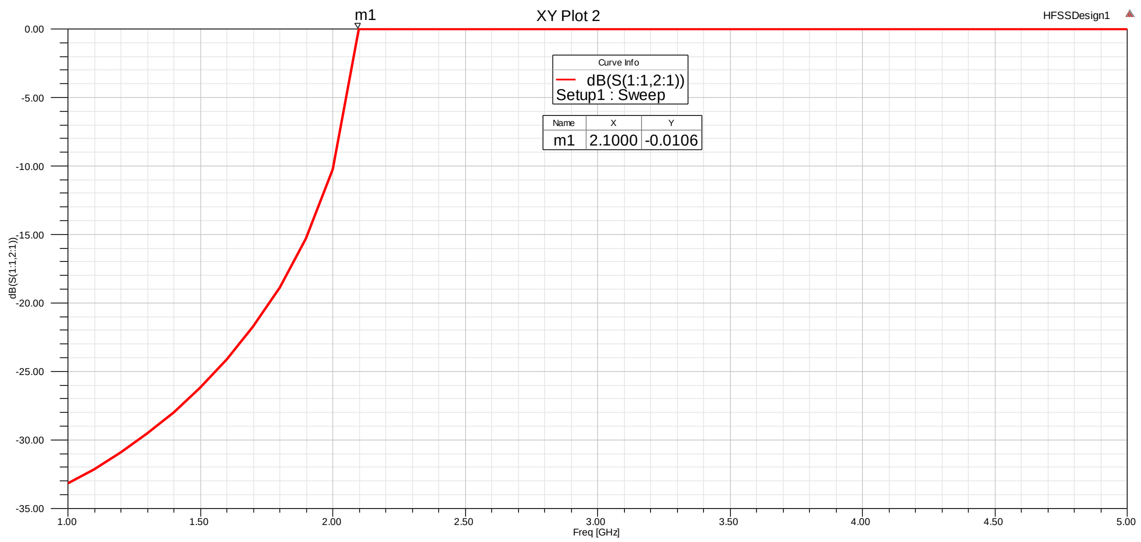


Fig 2(c) Scattering Parameter of TE_{10} Mode

Conclusion:

The given rectangular waveguide has been designed, the field patterns of various modes inside a rectangular waveguide are studied.

Experiment-1 Part B

Study The Mode Characteristics Of Rectangular Waveguide-Cavity Resonator WR284

Copper 5.8 x 10^7 S/m

Experiment-1B – Rectangular Cavity Resonator

Aim of Experiment:

Study of field patterns of various modes inside a rectangular waveguide cavity resonator – **WR284**

Specification:

Dimentions – **2.84 Inches (72.136 mm) x 1.34 Inches (34.036 mm)**

Cut-off frequenies of lowest order mode- **2.078 Ghz**

Cut-off frequencies of upper order mode- **4.156 Ghz**

Recommended Frequency Band- **2.60 to 3.95 Ghz**

Length of the resonator for lower order mode **14.42 cm**

$$d = \frac{n\ x\ c}{f}$$

n – odd multiples 1,3,5…

Conductivity of Copper - **5.8 x 10^7 S/m**

Software Requirement:

- Ansys HFSS

Theory:

Rectangular Cavity Resonator

A Cavity resonator is a useful microwave device used in high frequency because at high frequency the transmission lines quality factor decreases due to dielectric breakdown and becoming lossy. If we close off two ends of a rectangular waveguide with metallic walls, we have a rectangular cavity.

In this cavity the wave propagation will bounce if the two walls resulting in a standing wave in the propagation direction. Since all the sides of the cavity resonator is closed the number feeds becomes three that is with the **m** and **n** component**,** we usually used we now have **p** component due to the short circuited metals.

A cavity resonator is useful as filters and tuners in microwave circuits, as LC resonators are in RF circuits. Cavity resonators can also be used you measure the frequency of an electromagnetic signal.

A cavity resonator at the resonant frequency provides standing waves and this signifies that the electric and magnetic fields are stored.

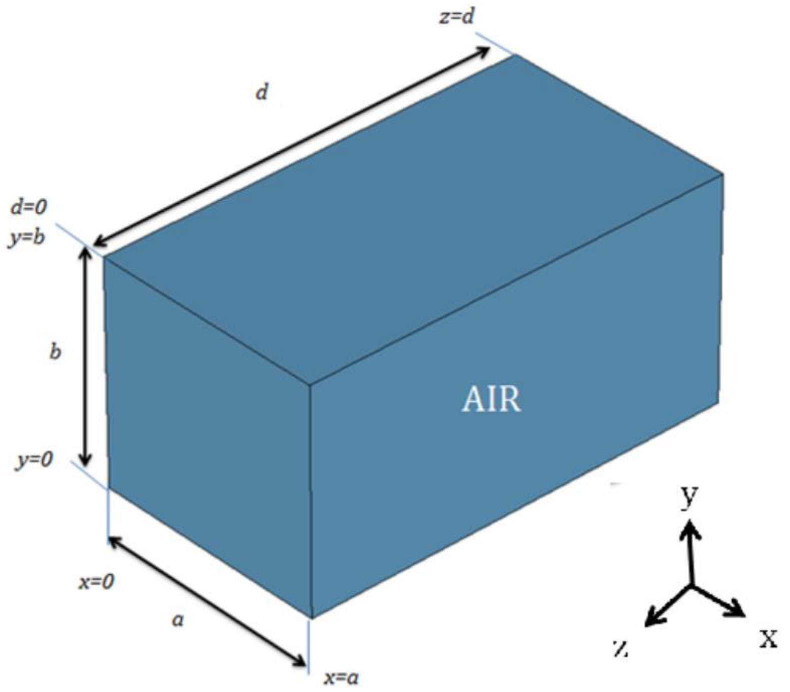


Fig 1 Air dimension inside the copper

Resonant Frequency Calculation

From Experiment 1A we determined the dominant mode of WR284, which is TE_{10} Mode. Now for the Rectangular Waveguide Cavity Resonator the length(l) is calculated for the dominant mode TE_{101} using the **Resonant Frequency** formula.

$$f_{mnl} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{l\pi}{d}\right)^2}$$

For $b < a < d$, the dominant resonant mode is always TE101 mode. The dominant TM resonant mode is the TM110 mode.

Here for this experiment our resonant frequency is considered to be the lower order cut off frequency **2.08 GHz** (appx)

Resistance and Quality Factor

$$Resitance\ (R_S) = \sqrt{\frac{\omega\mu_0}{2\sigma}}$$

Unloaded Quality Factor (Q)

The Unloaded Quality factor Q with lossy conducting walls (copper) but lossless dielectric is

$$Q_c = \frac{\pi\eta}{4R_s}\left(\frac{2b(a^2+d^2)^{3/2}}{ad(a^2+d^2)+2b(a^3+d^3)}\right) Dimensionless$$

Mode	Calculated Frequency (F_{mnl})	Resistance (R_s)	Quality Factor (Q)
TE_{101}	2.32389 GHz	4.9315 mΩ	13601.31
TE_{102}	2.93996 GHz	5.5485 mΩ	16573.147

Procedure:

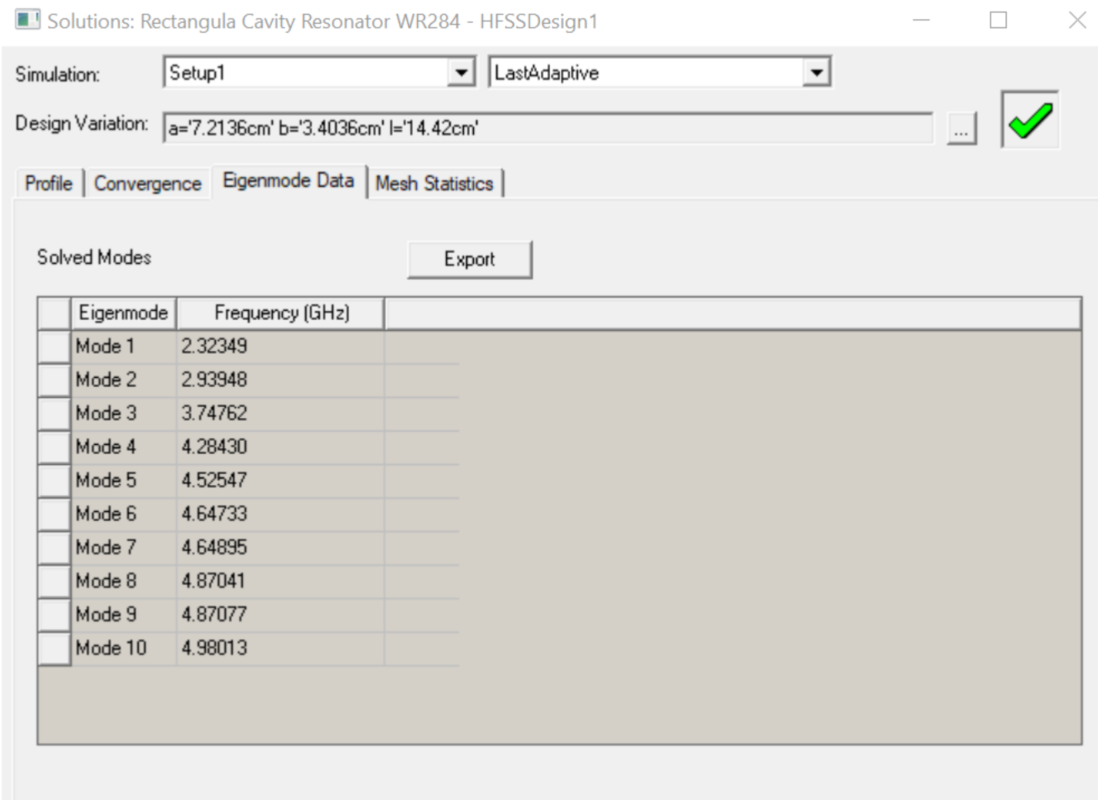
1. Solution type-Eigenmode
2. Draw a box based on calculated dimensions a, b, and d
3. Define minimum frequency and number of modes
4. Define boundary condition for rectangular box-Infinite conductivity

Simulation Results:

Number of modes	Resonant frequency (GHz)	Q-factor
Mode-1	2.32340	$Q_{101} = 13653.9$
Mode-2	2.93938	$Q_{102} = 16628.6$
Mode-3	3.74748	$Q_{103} = 19824.9$
Mode-4	4.28409	$Q_{104} = 17888.5$
Mode-5	4.52523	$Q_{105} = 14729.2$

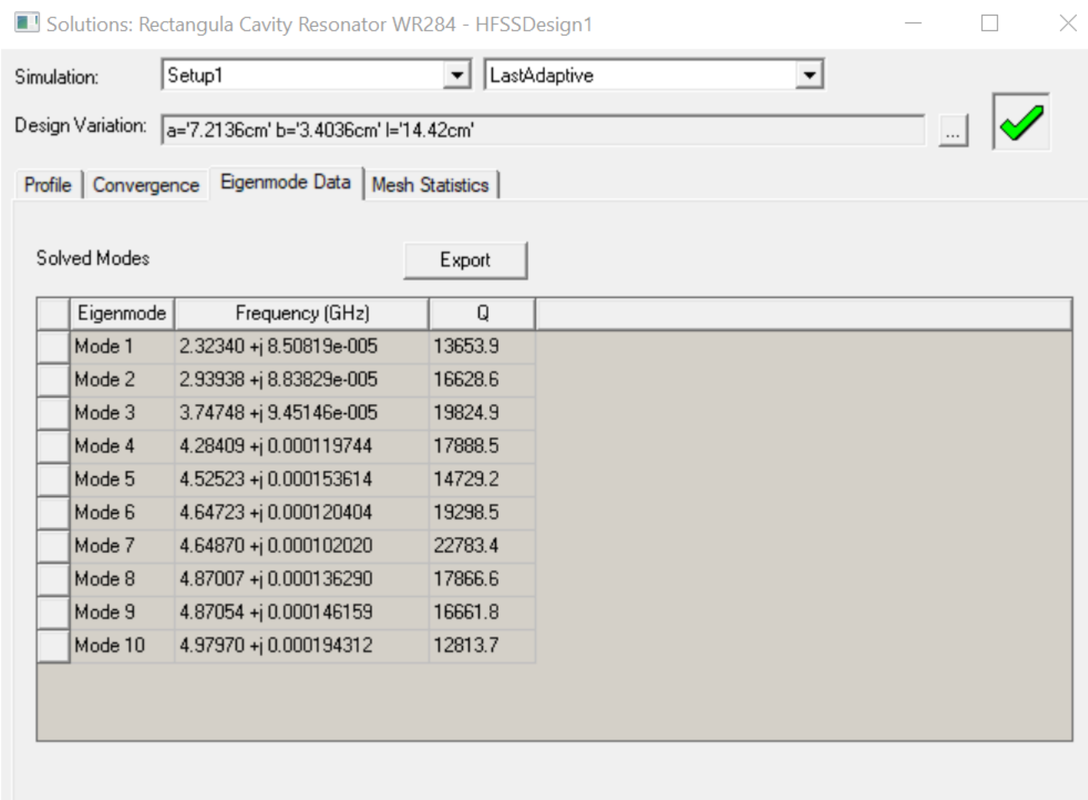
Results:

1. **Eigen Mode Values**



Eigenmode	Frequency (GHz)
Mode 1	2.32349
Mode 2	2.93948
Mode 3	3.74762
Mode 4	4.28430
Mode 5	4.52547
Mode 6	4.64733
Mode 7	4.64895
Mode 8	4.87041
Mode 9	4.87077
Mode 10	4.98013

Fig 1(a) Eigen Mode Values (Before Finite Conductivity)



Eigenmode	Frequency (GHz)	Q
Mode 1	2.32340 +j 8.50819e-005	13653.9
Mode 2	2.93938 +j 8.83829e-005	16628.6
Mode 3	3.74748 +j 9.45146e-005	19824.9
Mode 4	4.28409 +j 0.000119744	17888.5
Mode 5	4.52523 +j 0.000153614	14729.2
Mode 6	4.64723 +j 0.000120404	19298.5
Mode 7	4.64870 +j 0.000102020	22783.4
Mode 8	4.87007 +j 0.000136290	17866.6
Mode 9	4.87054 +j 0.000146159	16661.8
Mode 10	4.97970 +j 0.000194312	12813.7

Fig 1(a) Eigen Mode Values Finite Conductivity Copper 5.8 x 10^7 S/m

Note the Calculated Values and the theoretical values are matching

2. Magnitude of the Electric Field

Eigen Mode 1

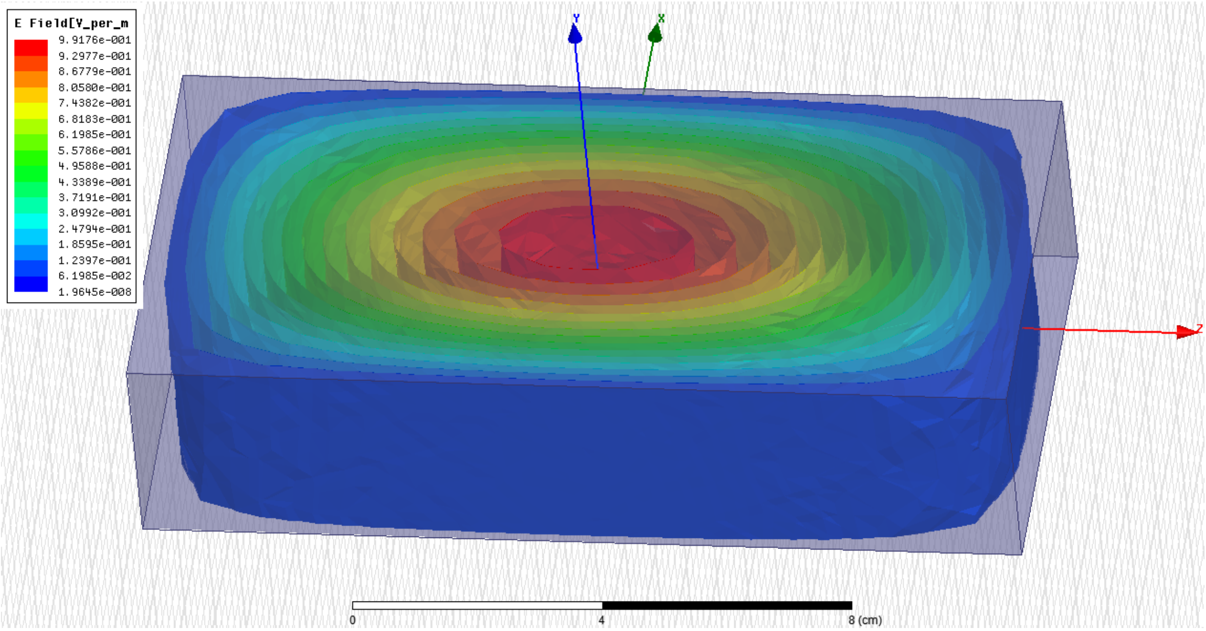


Fig 2(a) Eigen Mode 1 – Magnitude of Electric Field

Eigen Mode 2

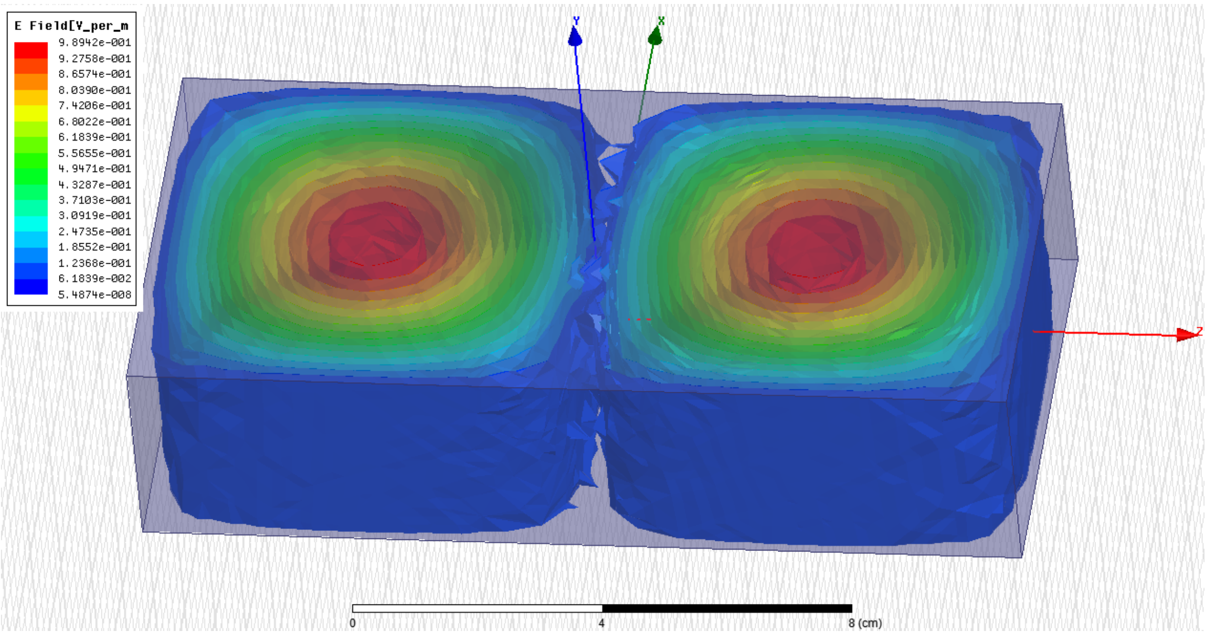


Fig 2(b) Eigen Mode 2 – Magnitude of Electric Field

Conclusion:

The air-filled, **COPPER** plated rectangular cavity has been designed, the resonant frequency and quality factor calculated.

Experiment 2 – Batch B23

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Experiment 2A – E Plane Tee WR284

Aim

To study the field patterns and properties of E-plane Tee for WR-284 and verify that the S-matrix satisfies the symmetric property.

Software Requirement

Ansys HFSS

Theory

1. An E-Plane Tee junction is formed by attaching a simple waveguide to the broader dimension of a rectangular waveguide, which has two ports. The arms of rectangular waveguides make two ports called collinear ports Port 1 & 2 (figure below), while the additional waveguide attached forms Port 3, and is called as Side arm or E-arm.

2. The axis of the side arm is parallel to the electric field and hence it is referred to as the E-plane Tee junction. It is also called the **Series Tee**.

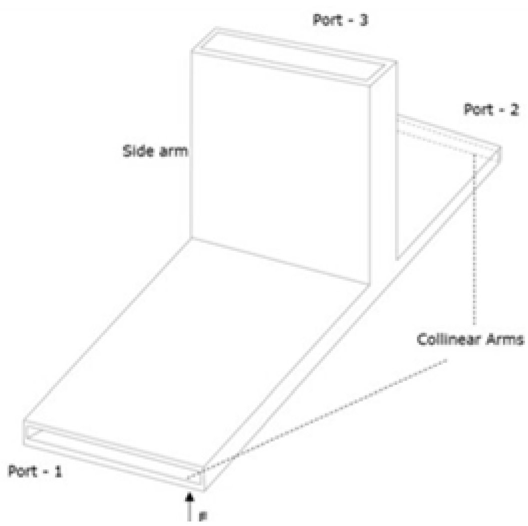


Fig 1 E Plane Tee

The properties of E-Plane Tee can be defined by the scattering matrix or S matrix.

$$S = \begin{bmatrix} S11 & S12 & S13 \\ S21 & S22 & S23 \\ S31 & S32 & S33 \end{bmatrix}$$

Input	Side Arm	Port 3

Outputs	Collinear Arms	Port 1 & 2

It is observed that when the port 3 is the input, the S-matrix coefficients S13 and S23 are **out of phase by 180°**.

Symmetric property in the S-matrix is observed as,

$$\boldsymbol{S13} = -\boldsymbol{S23}$$

These properties are systematically verified by employing the following procedure on the simulation tool.

Procedure

1. The dimensions of the waveguide are used to design the E-plane Tee. The material used is vacuum. (ε_r=1; μ_r=1).

Width of the waveguide (a)	72.136 mm
Height of the waveguide (b)	36.034 mm
Length of the waveguide (l)	100 mm
Frequency range of operation	2.60 – 3.95 GHz
Frequency band	1.35 GHz

2. Two waveguides are oriented along the XY plane (collinear arms) and a third is oriented perpendicular to thecollinear arms, in the +z direction (side arm).
3. The individual arms are joined using the Boolean 'UNITE' operation.

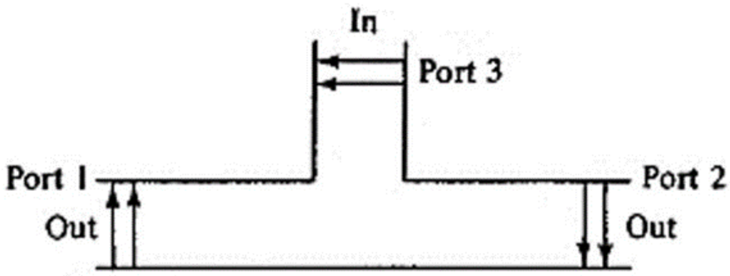


Fig 2 Excitation of E Plane Tee

4. The ports are defined as mentioned above. The collinear ports are assigned ports 1 and 2 and port 3 is definedat the side arm. The integration line is defined accordingly.
5. The ports are also defined to be input or output, and a magnitude of 1 W is assigned for the input port (port 3).

6. The solution frequency is set at **3.3 GHz**, with a frequency sweep from 2 GHz to 4.2 GHz, after which the designis validated and analysed.
7. The magnitude and vector plot of the Electric field is plotted. The Solution matrix is obtained for the desiredsolution frequency (in dB/phase).

Results

E Plane Tee Structure

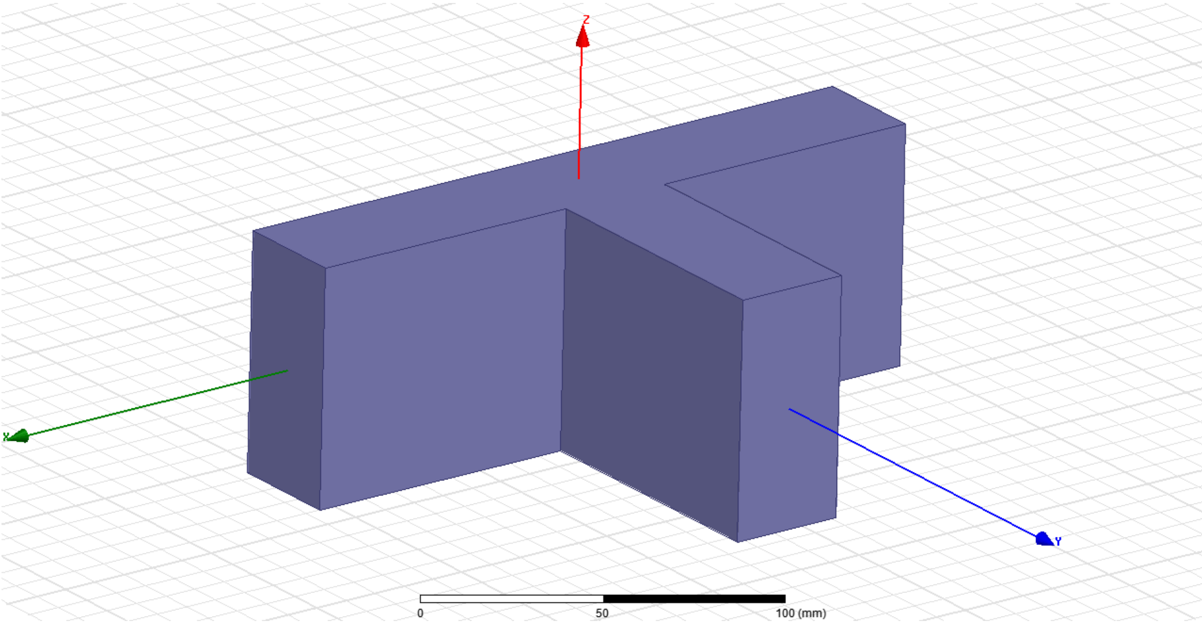


Fig 3 E Plane Tee Geometric Structure WR284

Magnitude Electric Field at 3.3 GHz

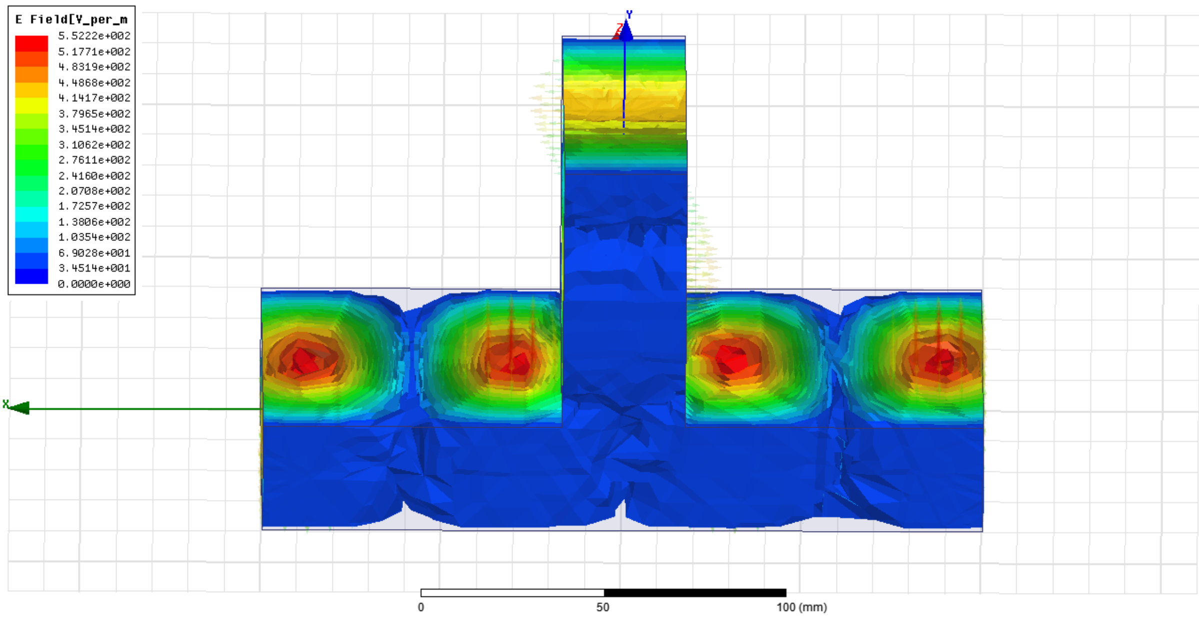


Fig 4 Magnitude of Electric Field WR284

The Electric field distribution is observed for the input and output ports defined above.

Vector Electric Field at 3.3 GHz

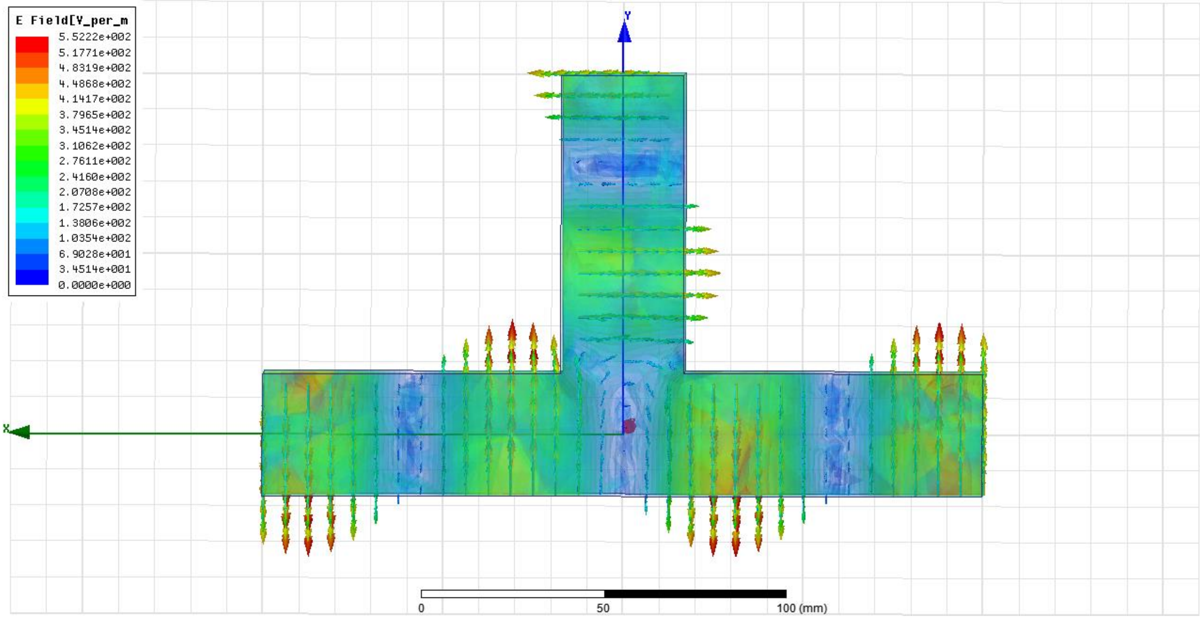


Fig 5 Vector of Electric Field (Outputs Out-of-Phase 180°)

The **output ports 1 and 2 have a phase difference of 180°** as the field vectors are oriented in opposite directions.

Scattering Matrix (dB/Phase) at 3.3 GHz

Nature of Tee	Input/Output	Port 1	Port 2	Port 3
	Port 1	-12.2,113°	-2.43, 117°	**-4.34, 144°**
E Plane Tee	**Port 2**	-2.43, 117°	-12.3, 113°	**-4.33, -35.6°**
	Port 3	-4.34, 144°	-4.33, -35.6°	-5.81, 169°

From the scattering matrix S, it is observed that, the coefficients **S13 and S23 are equal in magnitude and 180° out of phase.** That is,

$$\boldsymbol{S13 = -S23}$$

Conclusion

The E-plane Tee for WR284 has been designed, the electric field pattern and S-matrix have been studied to verify itsproperties.

Experiment 2B – Magic Tee Junction WR284

Nigil M R

Aim

To study the field patterns and properties of Magic Tee for **WR-284** and verify that the S-matrix and Magnitude of Electric Field for various inputs.

Software Requirement

Ansys HFSS

Theory & Procedure

1. An interesting type of T junction is the **Hybrid Tee**, commonly known as magic tee.
2. The device is **combination of E arm and H arm tees**.
3. If power is fed into port 1 and port 2, then the output at port 4 is zero and the output at port 3 will be additive.
4. If the poweris given into port 4 (E-arm) the power is divided between port 1 and 2 equally but in opposite phase.
5. If the power is given into port 3 (H-arm), then the power is divided betweenport 1 and 2 equally.

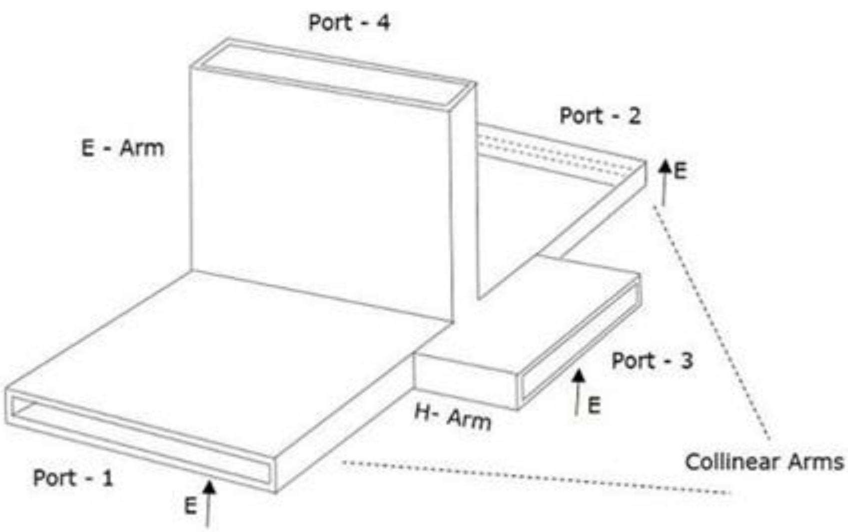


Fig 1 Diagram of Magic Tee

Results

Magic Tee Junction Structure

Width of the waveguide (a)	72.136 mm
Height of the waveguide (b)	36.034 mm

Length of the waveguide (l)	100 mm
Frequency range of operation	2.60 – 3.95 GHz
Frequency band	1.35 GHz

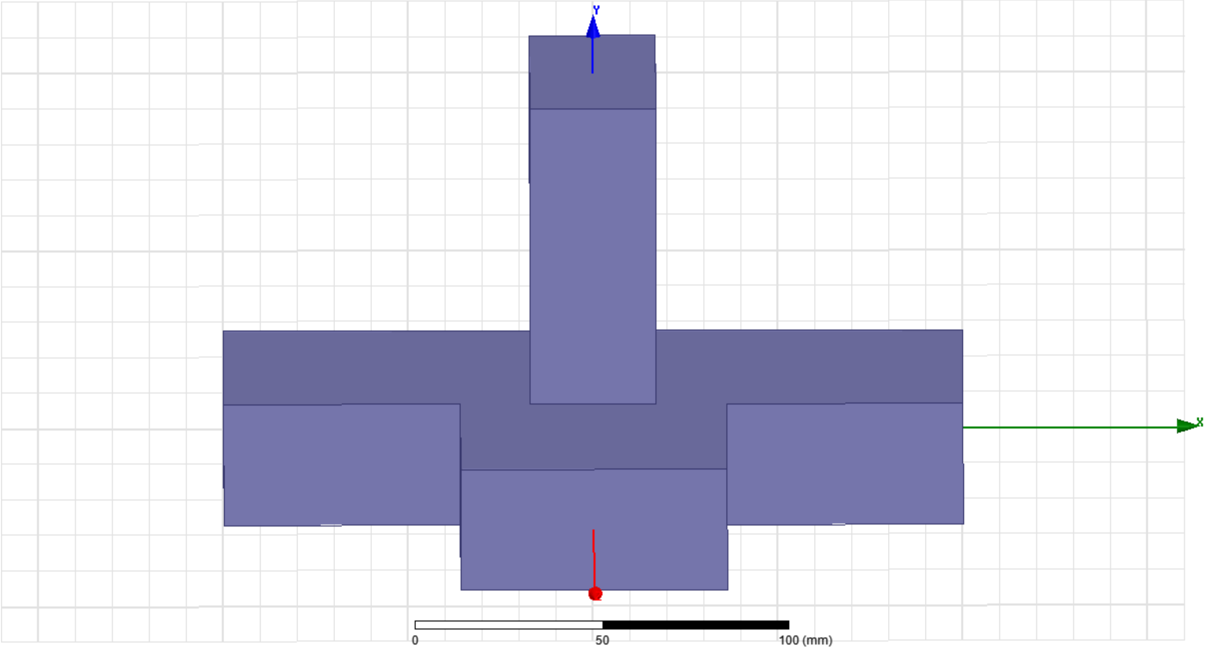


Fig 2 Magic Tee Junction Geometry WR284

Scattering Matrix (dB/Phase)

Case I - Power Feed in Port 3 (H-Arm)

Nature of Tee	Input/Output	Port 1	Port 2	Port 3	Port 4
Magic Tee	**Port 1**	-20.7,137^o	-5.22, 109^o	**-5.21, 137^o**	-4.09, 134^o
	Port 2	-5.22, 109^o	-20.7, 138^o	**-5.21, 137^o**	-4.1, -45.7^o
	Port 3	-5.21, 137^o	-5.21, 137^o	-4.01, -18.5^o	-59.3, 29.3^o
	Port 4	-4.09, 134^o	-4.1, -45.7^o	-59.3, 29.3^o	-6.57, 165^o

Magnitude Electric Field Case 1

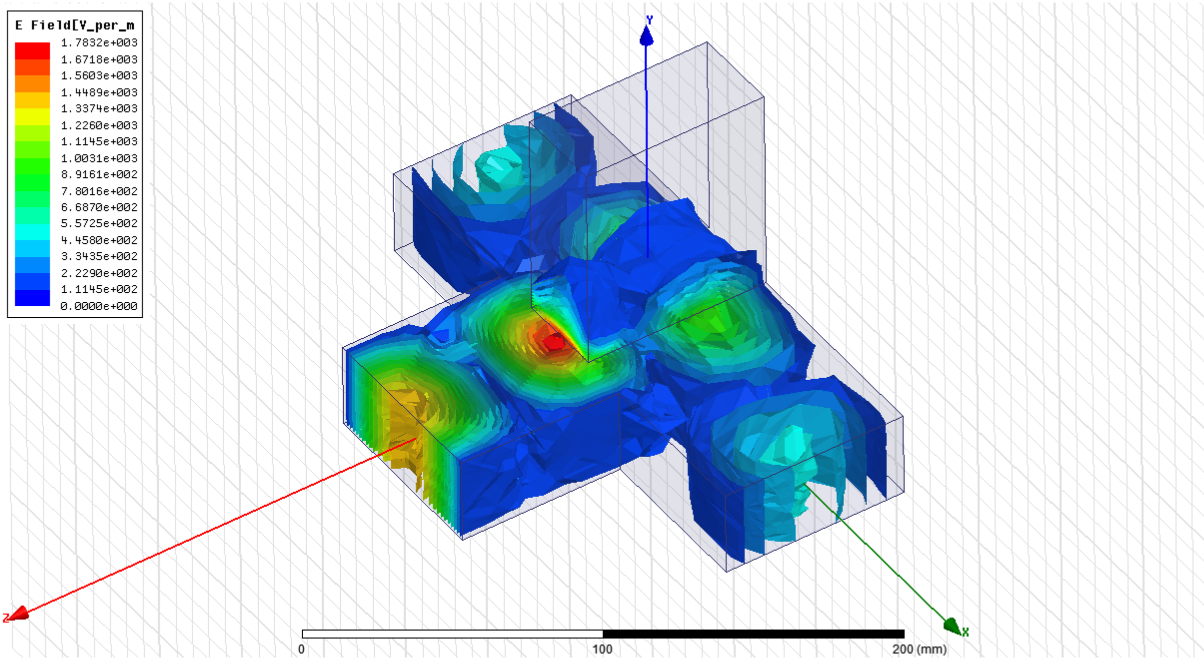


Fig 3 H Arm Power Feed Magnitude Electric Field

Case 2 - Power Feed in Port 4 (E-Arm)

Nature of Tee	Input/Output	Port 1	Port 2	Port 3	Port 4
Magic Tee	**Port 1**	-20.7,137°	-5.22, 109°	-5.21, 137°	**-4.09, 134°**
	Port 2	-5.22, 109°	-20.7, 138°	-5.21, 137°	**-4.1, -45.7°**
	Port 3	-5.21, 137°	-5.21, 137°	-4.01, -18.5°	-59.3, 29.3°
	Port 4	-4.09, 134°	-4.1, -45.7°	-59.3, 29.3°	-6.57, 165°

Magnitude Electric Field Case 2

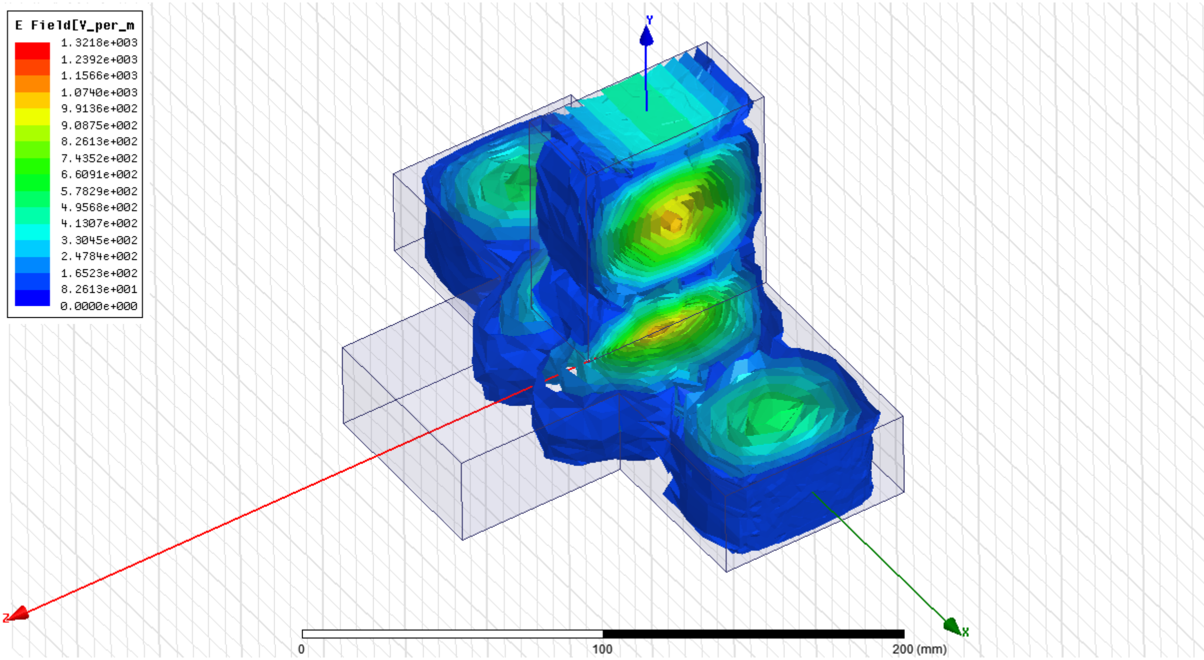


Fig 4 E Arm Power Feed Magnitude Electric Field

Case 3 – Power Feed in Port 1 & 2 In-Phase

Nature of Tee	Input/Output	Port 1	Port 2	Port 3	Port 4
Magic Tee	**Port 1**	-20.7,137°	-5.22, 109°	-5.21, 137°	-4.09, 134°
	Port 2	-5.22, 109°	-20.7, 138°	-5.21, 137°	-4.1, -45.7°
	Port 3	**-5.21, 137°**	**-5.21, 137°**	-4.01, -18.5°	-59.3, 29.3°
	Port 4	-4.09, 134°	-4.1, -45.7°	-59.3, 29.3°	-6.57, 165°

<u>Magnitude Electric Field Case 3</u>

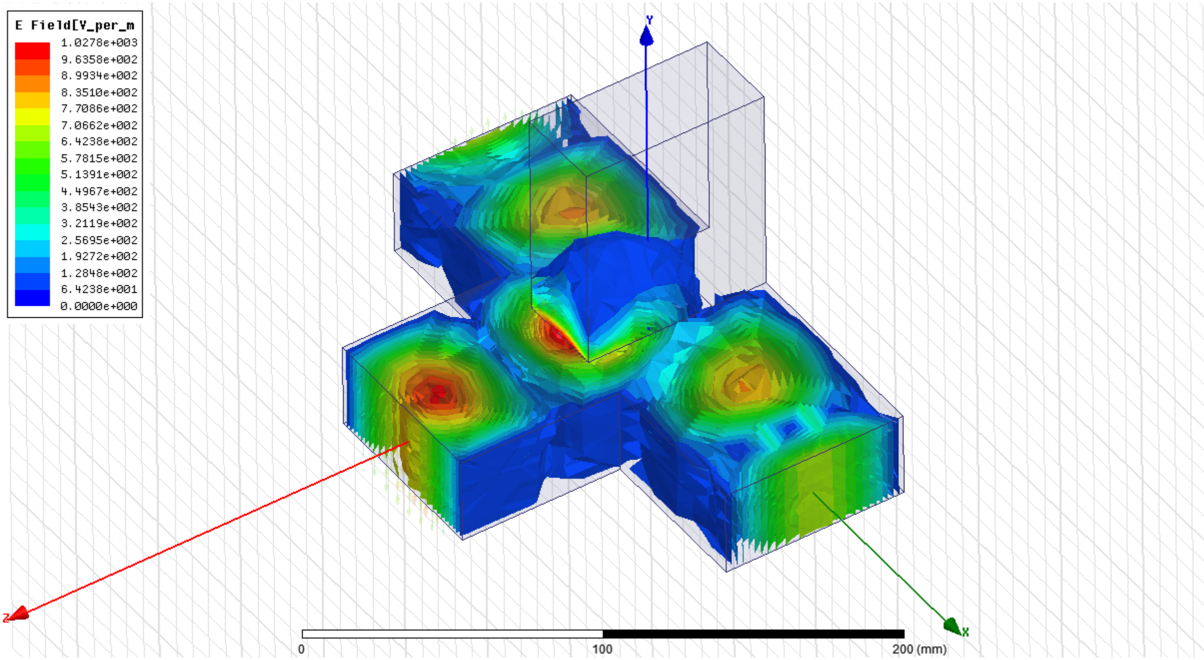


Fig 5 Power Feed in Port 1 & 2 In-Phase - Magnitude Electric Field

<u>Case 4 - Power Feed in Port 1 & 2 Out-of-Phase</u>

Nature of Tee	Input/Output	Port 1	Port 2	Port 3	Port 4
Magic Tee	**Port 1**	-20.7,137°	-5.22, 109°	-5.21, 137°	-4.09, 134°
	Port 2	-5.22, 109°	-20.7, 138°	-5.21, 137°	-4.1, -45.7°
	Port 3	-5.21, 137°	-5.21, 137°	-4.01, -18.5°	-59.3, 29.3°
	Port 4	**-4.09, 134°**	**-4.1, -45.7°**	-59.3, 29.3°	-6.57, 165°

<u>Magnitude Electric Field Case 4</u>

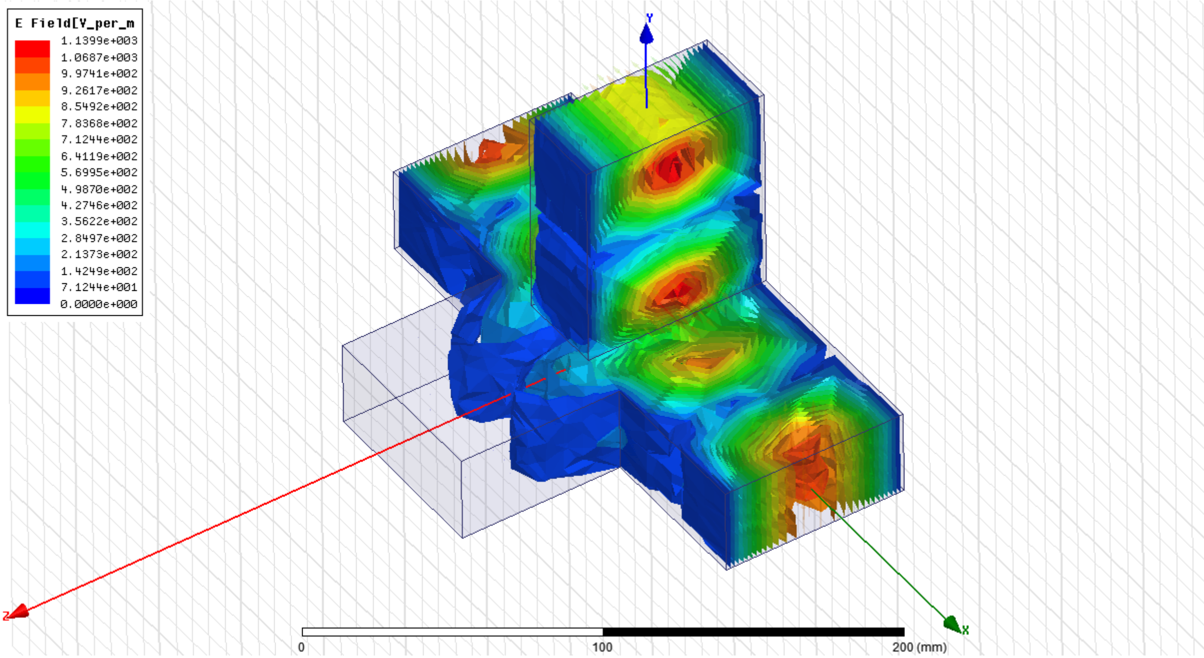


Fig 6 Power Feed in Port 1 & 2 Out-of-Phase - Magnitude Electric Field

Conclusion

The Magic Tee Junction for WR284 has been designed, the electric field pattern pf different cases and S-matrix of different input power feed cases have been studied to verify its properties.

Experiment-3 – Batch B23

Nigil M R

CB.EN.U4ECE19136

Experiment 3 – Microstrip Planar Transmission Line

Aim of Experiment:

To Design and simulate a 50 ohm Microstrip line structure

Specification:

Dielectric constant (ϵ_r) = 3

Dielectrice Height (h) = 0.8

Operating frequency (f) = 5 GHz

Characteristic Impedance = 50 Ohms

Software Requirement:

- Ansys HFSS

Theory:

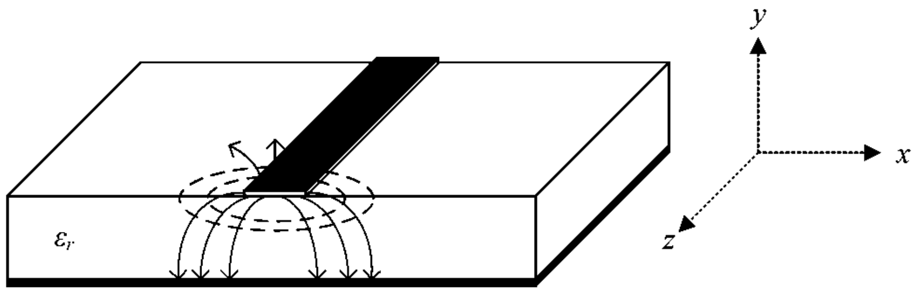


Fig 1 *Microstrip Line*

A microstrip line is a planar transmission line that can be fabricated using photolithographic processes and can be integrated into both active and passive microwave devices. A conductor of width W is printed on a thin, grounded dielectric substrate of thickness d and relative permittivity ε_r.

Unlike normal stripline, where all fields are contained in a homogenous dielectric region, microstrip lines has its fields in the dielectric region between the strip conductor and the ground plane and some part in the air region above the substrate as shown in the Fig 1. So, the microstrip line cannot be a pure TEM wave because of the non-phase-matching condition at the dielectric-air interphase.

Though the microstrip line constitute a hybrid TM-TE wave, in practical application the dielectric substrate is electrically very thin (d << λ) and the fields are quasi-TEM. This gives, good approximation for the phase velocity, propagation constant and characteristic impedance.

Theoretical calculation:

For a given characteristic impedance Z_0 and dielectric constant ε_r, the W/d ratio can be found as

$$\frac{W}{d} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} \ ; \ \dfrac{W}{d} > 2 \\ \dfrac{2}{\pi}\left[B - 1 - In(2B-1) + \dfrac{\varepsilon_r - 1}{2\varepsilon_r} - \left\{In(B-1) + 0.39 - \dfrac{0.61}{\varepsilon_r}\right\}\right] \ ; \ \dfrac{W}{d} < 2 \end{cases}$$

Where A and B are given as

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right) \ \& \ B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

In our case Z_0 = 50 and d = 0.8 mm

$$B = 6.838$$

$$\frac{W}{d} = 2.5137$$

$$W = 2.5137 * 0.8 = 2.01096 \ \approx 2.011\, mm$$

Procedure:

- Draw a rectangular box of dimension 20 mm x 40 mm x 0.8 mm and define its dielectric constant (ε_r=3) as given. This acts as the dielectric.
- Below the box, draw a similar rectangle of dimension 20 mm x 40 mm and define its boundary as perfect conductor. This acts as the ground for the microstrip line.
- Next, on the top of the rectangular box draw a rectangular strip of width W 2.011 mm and length as 40 mm. Draw the microstrip line such that it is placed at the center of the dielectric box.’
- Define the boundary of the micro stripline as perfect conductor (Perf E)
- Now draw two rectangles on the XZ plane such that it connects both the ground and microstrip line.
- Now, assign excitation to the rectangles, use lumped port to define the excitation to the two rectangles on the either side.
- For analysis create a radiation box filled with air such that it covers the whole of the microstrip line structure.

- Add frequency sweep at 5 GHz analyze and plot the S parameter and Z_0.

Results:

Geometry of Microstrip Structure

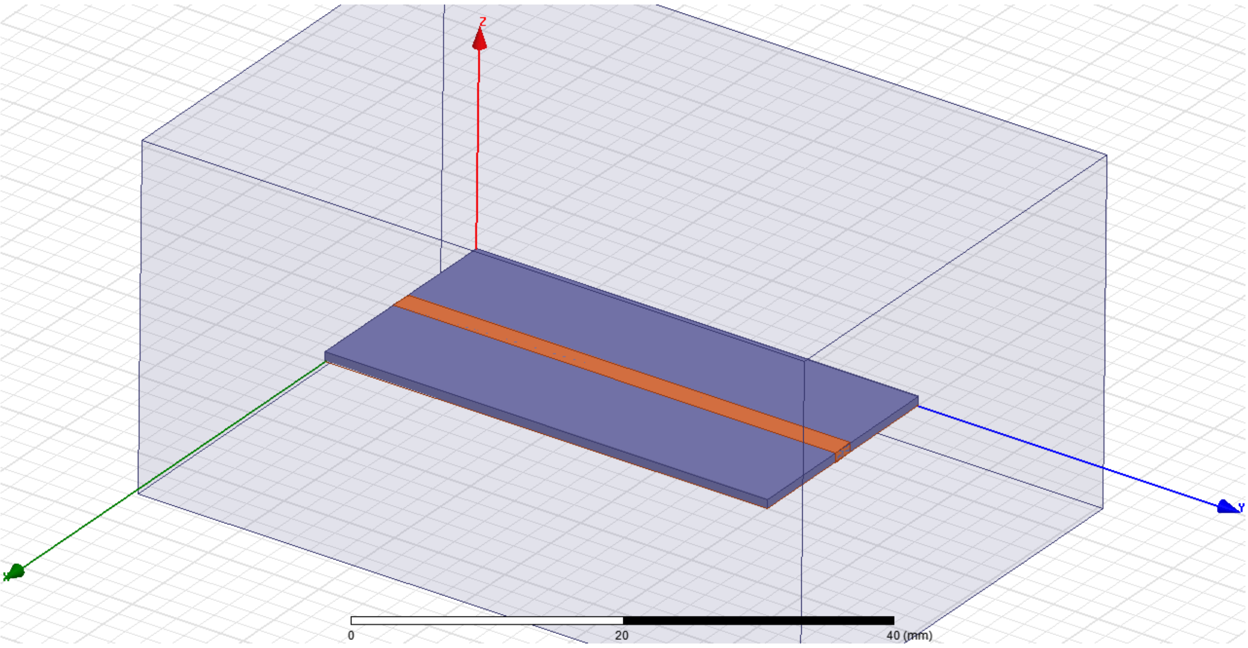


Fig 2 *Microstrip Structure*

Magnitudes of the Transmission Coefficient and Reflection Coefficient

(Frequency 5 GHz)

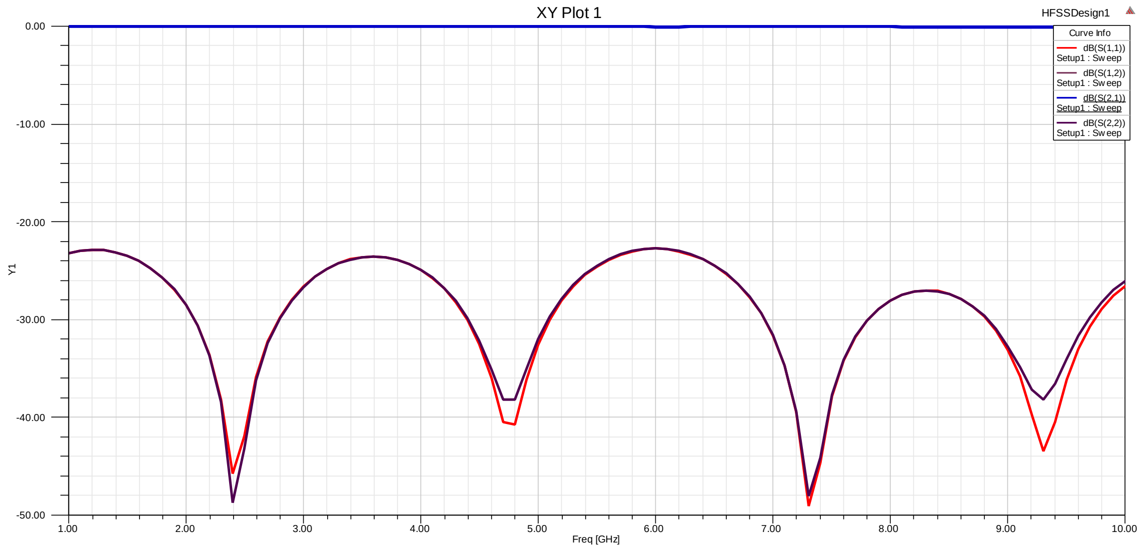


Fig 3 *Scattering Matrix Plot*

Reflection Coefficients **-** S (1,1) – Input matching & S (2,2) – Output matching

Transmission Coefficients - S (2,1) – Gain or Loss & S (1,2) – Isolation

Reflection Loss = $-20\log|\Gamma_{in}| = -20\log|S_{11}| = -20\log|0.0236|$ = ***32.5 dB***

Insertion Loss = $-20\log|\tau| = -20\log|S_{21}| = -20\log|0.993|$ = ***0.06 dB***

Scattering Matrix and Impedance

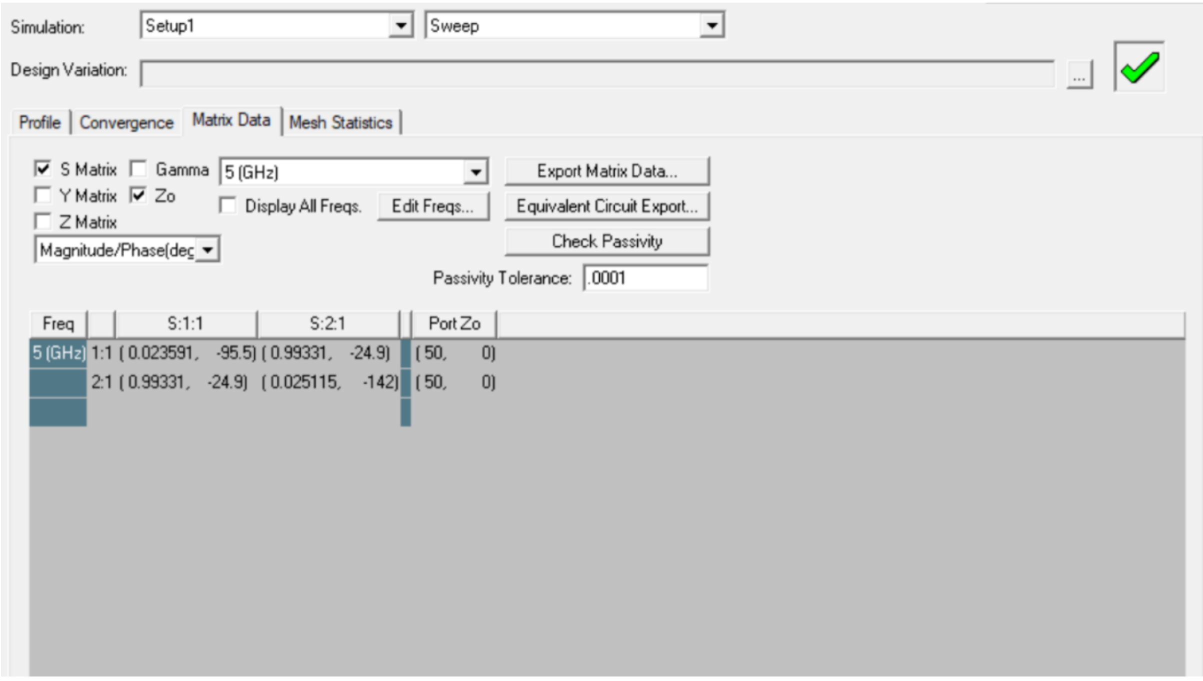


Fig 4 *Scattering Matrix and Impedance*

Impedance (Frequency 5 GHz)

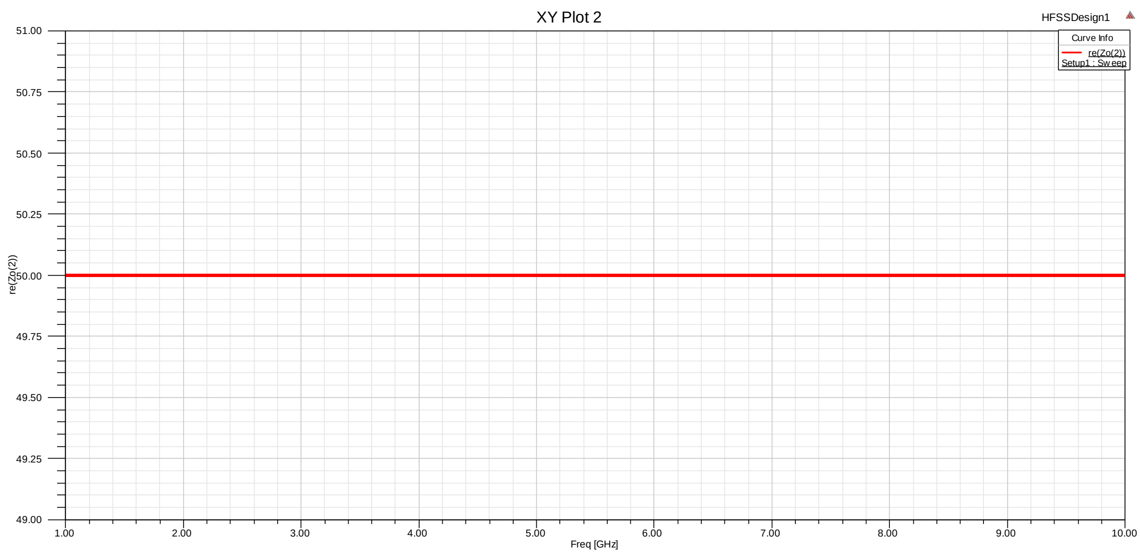


Fig 5 *Impedance Plot*

Results

The microstrip planar transmission line has been designed, the geometry, magnitude of the transmission coefficient and reflection coefficient and the impedance at the given operating frequency have been studied and also been verified using the simulation.

Experiment 4 – Batch B23

Nigil M R

CB.EN.U4ECE19136

Experiment 4 – Hybrid Ring Coupler 180^0 Phase Shift

Aim of Experiment:

To study the characteristics of 180^o hybrid coupler and its s-parameters. Also, calculate the coupling, directivity, isolation and insertion loss.

Specification:

Dielectric constant : 3

Dielectric height (h) : 0.8 mm

Operation Frequency : 5 GHz

Characteristic Impedance (Z_0) = 50 Ohms

Software Requirement:

- Ansys HFSS

Theory:

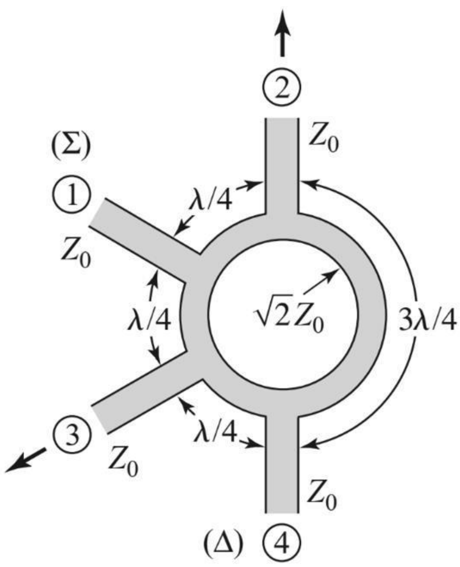


Fig 1 Planar Hybrid Ring Coupler

Definition and Working

A hybrid ring coupler is a four-port network with a 180^o phase shift between the two output ports. It can be operated so that the output ports are in phase. A hybrid ring coupler with 180^{o} phase shift is also called as rat-race coupler. The ring hybrid or rat race coupler can be easily constructed in both planar (microstrip or stripline) and waveguide versions.

The hybrid ring works as a power divider when a signal is applied to port 1, the signal will be evenly split into two in-phase components at port 2 and 3, and port 4 will be isolated. If the signal is applied to port 4, the signal will be equally split into two components with a 180^{o} phase difference at ports 2 and 3, and port 1 will be isolated.

When the hybrid ring is operated as a combiner, with the input signals applied at port 2 and 3, the sum of the inputs will be formed at port 1, while the difference will be formed at port 4. Hence, port 1 and 4 are referred to as the sum and difference port. The S-matrix of an ideal 3dB 180^{o} hybrid coupler is given below. It is unitary and symmetric.

$$[S] = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Performance Parameters

The performance of a hybrid ring coupler can be determined by calculating the coupling, directivity, isolation and insertion loss. An ideal coupler has infinite directivity and isolation (S_{14}=0). Coupling factor indicated the fraction of the input power that is coupled to the output port. Directivity is the measure of the coupler’s ability to isolate the forward and backward waves. Isolation is the measure of the power delivered to the uncoupled port. Insertion loss accounts for the input power delivered to the through port diminished by power to the coupled and isolated ports.

Calculations:

Circular Ring Dimensions

Characteristic Impedance of Circular Ring = $\sqrt{2}Z_0 = 70.7\ Ohms$

Electrical Length = 540^0 ; Width = $1.12\ mm$; Length = $59.04\ mm$

Circumference = $\frac{59}{2x3.14} = 9.4\ mm$;

Outer Circle Radius = $9.4\ mm + \frac{1.12}{2} = 9.96\ mm$

Inner Circle Radius = $9.4\ mm - \frac{1.12}{2} = 8.84\ mm$

Port Dimensions

Characteristic Impedance $Z_0 = 50\ Ohms$

Electrical Length = 90^0 ; Width = $2\ mm$; Length = $9.65\ mm$

Procedure:

- Create 2 circles of radius 9.96 mm and 8.84 mm respectively. Use the Boolean function subtract tool to create a hollow circle on the XY Plane.
- To create the ports, draw a rectangle and use the Duplicate Around Z axis function and duplicate the rectangle at angles $+90^0$, -90^0, $+30^0$ and -30^0. All the rectangles are merged to the circular ring using the Boolean function unite.
- Now, using the Duplicate Along function move the rectangle to the end of both 30^0 arms such that the moved rectangle is parallel and feed lines can be defined later.
- After the construction of the planar ring, define the substrates Ground and the dielectric. The ground and the hybrid ring strip is defined with the conductivity of copper and boundary is defined as Perf E.
- The dielectric substrate is defined with a material with relative permittivity of 3. Define the Lumped port excitations.
- Create a radiation box with air and define its boundary as radiation.
- For analysis add the frequency solution setup and define sweep for 5 GHz.

Results:

Design

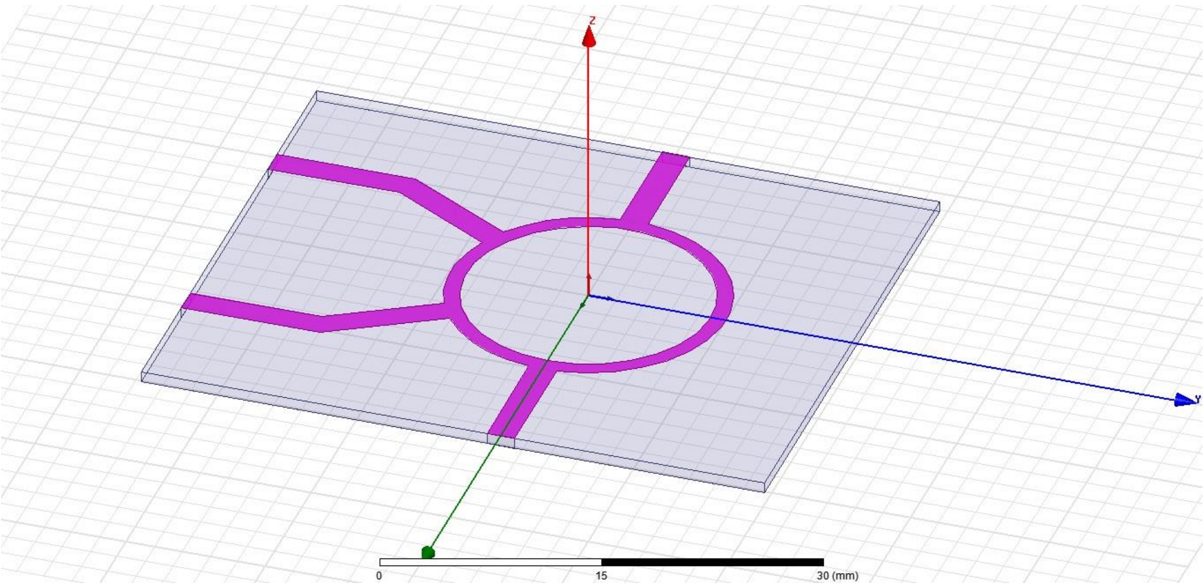


Fig 2 Planar Hybrid Ring Coupler

Graph

Plot Contains S11, S12, S21, S22 Parameters Only

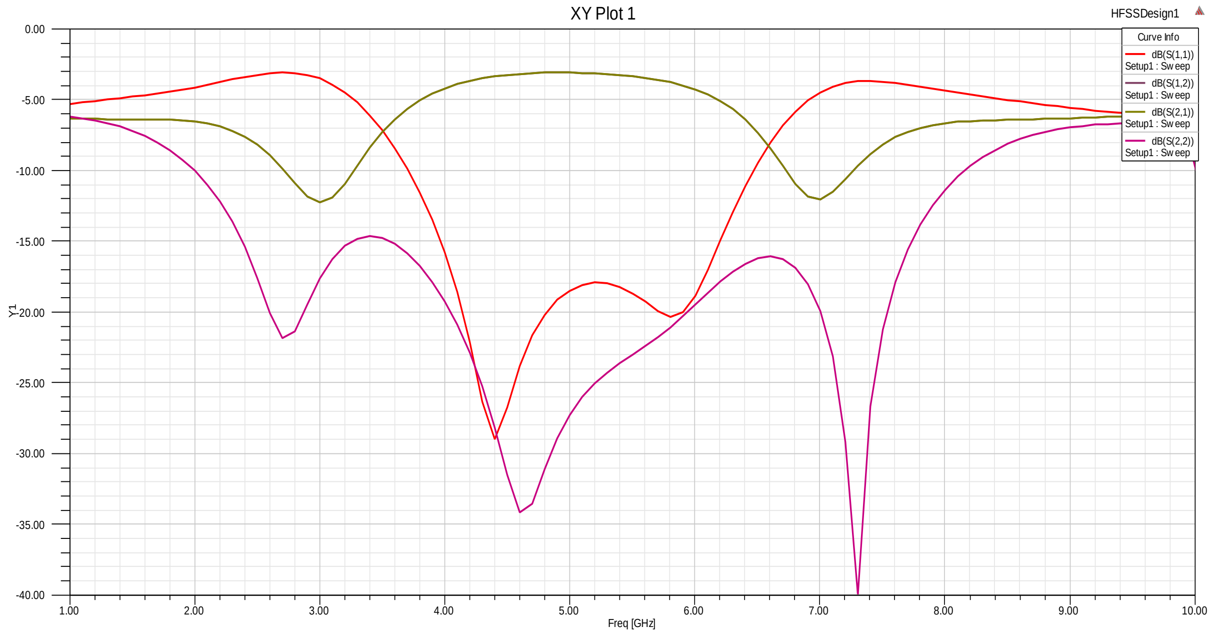
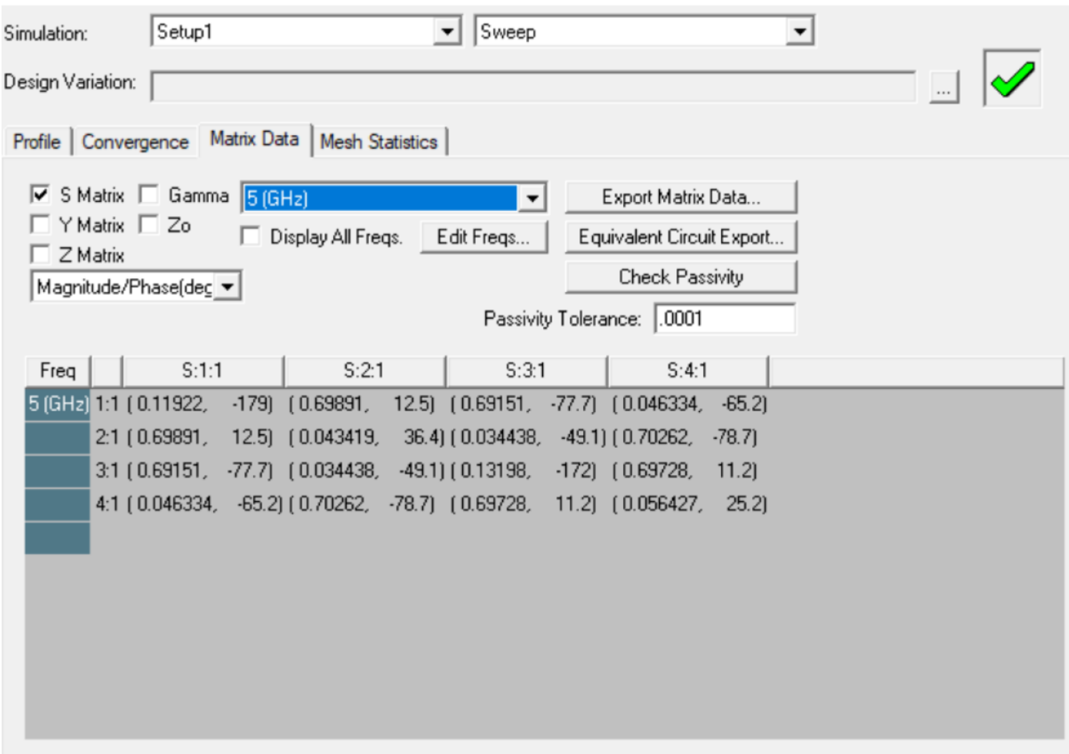


Fig 3 Scattering Matrix (dB) vs Frequency (GHz)

Performance Parameter Calculation



Freq		S:1:1	S:2:1	S:3:1	S:4:1
5 (GHz)	1:1	(0.11922, -179)	(0.69891, 12.5)	(0.69151, -77.7)	(0.046334, -65.2)
	2:1	(0.69891, 12.5)	(0.043419, 36.4)	(0.034438, -49.1)	(0.70262, -78.7)
	3:1	(0.69151, -77.7)	(0.034438, -49.1)	(0.13198, -172)	(0.69728, 11.2)
	4:1	(0.046334, -65.2)	(0.70262, -78.7)	(0.69728, 11.2)	(0.056427, 25.2)

Fig 4 Scattering Matrix at Operating Frequency

$|S_{12}|^2$ = Power Delivered to Port 2 $\alpha^2 = 1 - \beta^2$

$|S_{13}|^2$ = Coupling Factor β^2

Also, Isolation (I) = Coupling Factor (C) + Directivity (D)

Coupling factor (C) $= -20\log\beta$ dB $=$ **3.20 dB**

Directivity (D) $= +20\log\frac{\beta}{|S_{14}|}$ dB $=$ **23.48 dB**

Isolation (I) $= -20\log|S_{14}|$ dB $=$ **26.7 dB**

Insertion loss (L) $= -20\log|S_{12}|$ dB $=$ **3.11 dB**

Conclusion:

The planar hybrid ring coupler with 180^0 phase shift has been simulated using the Ansys HFSS and the scattering parameter vs frequency plot has been plotted and also, the performance parameter is calculated using the scattering matrix at operating frequency successfully.

Experiment 5 – Batch B23

Nigil M R

CB.EN.U4ECE19136

Experiment 5 – Equal Split Wilkinson Power Divider

Aim of Experiment:

To simulate and vereify the characteristics and the s-parameters of wilkinson power dividers.

Specification:

Dielectric constant : 3.2

Dielectric height (h) : 0.8 mm

Operation Frequency : 3.5 GHz

Characteristic Impedance (Z_0) = 50 Ohms

Software Requirement:

- Quite Universal Circuit Simulator (QUCS)

Theory:

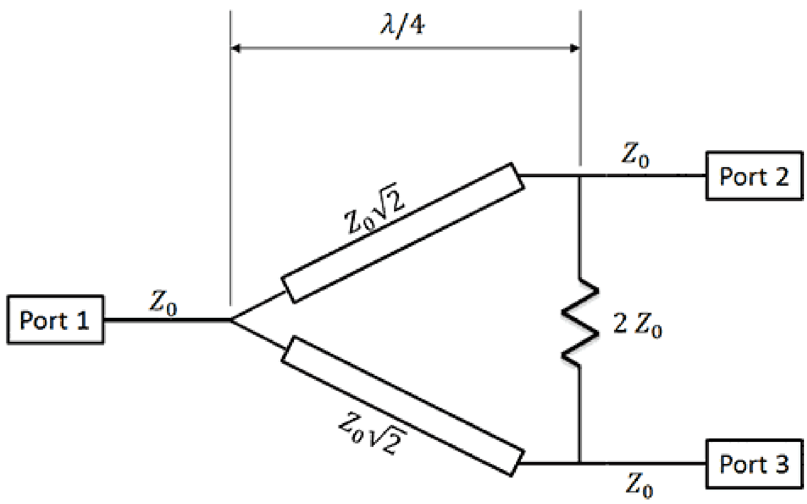


Fig 1 Wilkinson Power Divider Circuit-Diagram

Planar power dividers such as the lossless T-junction divider and resistive divider suffer from few disadvantages. The lossless T-junction divider though being lossless, it is not matched at all ports and it does not have isolation between the output ports. Similarly, the resistive divider though matched at all ports, it is not lossless and isolation is not achieved.

A planar power divider with a lossy-three port network having impedance match at all ports and with isolation between output ports can be designed, such a circuit is called as *Wilkinson power divider*. The Wilkinson power divider has a useful property of appearing lossless when the output ports are marched; that is, only reflected power from the output ports is dissipated.

For our design, we consider an equal power split Wilkinson divider, unequal power split can also be achieved. This divider is often made in microstrip or stripline form as depicted in **Figure 1**. To obtain the S-parameter matrix, the analysis is done by reducing the circuit into two simpler circuits driven by symmetric and anti-symmetric sources at the output ports. This is called the Even-Odd mode analysis technique. The obtained S-matrix is given below in **Figure 2**.

$$[S] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Fig 2 S-Matrix Wilkinson Power Divider

Calculations:

Quarter-Wave Length Line

Characteristic Impedance $\sqrt{2}Z_0 = 70.7\ Ohms$

Electrical Length = 90^0 ; Width = $1.06\ mm$; Length = $13.66\ mm$

Input and Output Port Lines

Characteristic Impedance $Z_0 = 50\ Ohms$

Electrical Length = 45^0 ; Width = $1.92\ mm$; Length = $6.68\ mm$

Procedure:

- Open Quite Universal Circuit Simulation (QUCS)
- Go to Components → Transmission Line → Choose “Substrate”. Define the dielectric constant and the height of the dielectric by clicking on the substrate in the schematic area.
- Now, for the calculation of the microstrip line parameters, go to “Tools” in the menu bar → Line Calculation → Microstrip Line. Calculate the width and length for both Z_0 and $\sqrt{2}Z_0$.
- Again, from the Components Box → Transmission Line → Choose “Microstrip Lines: and define the respective width and length calculated above. Connect the circuit elements using the “Wire” tool in the tool bar.
- For defining the power sources go to Component → Source → Choose “Power Source” and connect the power sources to the three ports of the schematic.

- For defining the isolation resistor, go to Components → Lumped Components → Choose "Resistor US" and define the resistance as 100 Ohms.
- For the analysis of the circuit go to Components → Simulation → Choose "S-Parameter" and define the operating frequency, samples and start, stop values. Choose the "Simulation" icon on the tool bar. Use the "Equation" icon to convert the values to decibels.
- In the simulation page choose "Cartesian Plot" and select the S-parameters for plotting the magnitude response and then choose "Tabular Column" and select the respective S-parameter to plot the phase response.

Results:

Schematic Design

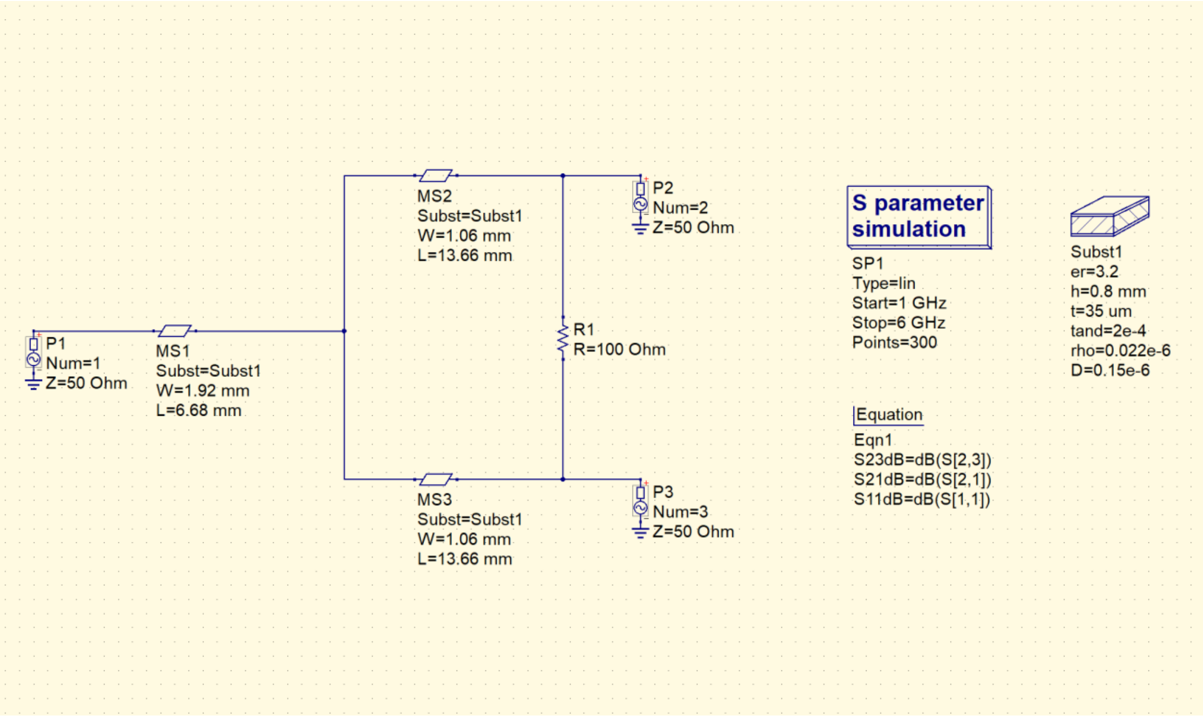


Fig 3 Wilkinson Power Divider Circuit

Magnitude Response Graph

Plot Contains S11, S21, S23 Parameters Only

At the operating frequency 3.5 GHz, the S-parameters **S11** and **S23** are **zero** and also **S21** is **-3 dB** which matches the ideal S-matrix values shown in **Figure 2**.

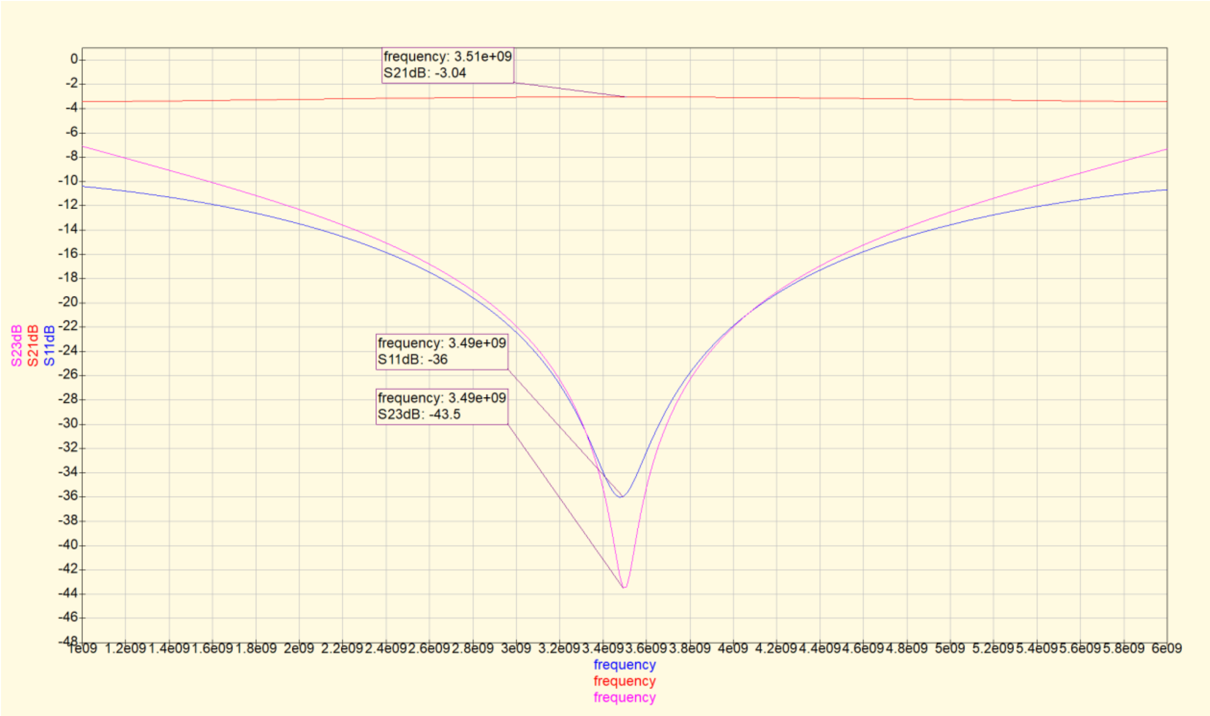


Fig 4 Magnitude Plot (dB) - Scattering Matrix

Phase Response Tabular Column

At the operating frequency 3.5 GHz, the **S12** parameter has **0.705 ∟-89.7**° which is almost equal to the value $\frac{-i}{\sqrt{2}}$ of the ideal S-matrix value shown in **Figure 2**.

frequency	S[1,2]
3.24e09	0.705 / -82.4°
3.26e09	0.705 / -82.9°
3.27e09	0.705 / -83.4°
3.29e09	0.705 / -83.8°
3.31e09	0.705 / -84.3°
3.32e09	0.705 / -84.7°
3.34e09	0.705 / -85.2°
3.36e09	0.705 / -85.6°
3.37e09	0.705 / -86.1°
3.39e09	0.705 / -86.5°
3.41e09	0.705 / -87°
3.42e09	0.705 / -87.4°
3.44e09	0.705 / -87.9°
3.46e09	0.705 / -88.4°
3.47e09	0.705 / -88.8°
3.49e09	0.705 / -89.3°
3.51e09	0.705 / -89.7°
3.53e09	0.705 / -90.2°
3.54e09	0.705 / -90.6°
3.56e09	0.705 / -91.1°
3.58e09	0.705 / -91.5°
3.59e09	0.705 / -92°
3.61e09	0.705 / -92.5°
3.63e09	0.705 / -92.9°
3.64e09	0.705 / -93.4°
3.66e09	0.705 / -93.8°
3.68e09	0.705 / -94.3°
3.69e09	0.705 / -94.7°
3.71e09	0.705 / -95.2°
3.73e09	0.705 / -95.6°
3.74e09	0.705 / -96.1°
3.76e09	0.705 / -96.6°
3.78e09	0.704 / -97°
3.79e09	0.704 / -97.5°
3.81e09	0.704 / -97.9°
3.83e09	0.704 / -98.4°
3.84e09	0.704 / -98.8°
3.86e09	0.704 / -99.3°
3.88e09	0.704 / -99.7°

Fig 5 Phase Plot (Degree) - Scattering Matrix

Conclusion:

The Wilkinson power divider has been successfully designed, simulated and the following parameter S11,S21,S23 of the S-matrix are successfully verified using the magnitude and phase plots with Quite Universal Circuit Simulator (QUCS).

Experiment 6 – Batch B23

Nigil M R

CB.EN.U4ECE19136

Experiment 6 - Microstrip Inset Patch Antenna

Aim of Experiment:

To simulate microstrip inset-feed patch antenna and verify its reflection loss, electric and magnetic field vector and respective radiation patterns along with gain v frequency plot.

Specification:

Dielectric constant : 2.45

Dielectric height (h) : 0.8 mm

Operation Frequency : 5.7 GHz to 5.9 GHz (5.8 GHz)

Characteristic Impedance (Z_0) = 50 Ohms

Software Requirement:

- Ansys HFSS

Theory:

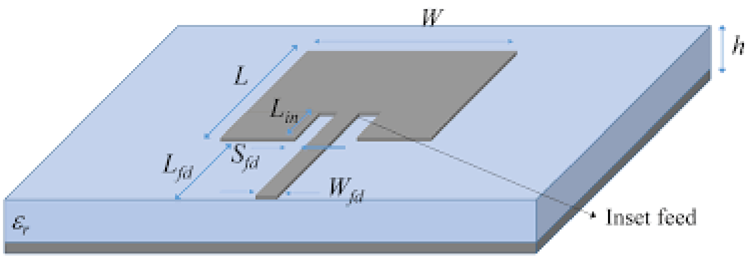


Fig 1a Microstrip Inset-Feed Patch Antenna

Microstrip patch antenna is a type of microstrip antenna. It consists of a conducting patch of any planar or non-planar geometry on one side of the dielectric substrate and a ground plane on the other side. The metallic patch can be made of any conducting material and the patch can be of any shape. Here, the patch is designed as rectangular shaped patch. Microstrip patch antenna have low profile configuration and are capable of dual & triple frequency. Due to these advantages these antennas are most suitable for aerospace and mobile applications.

There are different types of feeding techniques such as coaxial probe, microstrip line, non-contact aperture coupling and proximity coupling. The inset feed patch antenna is a fed via a microstrip feed line connected to a specific point within the patch. Through varying the location of where the microstrip connects to the patch the measured input impedance can be controlled.

The microstrip patch antenna is a little different than many antennas, as the structure itself does not radiate, but rather the edge gaps between the patch and the ground plane radiates.

Calculations and Dimensions

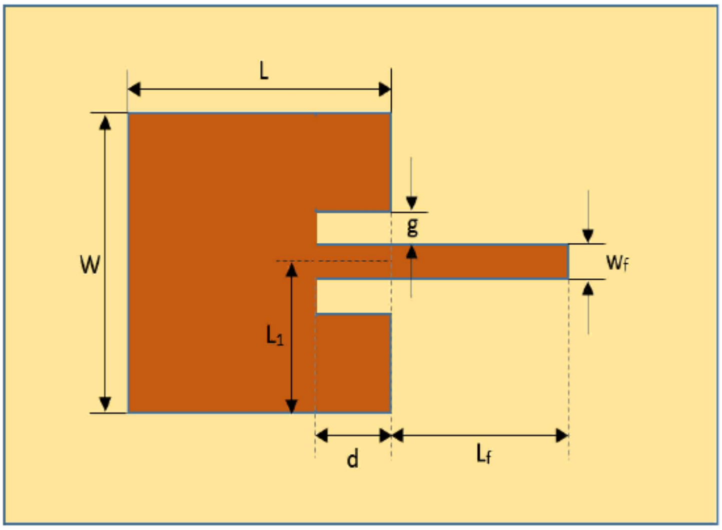


Fig 1b Top View - Microstrip Inset-Feed Patch Antenna

(Resonant Frequency 5.8 GHz)

Calculated input impedance (Z_{in}) 155.25 Ohms

$R_{in} = \sqrt{Z_o Z_{in}}$ = 88.10 Ohms

Ground Plane & Substrate

Width x Length = 35 mm x 35 mm

(i) <u>Patch Dimension</u>

Width x Length = 19.691 mm x 16.1614 mm

(ii) Stripline Dimension

Width x Length = 2.2937 mm x 9.04 mm

(iii) Inset Feed-Line Dimension

$Y_o \text{or } d = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{Z_o}{R_{in}}}$ = 5.69 mm (*For 50 Ohms*)

Usually, the gap (**g**) width to create the inset line is taken as same as the width of the stripline (**W$_f$**). In our case for a 50 Ohms impedance the width is taken as half of the width (**W$_f$/2**) of the stripline on both the sides.

Procedure:

- Design the **Ground** rectangular plane.
- Construct the **Substrate** on the top of the ground plane with the same dimension and a thickness of 0.8 mm.
- Construct a **Patch** at the center of the substrate with the dimension specified above.
- Construct a **Stripline** using the above specified dimensions, such that it ends at the center of the patch.
- Make a **Cut**, in order to match the impedance in the patch as well as the substrate. The cut has to be made at a length of Y_0, with a width of the feed line extended on both sides. In this case half of the feedline width is used as the gap on both sides, so, that impedance match can be achieved.
- Subtract and unite to make a rectangular microstrip inset feed-line patch antenna.
- Construct a lumped port joining the feed, patch, ground. Assign excitation.
- Assign boundaries to both patch and ground plane as perfect conductors (Perf E).
- Construct a radiation box of dimensions sufficient enough to enclose the design structure.
- Add frequency setup and mention the resonant frequency. Simulate and record the results.

Results:

Simulated Design

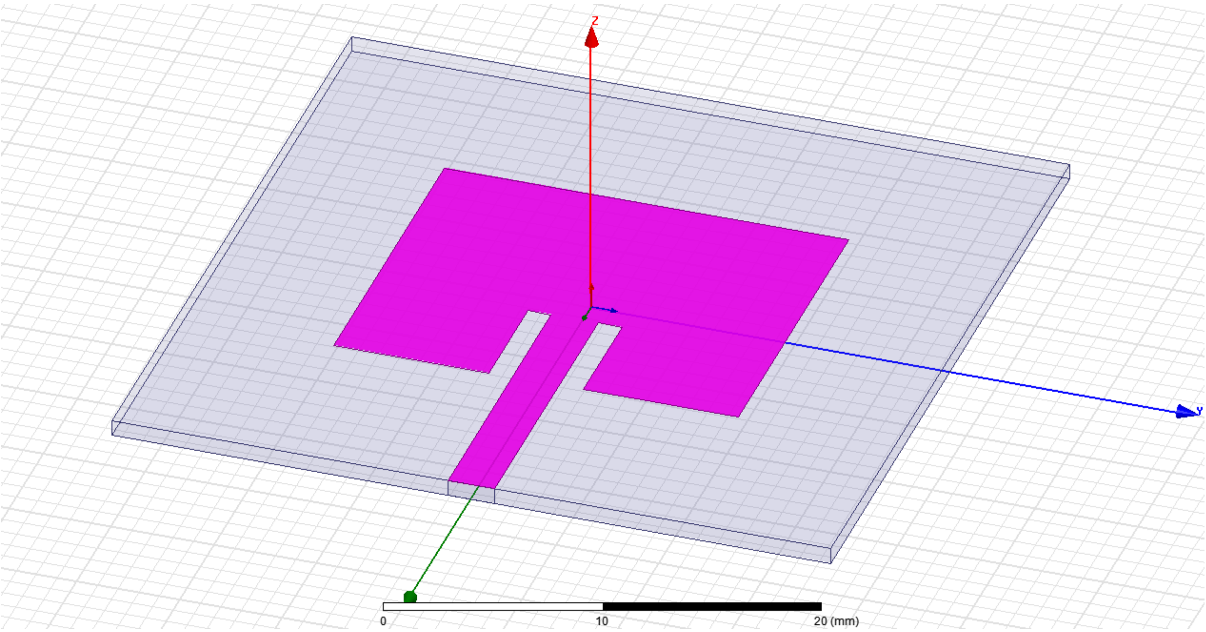


Fig 2 Microstrip Inset-Feed Patch Antenna Simulation Design

Reflection Coefficient Plot

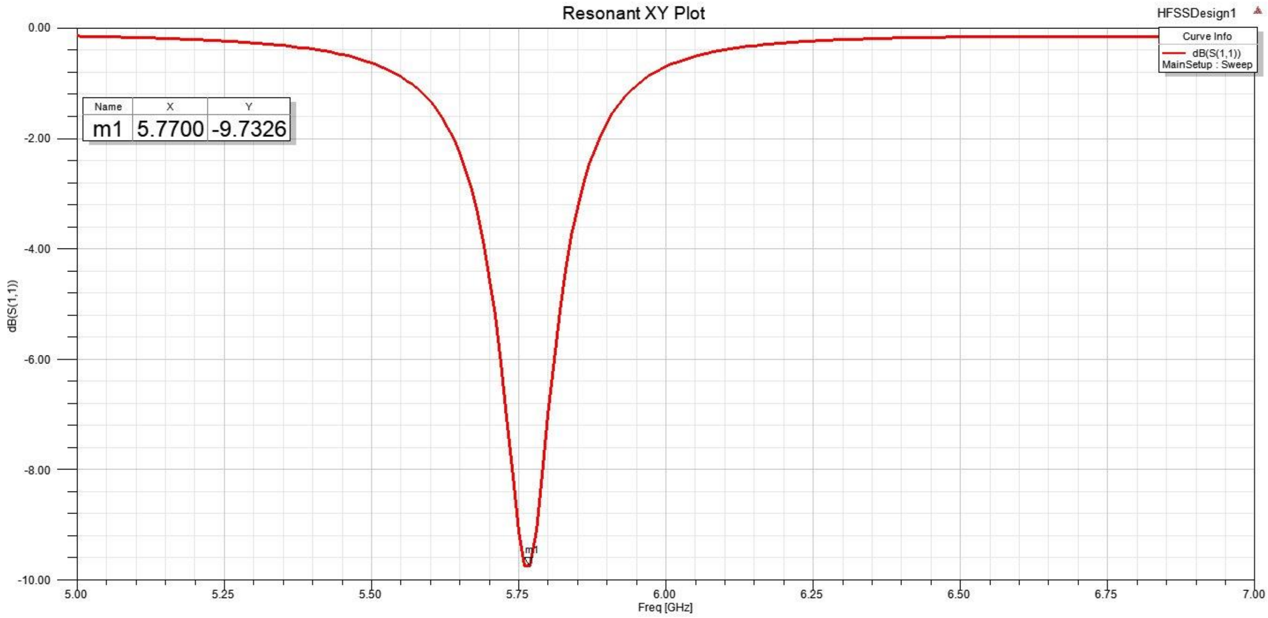


Fig 3 Reflection Coefficient Plot ***(Resonant Frequency 5.8 GHz)***

Electric Field Far Field - 3D Polar Plot

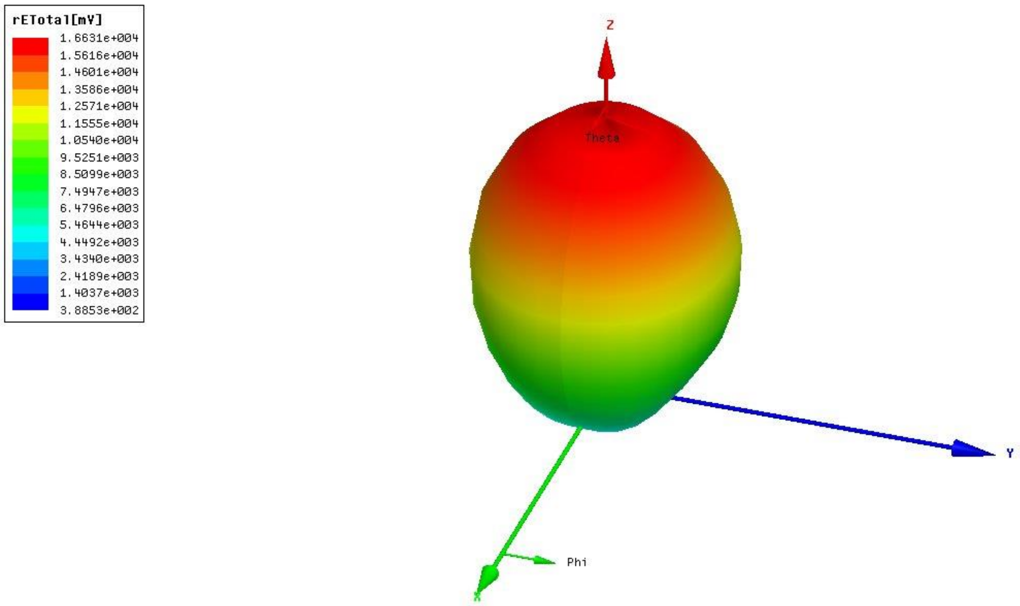


Fig 4 Electric Field Radiation – 3D Polar Plot

Electric Field Radiation Pattern

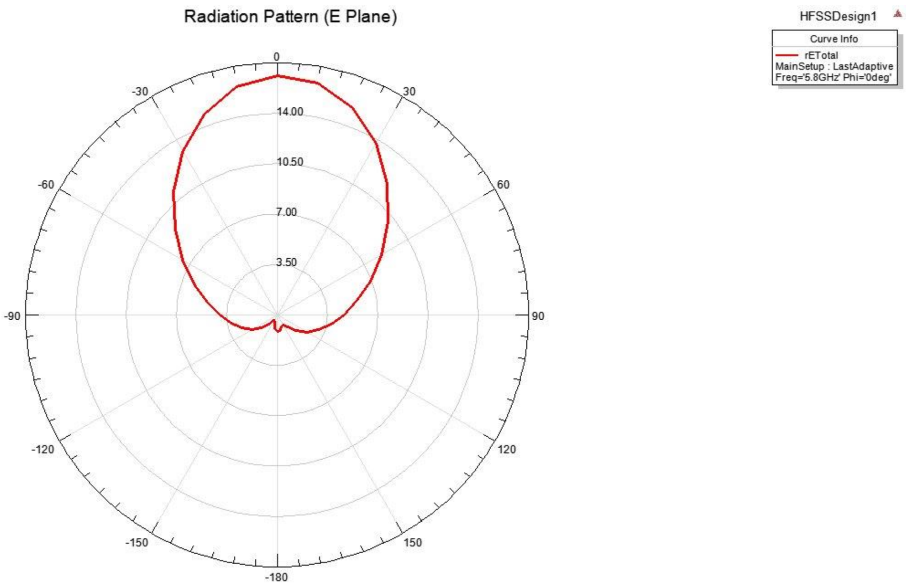


Fig 5 Electric Field Radiation Pattern

Magnetic Field Radiation Pattern

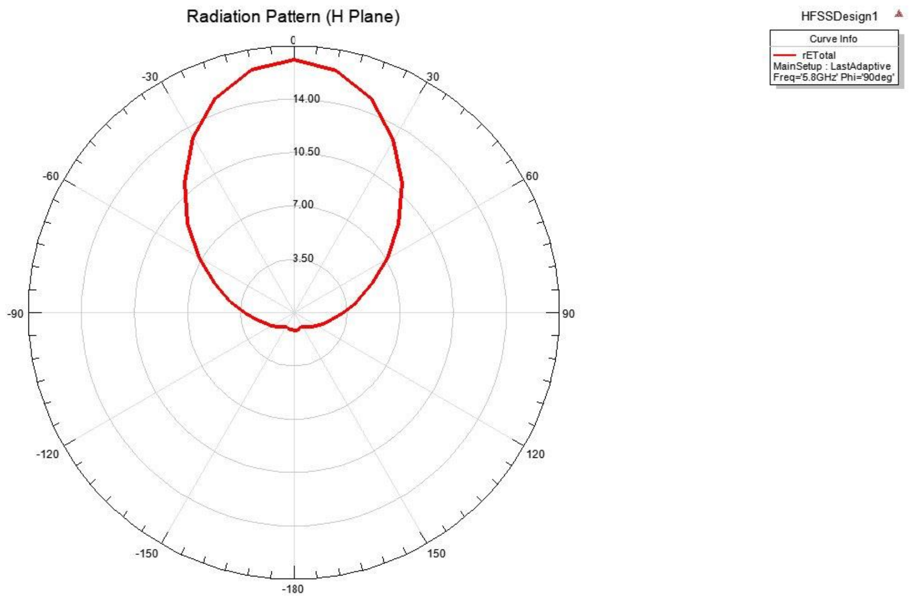


Fig 6 Magnetic Field Radiation Pattern

Gain vs Frequency Plot

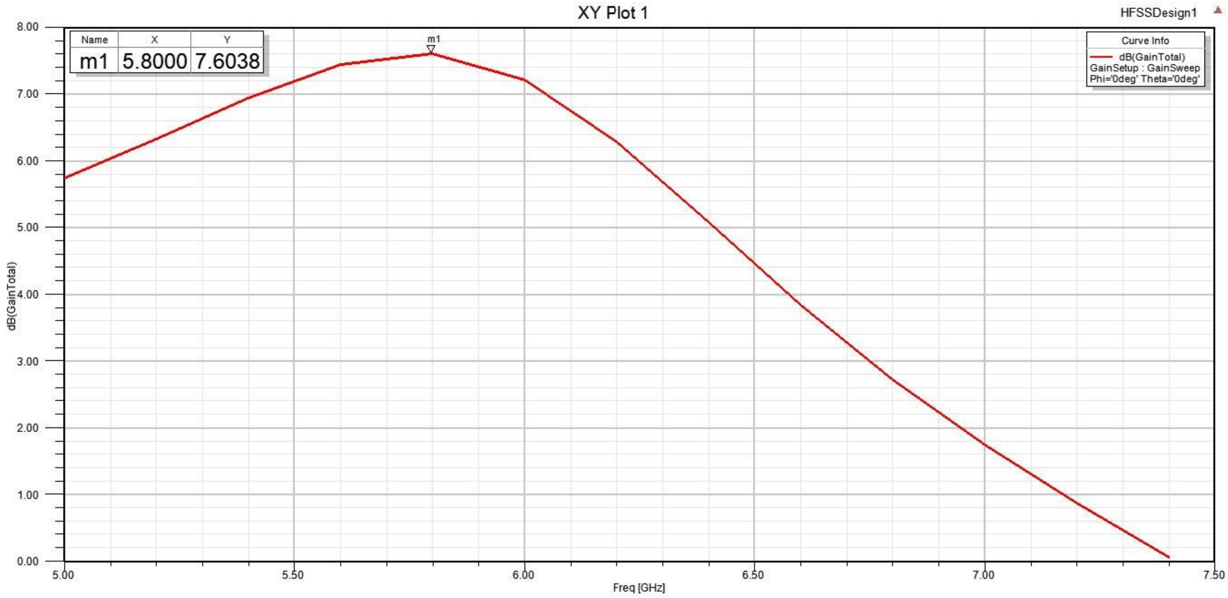


Fig 7 Gain v Frequency Plot ***(Resonant Frequency 5.8 GHz)***

Inference:

- From **Fig 3** the reflection loss at the resonance frequency 5.8 GHz is minimum or zero.
- Both **Fig 5** and **Fig 6** gives the radiation spread of the electric and magnetic field respectively. Also, from the figures we can conclude that there are no side lobes, verifying minimum leakage or loss.
- From **Fig 4**, the direction of the radiation can be confirmed that is in the Z-axis direction.
- From **Fig 7** at the resonant frequency, we have the maximum gain 7.6 dB for the radiating structure.

Conclusion:

The microstrip inset feed-line patch antenna has been successfully designed and the following results radiation pattern of both electric and magnetic fields, reflection coefficient, electric field polar plot and gain versus frequency plot are simulated and verified using Ansys HFSS.