Vidyavardhini's
College of Engineering & Technology
Vasai Road (W)

Department of
Electronics and Telecommunication Engineering

Lab Manual

Semester	VII	Class	BE
Course Code	ECL701	Academic Year	2023-24
Course Name	Microwave Engineering Laboratory		
Name of Faculty	Mrs. Neha Gharat		
Supporting Staff	Mrs. Bhagyashree Rane		

Vidyavardhini’s College of Engineering & Technology

Vision

To be a premier institution of technical education, aiming at becoming a valuable resource for industry and society.

Mission

- To provide technologically inspiring environment for learning.
- To promote creativity, innovation and professional activities.
- To inculcate ethical and moral values.
- To cater personal, professional and societal needs through quality education.

Department Vision:

To contrive educational and research environment to serve industry and society needs in the field of electronics and telecommunication engineering.

Department Mission:

1. To enrich soft skills, ethical values, environmental and societal awareness.
2. To develop technical proficiency through projects and laboratory work.
3. To encourage students for lifelong learning through interaction with outside world.

Program Education Objectives (PEOs):

- The graduates will exhibit knowledge of mathematics, science, electronics, and communication, and will be able to apply the same in diversified field.
- The graduates will develop a habit of continuous learning while working in multidisciplinary environment.
- The graduates will grow as an individual with proficiency in technical skills, ethical values, communication skills, teamwork and professionalism.

Program Specific Outcomes (PSOs):

At the end of the program engineering graduate will be able to:

1. Apply the knowledge of Electronics and Communication to analyse, design and implement application specific problems with modern tools.
2. Adapt emerging technologies with continuous learning in the field of Electronics and Telecommunication engineering with appropriate solutions to real life problems.

Program Outcomes (POs):

Engineering Graduates will be able to:

- **PO1. Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
- **PO2. Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
- **PO3. Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
- **PO4. Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
- **PO5. Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
- **PO6. The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
- **PO7. Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
- **PO8. Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
- **PO9. Individual and teamwork:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
- **PO10. Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
- **PO11. Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

- **PO12. Life-long learning:** Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Course Objectives

1	To become familiar working with rectangular waveguides and doing microwave bench set up.
2	To determine the characteristics of various microwave components
3	To be able to measure wave parameters like impedance, frequency, wavelength using microwave bench and VSWR/power meter
4	To study characteristics and behaviour of various microwave semiconductor devices.

Course Outcomes

At the end of the course, students will be able to:		Action verb	Bloom Level
ECL701.1	To **analyze** S-parameters of distributed types of impedance-matching networks using	Analyse	Level 4
ECL701.2	To **design** the transmission lines using simulation software.	Design	Level 3
ECL701.3	To **design rectangular waveguide** using simulation software.	Design	Level 3
ECL701.4	To **demonstrat**e the characteristics of waveguide junctions.	Demonstrate	Level 3
ECL701.5	To **analyze** characteristics of different modes of Reflex Klystron.	Analyze	Level 4
ECL701.6	To **determin**e the VSWR, Frequency, and wavelength of the signal.	determine	Level 3

Mapping of Course Outcomes with Program Outcomes and Program Specific Outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
ECL701.1	3	3	2		3			2	2	2			3	3
ECL701.2	3	3	2		3			2	2	2			3	3
ECL701.3	3	3	2		3			2	2	2			3	2
ECL701.4	3	1						2	2	2			3	2
ECL701.5	3	2						2	2	2			3	2
ECL701.6	3	1						2	2	2			3	2
Average	3.00	2.17	2.00		3.00			2.00	2.00	2.00			3.00	2.33
Rounded Avg.	3	2	2		3			2	2	2			3	2

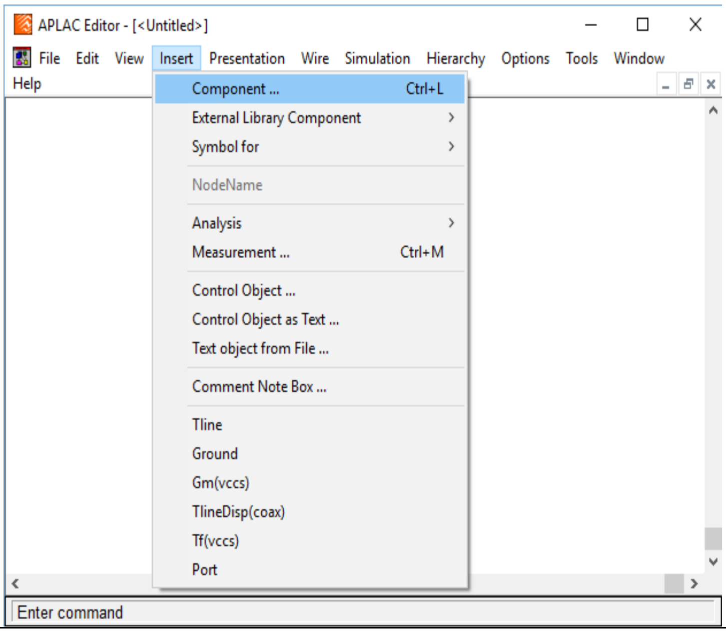
Enter correlation level 1, 2 or 3 as defined below

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High)

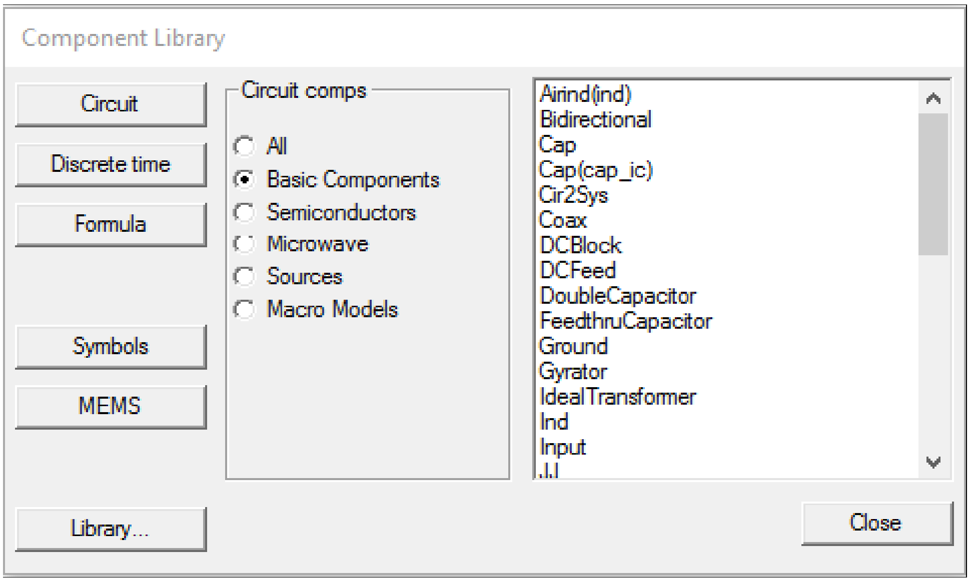
If there is no correlation put “—"

Mapping of Experiments with Course Outcomes

Experiment	Course Outcomes			
	ECL701.1	ECL701.2	ECL701.3	ECL701.4
Design Single stub matching network using APLAC.	3			
Design double stub matching network using APLAC.	3			
Find the change in characteristics impedance and reflection coefficients of the transmission line by changing the dielectric properties of materials Embedded between two conductors using a Virtual lab.	3			
Design a 50Ω microstrip line using SONNET.	3			
Design a Rectangular waveguide using COMSOL. Or Study of field patterns of various modes inside a rectangular waveguide using a Virtual lab		3		
Study of field patterns of various modes inside a rectangular waveguide cavity using a Virtual lab.		3		
To demonstrate E plane TEE and H plane TEE				
Introduction to microwave components			3	
Study the modes of Reflex Klystron.			3	
Measurement of microwave frequency using the direct method.				3
Measurement of guide wavelength.				3
Determine the VWSR and reflection coefficient of the signal.				3

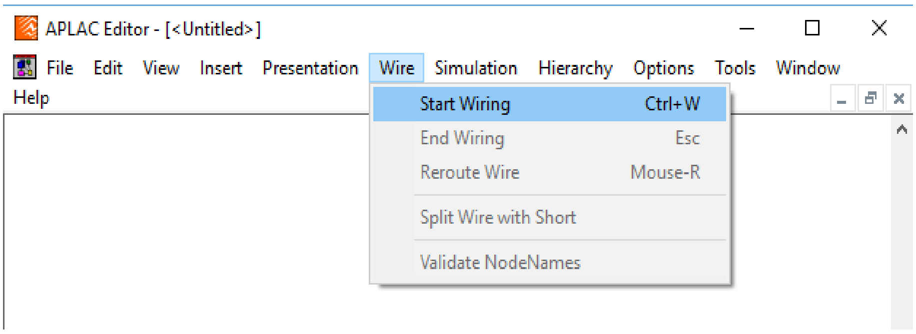
Experiment No:1	**Design Single stub matching network using APLAC software**
Aim:	To study the single stub matching and simulate it using APLAC software
Theory:	Transmission lines are used for the transmission of power and information. For radio frequency power transmission, it is highly desirable that maximum power is transmitted from the generator to the load and less power is lost on the line itself. This will require that the load be matched to the characteristic impedance of the line so that the standing-wave ratio on the line is as close to unity as possible. If it is not so then power is reflected from the source and due to this reflection, it may be possible that the source get damaged. Matching the source and load to the transmission line or waveguide in a general microwave network, we have used two types of impedance matching, single-stub and double-stub. In this experiment, we are going to study single-stub for impedance matching.
Problem Statement	Design single-stub (short circuit) shunt tuning networks to match a load impedance $Z_L = 60 - j80\ \Omega$, to a 50 Ω line. Assuming that the load is matched at 2 GHz.
	1. Design the circuit as per the specifications given. Open APLAC software. 2. Design the circuit as per the specifications given. Open APLAC software. 3. From File menu select New Circuit (Ctrl+N). 4. How to draw the circuit into the drawing space provided: Insert > Components. Now Select Circuit > Basic Components > Select the component of your choice and drop it in drawing space. 

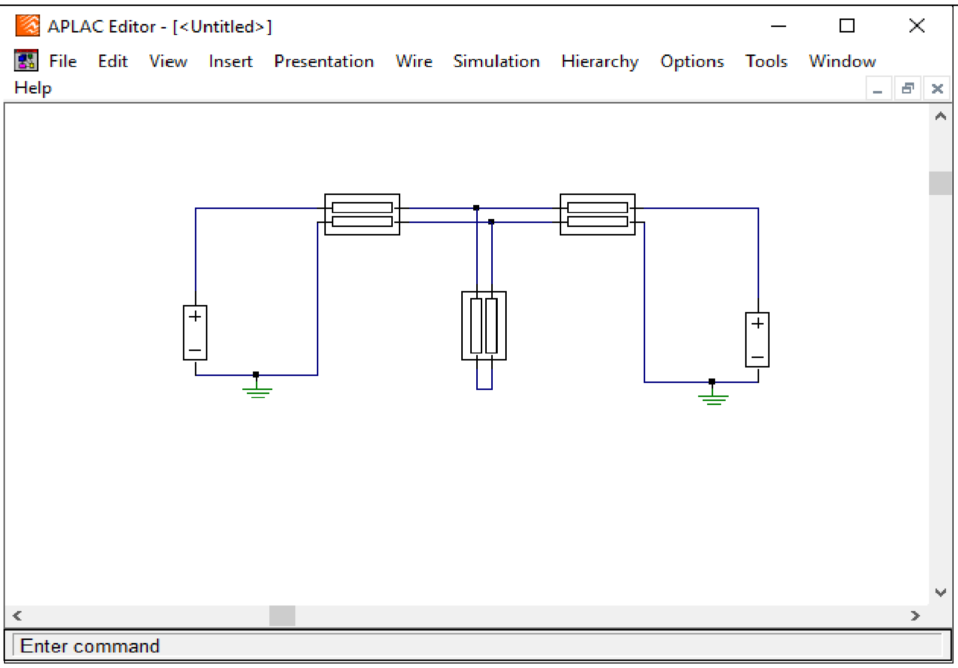
Procedure:	



Or Right click anywhere in the open space > Select Basic > Select the component Ind and Cap. Or Right click anywhere > Select Basic > Select the component of your choice. First insert 'Tline' (for transmission line). Then insert two 'Port' (one for source and other for load).

5. To wire the components click on Wire menu > Start Wiring (Ctrl+W). Join the terminals of the components using wires accordingly. Press Esc to stop wiring. Add the Ground at the load resistance.

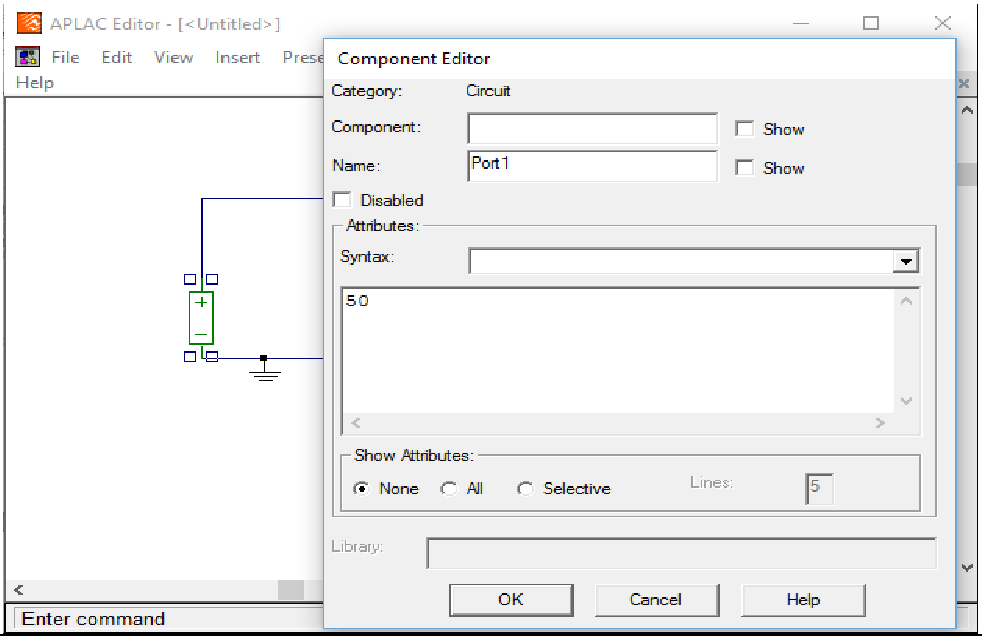




6. Assign specifications of components: Double click on the component to change its values.

a. For Input/Output port:

Input port impedance default value is 50 Ohms (No need to state the units). You can change this source impedance value.



Category: Circuit

Component: ☐ Show

Name: Port1 ☐ Show

☐ Disabled

Attributes:

Syntax:

50

Show Attributes: ● None ○ All ○ Selective Lines: 5

Library:

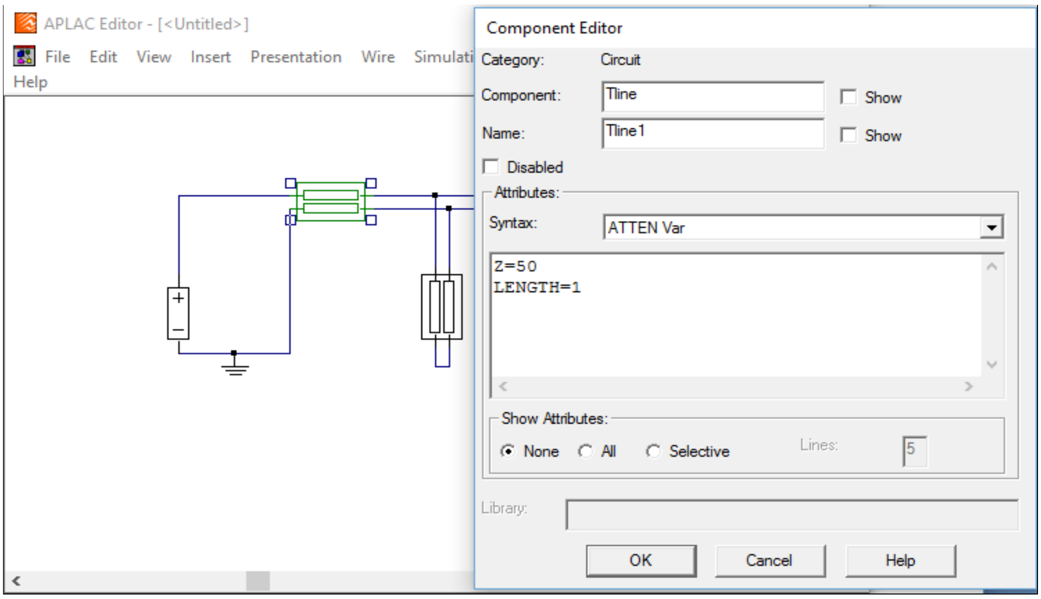
Similarly double click on output port and enter impedance value (eg .75+150*j).

b. For Transmission Lines:

Here we need to specify the characteristic impedance and length of each transmission line.

For the transmission line joining the source and the circuit, enter arbitrary length. Usually 1 meter. Eg. Z=50

LENGTH=1 (The length is in meters)



Category: Circuit

Component: Tline

Name: Tline1

Syntax: ATTEN Var

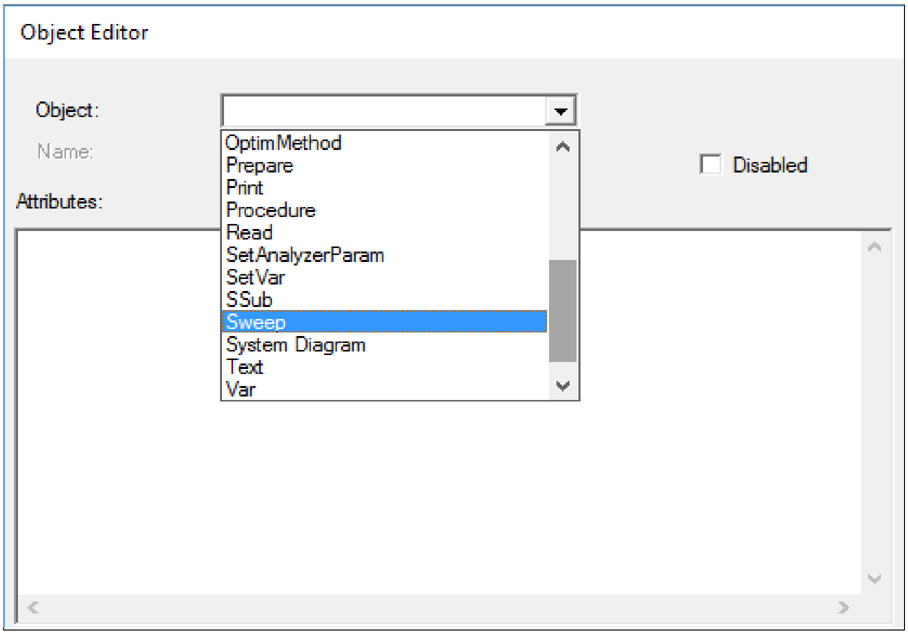
```
Z=50
LENGTH=1
```

Similarly calculate and enter impedance and length of other transmission lines.

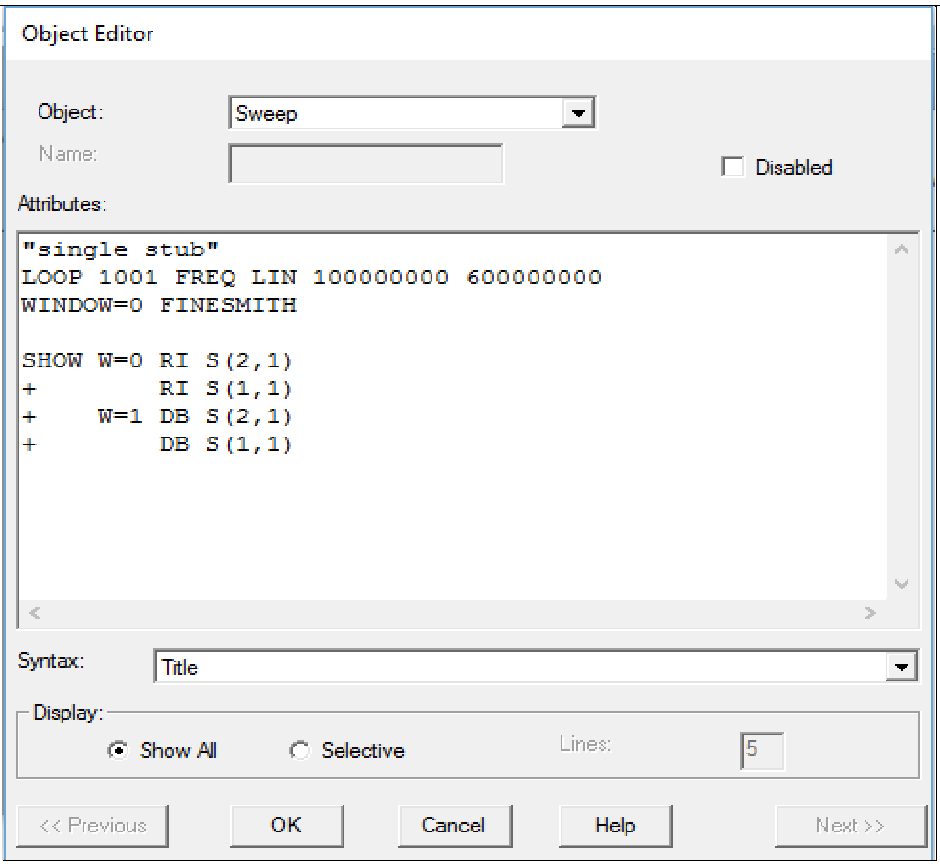
6. To assign the working conditions of the circuit:

   Select Insert menu > Control object

   In the Object Editor window select Sweep mode for the Object.



In the text space provided type the following code:



Object Editor

Object: Sweep

Name:

☐ Disabled

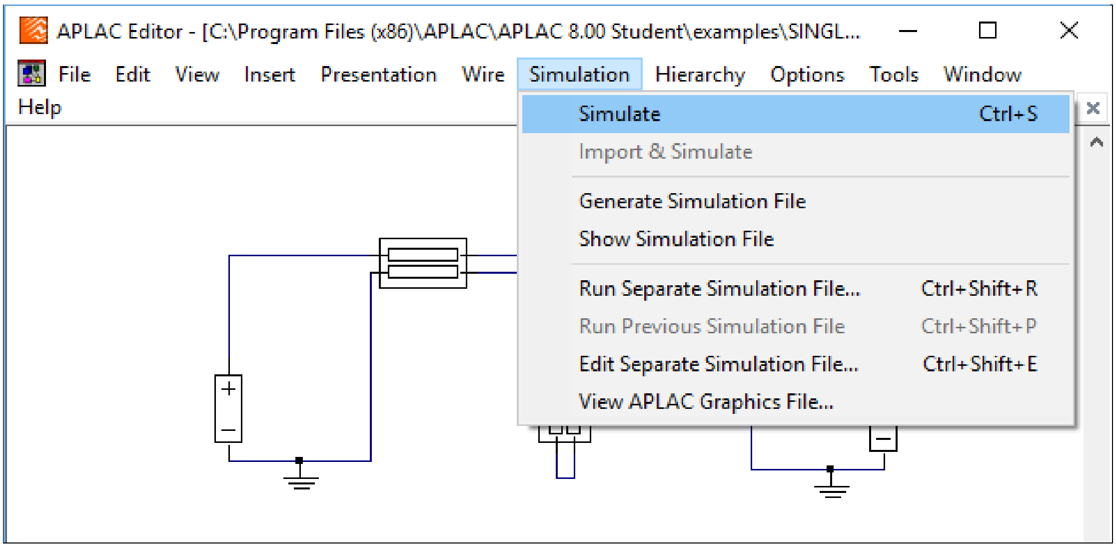
Attributes:

```
"single stub"
LOOP 1001 FREQ LIN 100000000 600000000
WINDOW=0 FINESMITH

SHOW W=0 RI S(2,1)
+        RI S(1,1)
+    W=1 DB S(2,1)
+        DB S(1,1)
```

Syntax: Title

Display: ● Show All ○ Selective Lines: 5

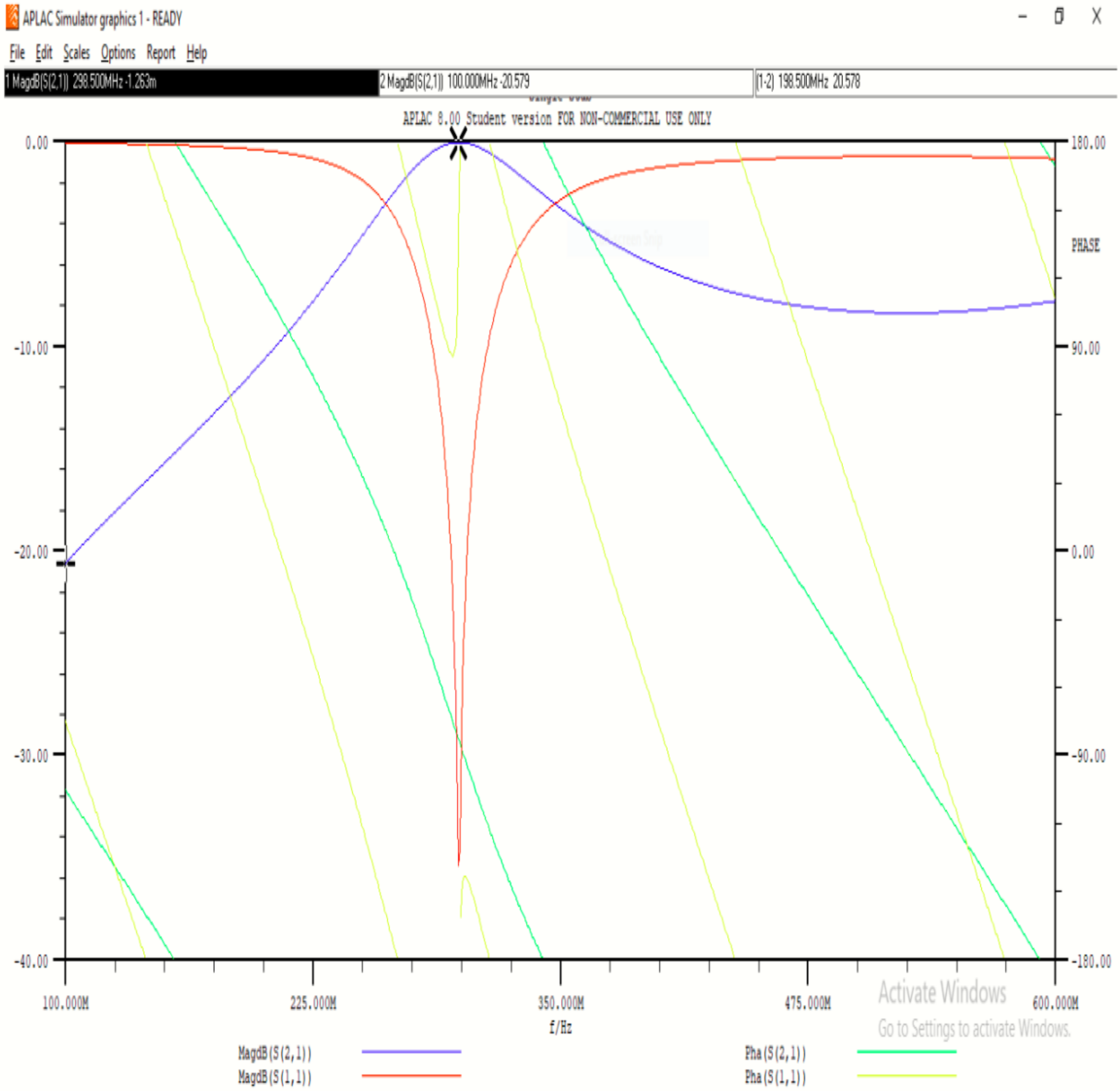
7. To simulate the file click on the Simulation menu > Simulate (Ctrl+S). Observe the S_{11}, S_{21} parameters and the Smith Chart graph.



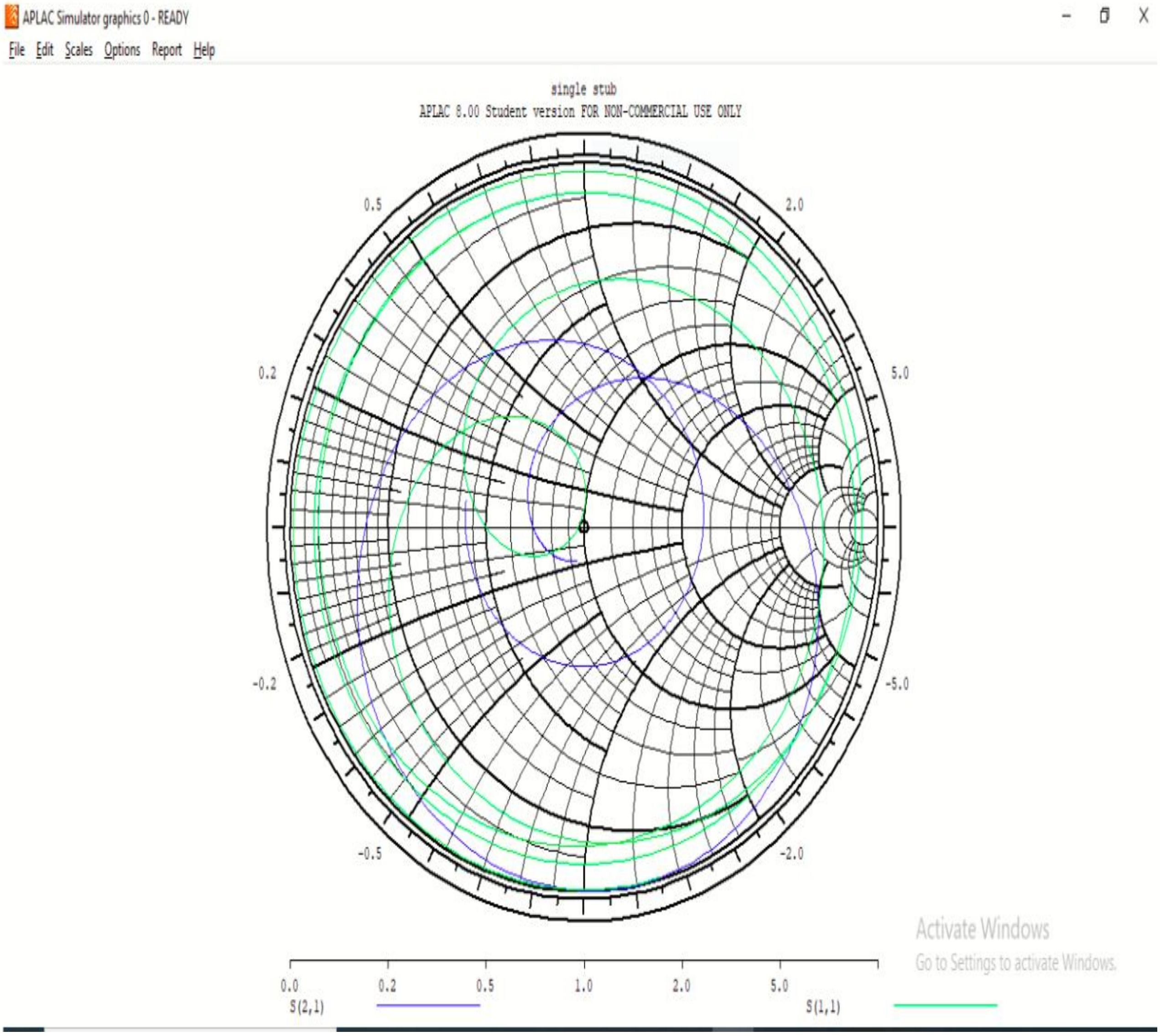
APLAC Editor - [C:\Program Files (x86)\APLAC\APLAC 8.00 Student\examples\SINGL...

Observations:	Observe values of S_{11} and S_{21} for matching impedance. S_{11} = -38db and S_{21} = 0db at 298.5 MHz
Result Analysis and Conclusion:	
Post Experiment Question	Explain the significance of the Impedance Matching network. Explain significance of S_{11} and S_{21} in impedance matching network.

Output:



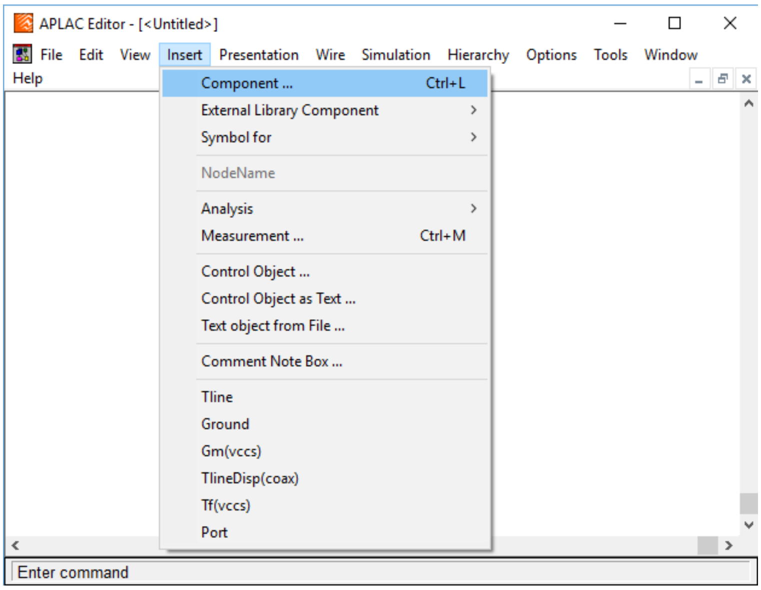
```
1 MagdB(S(2,1)) 298.500MHz -1.263m    2 MagdB(S(2,1)) 100.000MHz -20.579    (1-2) 198.500MHz 20.578
```

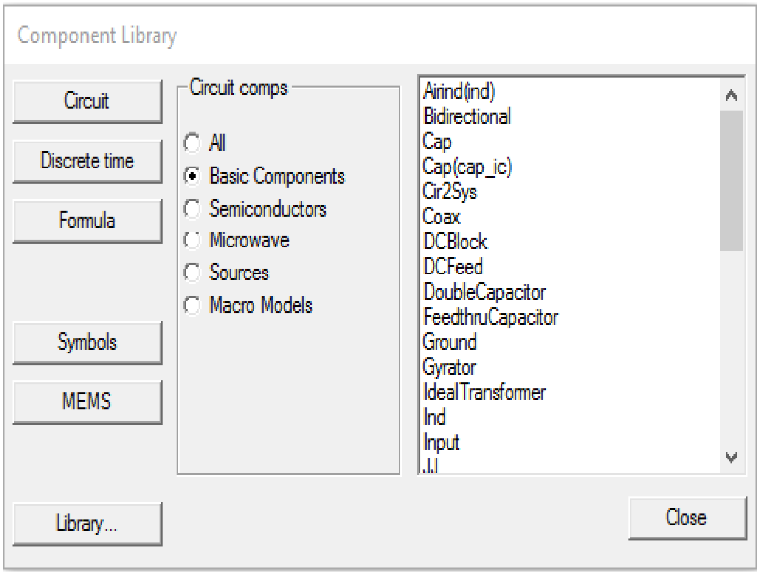

APLAC Simulator graphics 0 - READY
File Edit Scales Options Report Help
single stub
APLAC 8.00 Student version FOR NON-COMMERCIAL USE ONLY
0.5
2.0
0.2
5.0
-0.2
-5.0
-0.5
-2.0
0.0
0.2
0.5
1.0
2.0
5.0
S(2,1)
S(1,1)
Activate Windows
Go to Settings to activate Windows.

Experiment No: 2	**Design Double stub matching network using APLAC software**
Aim:	To design the double stub matching network.
Theory:	Transmission lines are used for the transmission of power and information. For radio frequency power transmission, it is highly desirable that maximum power is transmitted from the generator to the load and less power is lost on the line itself. This will require that the load be matched to the characteristic impedance of the line so that the standing-wave ratio on the line is as close to unity as possible. If it is not so then power is reflected from source and due to this reflection, it may be possible that the source get damage. In microwave circuits, impedance mismatches can lead to reflections, standing waves, and power loss. Double stub matching is used to cancel these reflections and ensure maximum power transfer. Matching the source and load to the transmission line or waveguide in a general microwave network, we have used two types of impedance matching, single-stub and double-stub. In this experiment we are going to study single-stub for impedance matching. Double stub matching is a technique used in microwave engineering to match the impedance of a load to the characteristic impedance of a transmission line. This method employs two adjustable stubs placed at specific distances from each other and from the load to achieve impedance matching. The double stub method fixes the location of the stubs and varies the lengths. Two stubs are placed along the transmission line at specific locations. The distances between the stubs and the load are critical and are usually a fraction of the wavelength (λ) of the signal. The lengths of the stubs are adjustable to create the required reactance to cancel out the reactive component of the load impedance. By adjusting the lengths and positions of the stubs, the combined impedance seen by the transmission line becomes purely resistive and matches the characteristic impedance of the line. Double stub matching is a powerful technique for impedance matching in high-frequency circuits, ensuring efficient signal transmission and minimal power loss.
Problem Statement 2:	Match a load of (100+j10) Ω to a line of 50 Ω using a double stub matching technique (both parallel short circuit stubs). Assume the distance between the stubs as 3λ/8.

Procedure:

1. Design the circuit as per the specifications given. Open APLAC software.
2. From File menu select New Circuit (Ctrl+N).
3. How to draw the circuit into the drawing space provided : Insert > Now Select Circuit > Basic Components. Components > Select the component of your choice and drop it in drawing space.

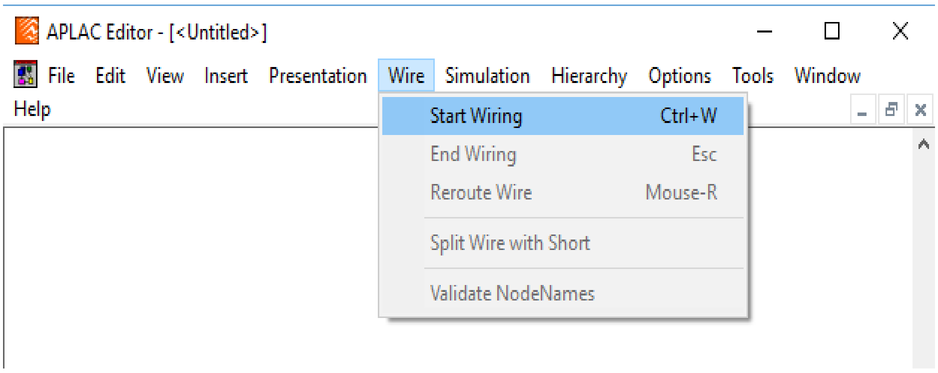




Or Right click anywhere in the open space > Select Basic > Select the component Ind and Cap.

Or Right click anywhere > Select Basic > Select the component of your choice. First insert 'Tline' (for transmission line). Then insert two 'Port' (one for source and other for load).

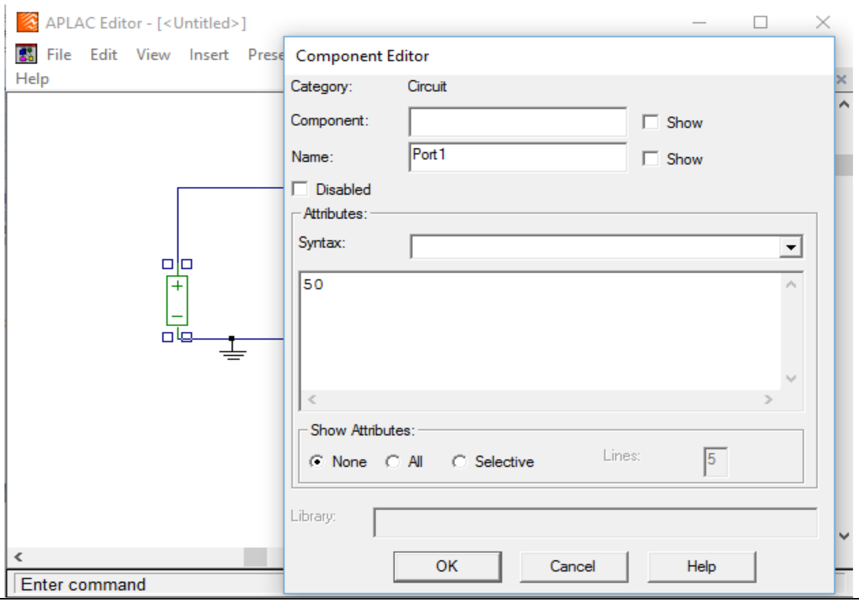
5. To wire the components click on Wire menu > Start Wiring (Ctrl+W). Join the terminals of the components using wires accordingly. Press Esc to stop wiring. Add the Ground at the load resistance.



6. Assign specifications of components: Double click on the component to change its values.

a. For Input/Output port:

Input port impedance default value is 50 Ohms (No need to state the units). You can change this source impedance value.



Category: Circuit

Component: ☐ Show

Name: Port1 ☐ Show

☐ Disabled

Attributes:

Syntax:

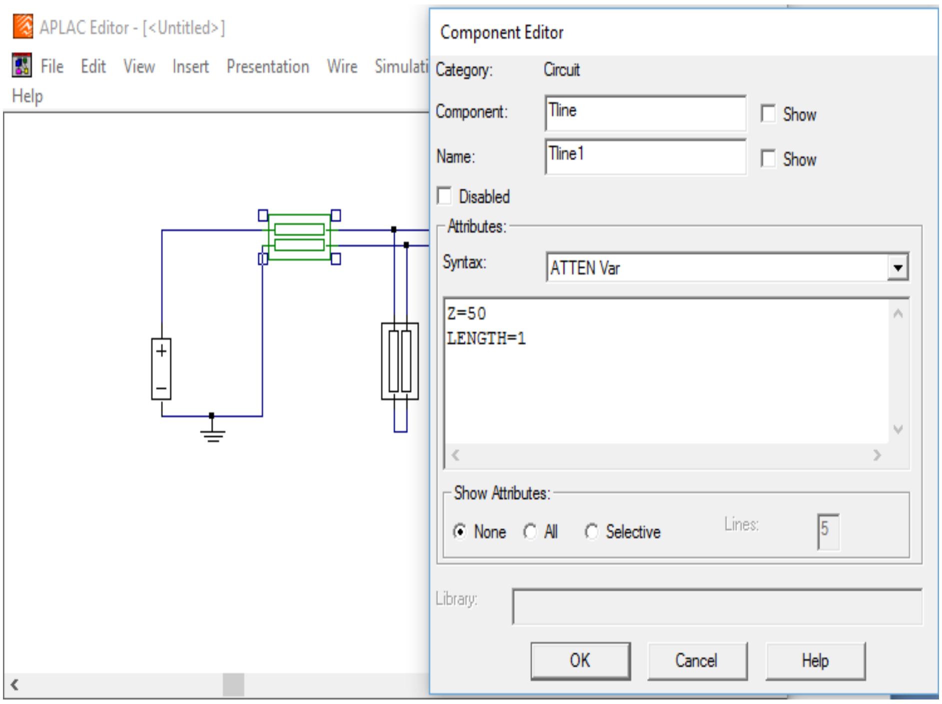
50

Show Attributes:

● None ○ All ○ Selective Lines: 5

Library:

Similarly, double click on output port and enter impedance value (eg 75+150*j).



Category: Circuit
Component: Tline ☐ Show
Name: Tline1 ☐ Show
☐ Disabled
Syntax: ATTEN Var

```
Z=50
LENGTH=1
```

● None ○ All ○ Selective Lines: 5

b. For Transmission Lines:

Here we need to specify the characteristic impedance and length of each transmission line. For the transmission line joining the source and the circuit, enter arbitrary length. Usually 1 meter.

Eg. Z=50

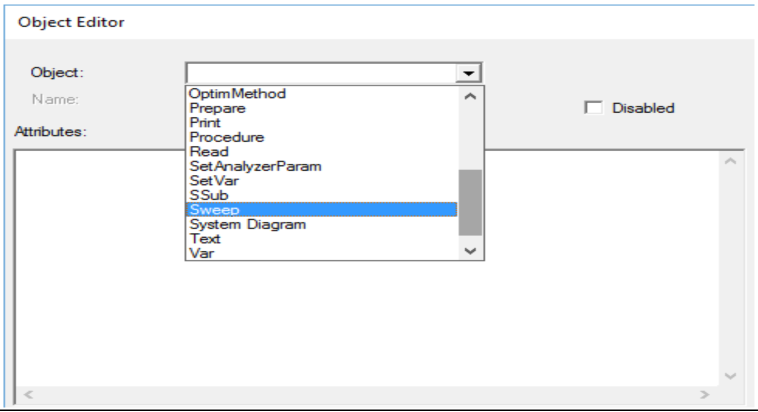
LENGTH=1 (The length is in meters)

Similarly calculate and enter impedance and length of other transmission lines.

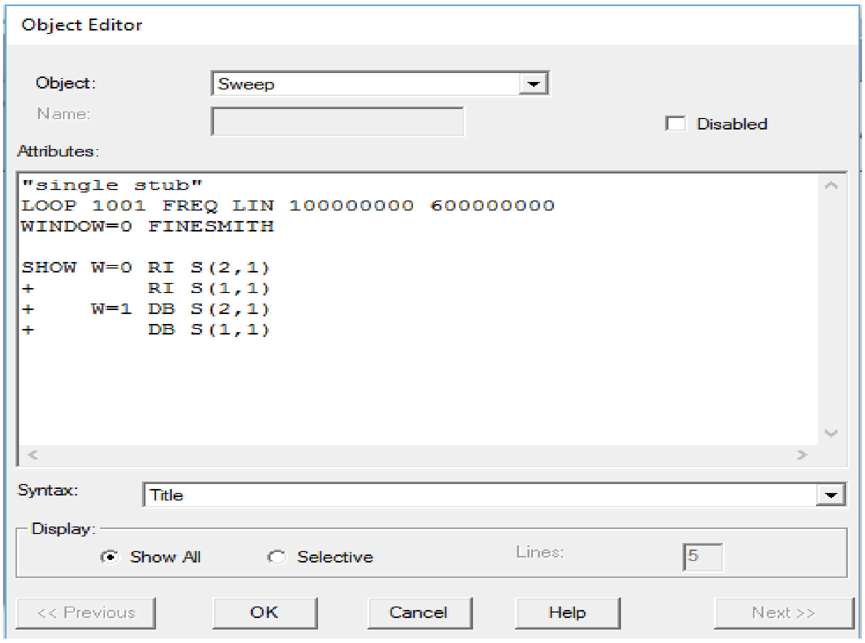
7. To assign the working conditions of the circuit:

   Select Insert menu > Control object

   In the Object Editor window select Sweep mode for the Object.



In the text space provided type the following code:



Object: Sweep

Name:

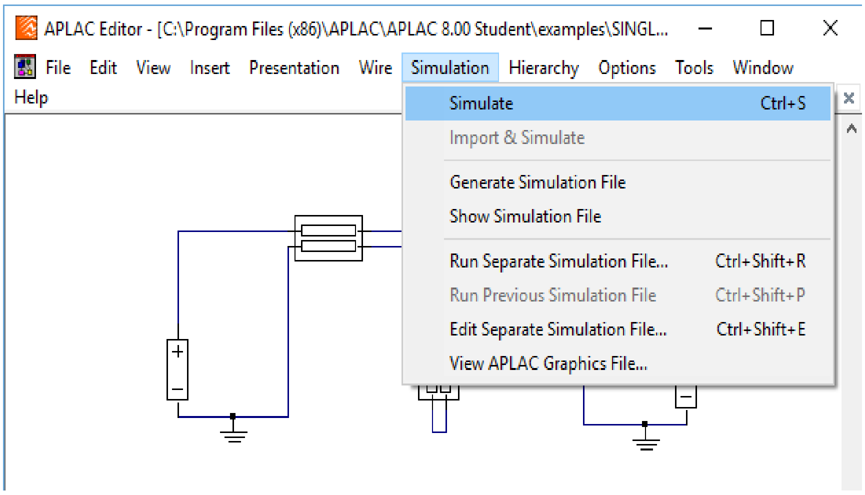
☐ Disabled

Attributes:

```
"single stub"
LOOP 1001 FREQ LIN 100000000 600000000
WINDOW=0 FINESMITH

SHOW W=0 RI S(2,1)
+        RI S(1,1)
+    W=1 DB S(2,1)
+        DB S(1,1)
```

Syntax: Title

Display: ● Show All ○ Selective Lines: 5



Observations:

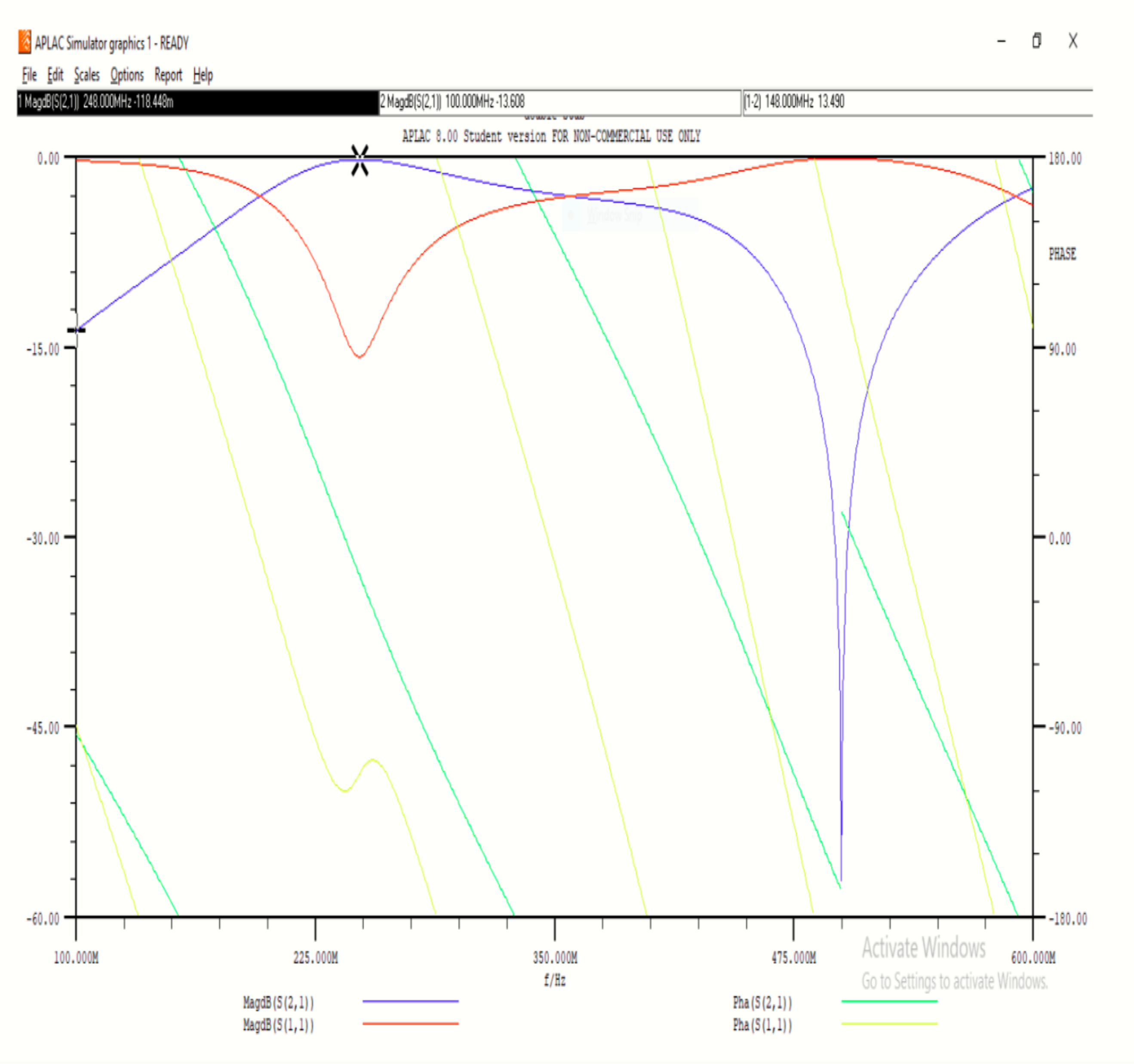
S_{11} = -15db and S_{21} = 0db at 240 MHz

Conclusion:

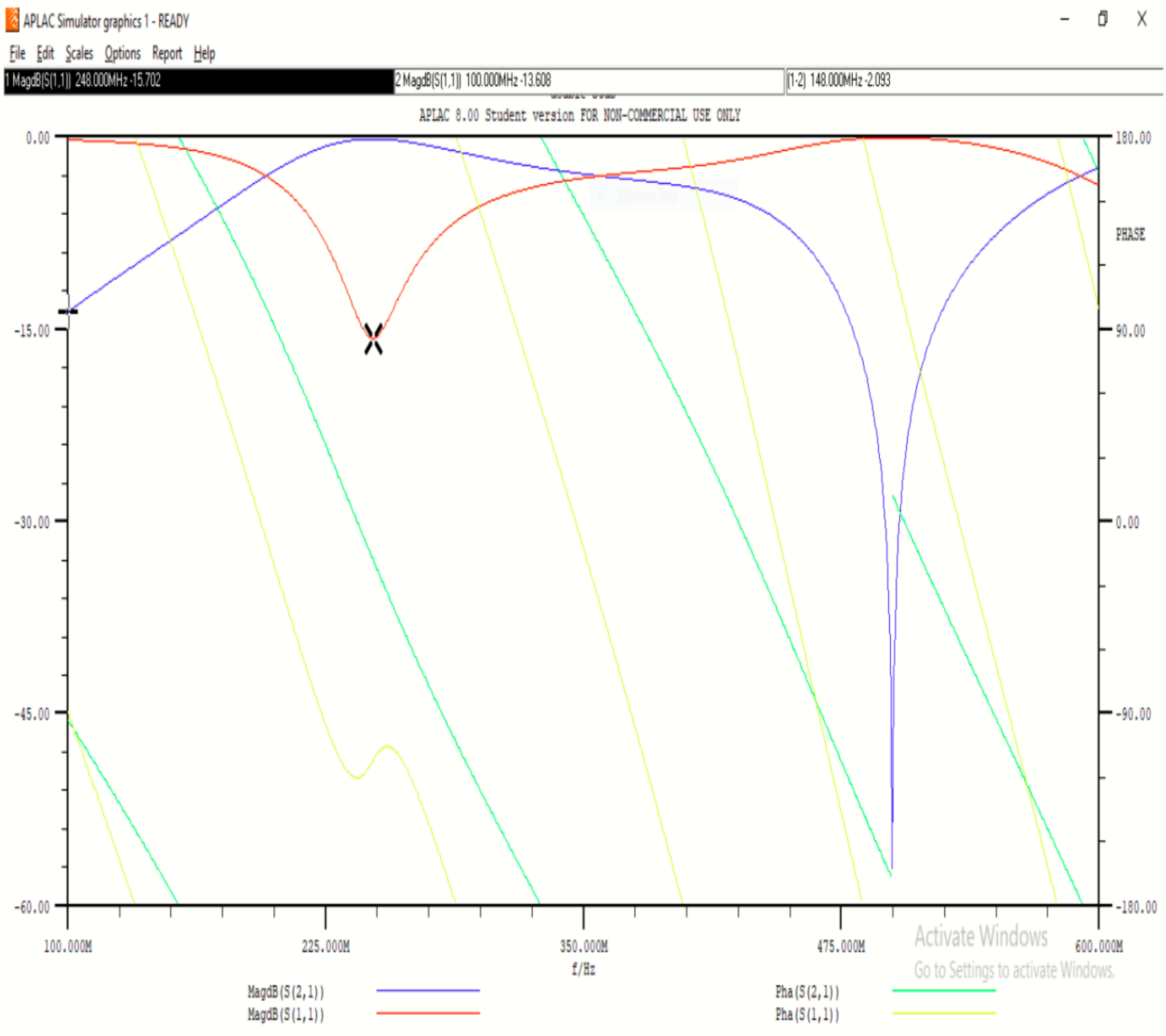
Post Experiment quiz

Explain the advantages of double stub over the single stub.

Output:



1 MagdB(S(2,1)) 248.000MHz -118.448m
2 MagdB(S(2,1)) 100.000MHz -13.608
[1-2] 148.000MHz 13.490



1 MagdB(S(1,1)) 248.000MHz -15.702

2 MagdB(S(1,1)) 100.000MHz -13.608

(1-2) 148.000MHz -2.093

Experiment No: 3	**Find the change in characteristics impedance and reflection coefficients.**
Aim:	Find the change in characteristics impedance and reflection coefficients of the transmission line by changing the dielectric properties of materials embedded between two conductors

Theory

Transmission Lines:

The transmission lines are used as wave-guiding structures for transferring power and information from one point to another. The transmission line is often schematically represented as a two-wire line since transmission lines always have at least two conductors. A maximum transfer of power from a given voltage source occurs under "matched conditions". A line is matched when the load impedance is equal to the characteristic impedance of the line.

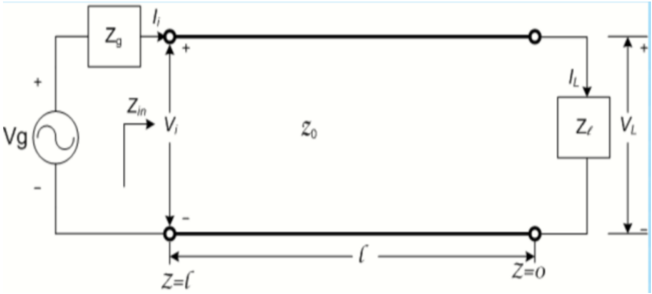


Figure1. The transmission line terminated with load impedance ZL

For a finite transmission line having a characteristic impedance Z_o is terminated by a load impedance of Z_L, and the length of the line is "*l*". A sinusoidal voltage source V_g with an internal impedance Z_g is connected to the line at z=0. In such a case, the total voltage on the line can be written as the sum of incident and reflected waves

$$V(z)= V_o^{+}e^{-j\beta z} + V_o^{-}e^{j\beta z}$$

Similarly, the total current on the line is described as:

$$I(z) = (V_o^{+} / Z_o)e^{-j\beta z} - (V_o^{-} / Z_o)e^{j\beta z}$$

The total voltage and current at the load are related by the load impedance, so at z=0 we must have

$$Z_L = V(0) / I(0) = [(V_o^{+} + V_o^{-}) / (V_o^{+} - V_o^{-})]*Z_o$$

Solving for Vo- gives

$$V_o^{-} = [(Z_L - Z_o) / (Z_L + Z_o)]*V_o^{+}$$

The amplitude of the reflected voltage wave normalized to the amplitude of the incident voltage wave is defined as the voltage reflection coefficient, Γ :

$$\Gamma = V_o^{-} / V_o^{+} = (Z_L - Z_o) / (Z_L + Z_o)$$

From the above relation, we can see that only when Γ = 0, there is no reflected wave.

Strip Lines:

This is a planar type of transmission line that lends itself well to microwave-integrated circuitry and photolithographic fabrication. A thin conducting strip of width 'W' is centered between two wide conducting ground planes of separation 'H', the thickness of the strip is 'T' and the entire region between the ground planes is filled with dielectric, εr. Since the strip line has two conductors and a homogeneous dielectric, it can support a TEM wave, and this is the usual mode of operation

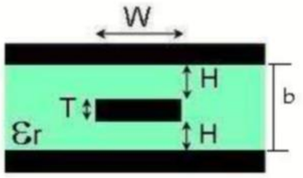


Figure 1. Geometry of strip lines

Microstrip Lines: The microstrip line is one of the most popular types of planar transmission lines because it can be fabricated by photolithographic processes and is easily integrated with other passive and active microwave devices. The geometry of a microstrip line is shown in the figure below. A conductor of width 'W' is printed on a thin, grounded dielectric substrate of thickness 'h' and relative permittivity εr

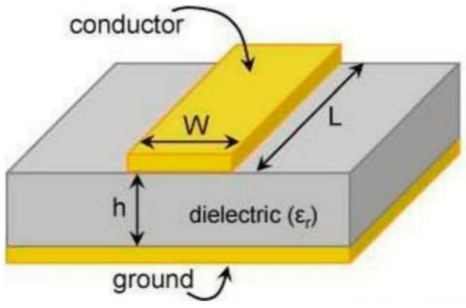


Figure 2 Geometry of microstrip line

The presence of the dielectric, and particularly the fact that the dielectric does not fill the air region above the strip, complicates the behavior of the microstrip line. The microstrip has some (usually most) of its field lines in the dielectric region, concentrated between the strip conductor and the ground plane, and some fraction in the air region above the substrate. For this reason, the microstrip line cannot support a pure TEM wave, since the phase velocity of TEM fields in the dielectric region would be c/√εr, but the

	phase velocity of TEM fields in the air region would be c. Thus, a phase mismatch occurs at the dielectric- air interface. Microstrip lines support quasi-TEM mode. Since some of the field lines are in the dielectric region and some are in the air, the effective dielectric constant satisfies the relation: $1 < \varepsilon e < \varepsilon r$ and is dependent on the substrate thickness, h, and the conductor width, W.
Procedure:	Please download the files to perform the actual experiment. The exe file is the LabView file that will run on the Lab VIEW Run time Engine. Step 1: Set the maximum frequency range between 5-10 GHz. Step 2: Select the type of transmission line from the drop-down menu. Step 3: Now select the sample material for which you wish to find the change in characteristic impedance and reflection coefficient of the transmission line. Step 4: Run the VI to see the characteristic impedance (Zo), the $\|\Gamma\|$ vs. frequency curve, and the reflection coefficient phase angle vs. frequency curve. Step 5: In case, you wish to see the characteristic impedance (Zo), the $\|\Gamma\|$ vs. frequency curve, and the reflection coefficient phase angle vs. frequency curve for other sample materials, then click stop and repeat steps 1, 2, and 3 before running the exe file again.

Observations:

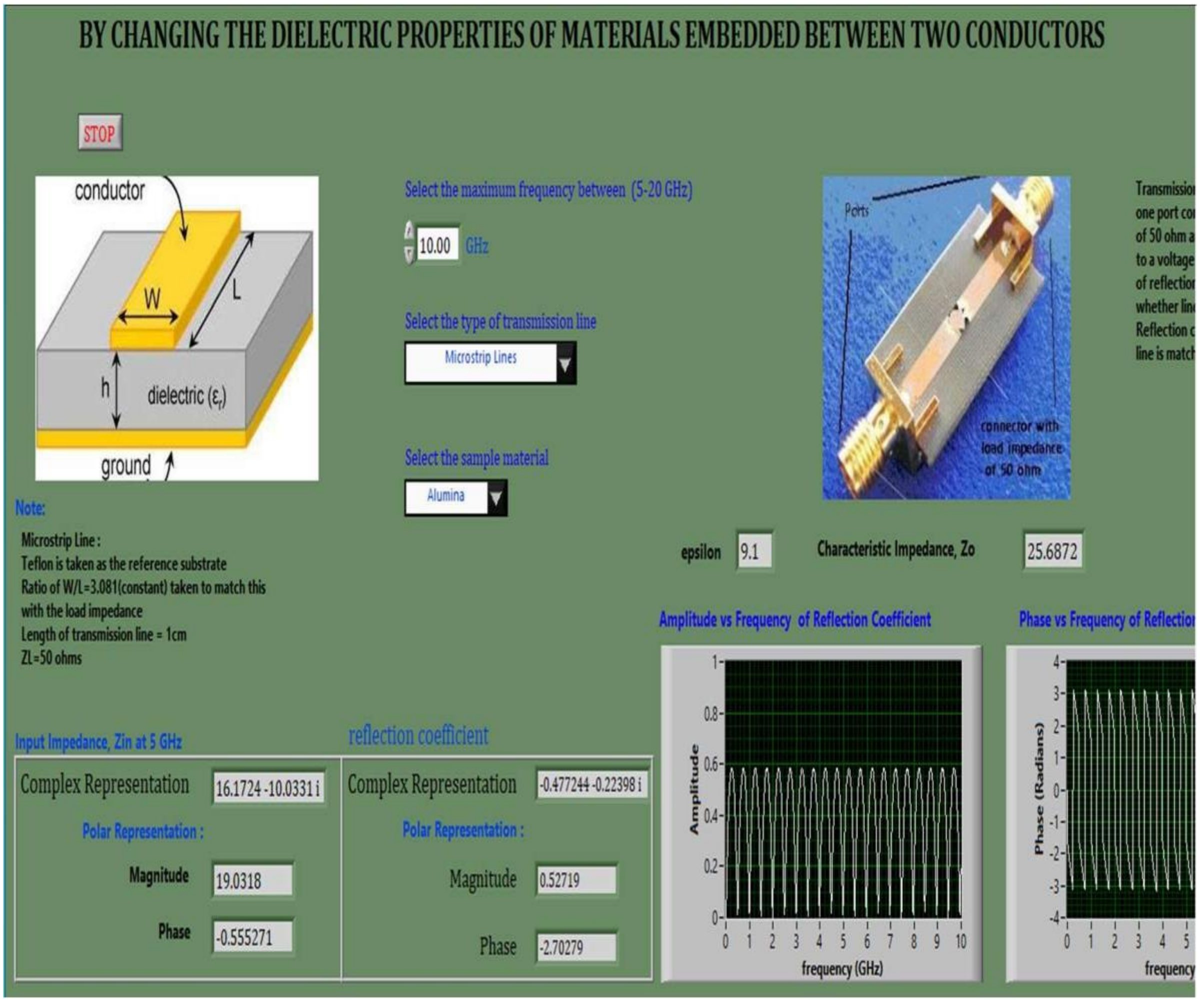
Sr. No.	Type of Transmission line	Observations			
		Frequency	**Dielectric material**	**Reflection coefficient**	**Input impedance**
1.	**Microstrip Line**	10 GHz	Alumina	0.52719 - 2.70279	19.0318 - 0.5552
			Teflon	0.00482 0.52356	50.4193 0.00482
			Resin	0.14146 - 2.6238	39.102 - 0.14193
			Air	0.25491 0.50460	78.1446 0.25774
2.	**Strip Line**	10 GHz	Alumina	0.56985 - 2.71837	17.379 - 0.60612
			Teflon	9.757e-6 0.52335	50.0008 9.753e-6
			Resin	0.16733 - 2.62363	37.3664 - 0.16805
			Air	0.31230 0.49472	86.7023 0.31748
3.	**Coaxial Cable**	10 GHZ	Alumina	0.75818 - 2.80952	10.8369 - 0.86050
			Teflon	0.31229 - 2.64666	28.8366 - 0.3175
			Resin	0.45891 - 2.68129	21.8521 - 0.47676
			Air	4.503e-6 - 2.6180	49.6691 4.503e-6

Result Analysis and Conclusion:

Post Experiment Questions

1. Explain the change in characteristic impedance and reflection coefficient magnitude and phase for the Microstrip line and Strip line.
2. Compare Microstrip line and Strip line.

Output:



BY CHANGING THE DIELECTRIC PROPERTIES OF MATERIALS EMBEDDED BETWEEN TWO CONDUCTORS

Select the maximum frequency between (5-20 GHz)

10.00 GHz

Select the type of transmission line

Microstrip Lines

Select the sample material

Alumina

Transmissio
one port co
of 50 ohm a
to a voltage
of reflectio
whether lin
Reflection c
line is match

Note:

Microstrip Line :
Teflon is taken as the reference substrate
Ratio of W/L=3.081(constant) taken to match this with the load impedance
Length of transmission line = 1cm
ZL=50 ohms

epsilon 9.1

Characteristic Impedance, Zo 25.6872

Input Impedance, Zin at 5 GHz

Complex Representation 16.1724 -10.0331 i

Polar Representation :

Magnitude 19.0318

Phase -0.555271

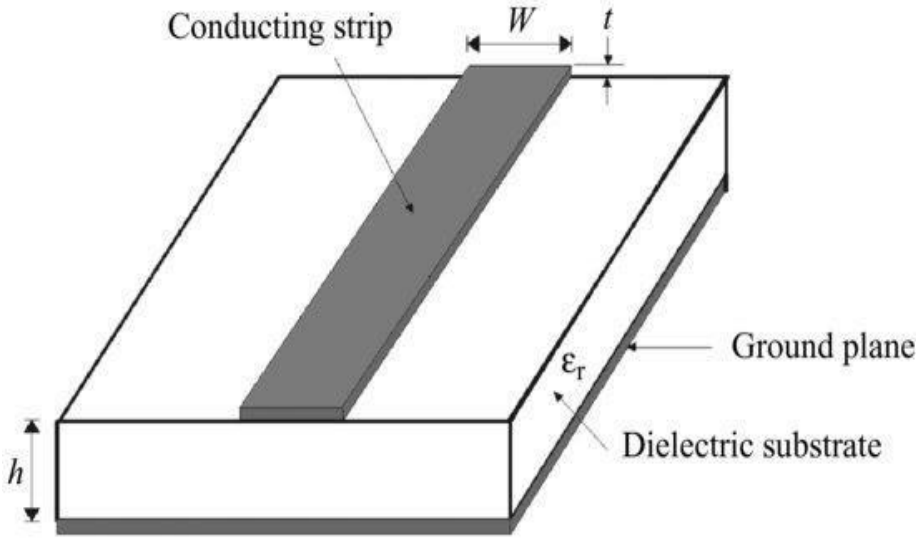
reflection coefficient

Complex Representation -0.477244 -0.22398 i

Polar Representation :

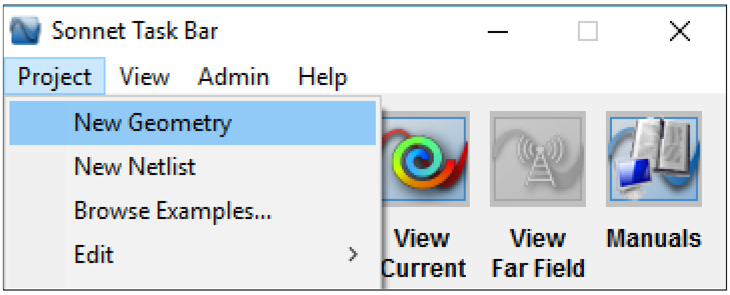
Magnitude 0.52719

Phase -2.70279

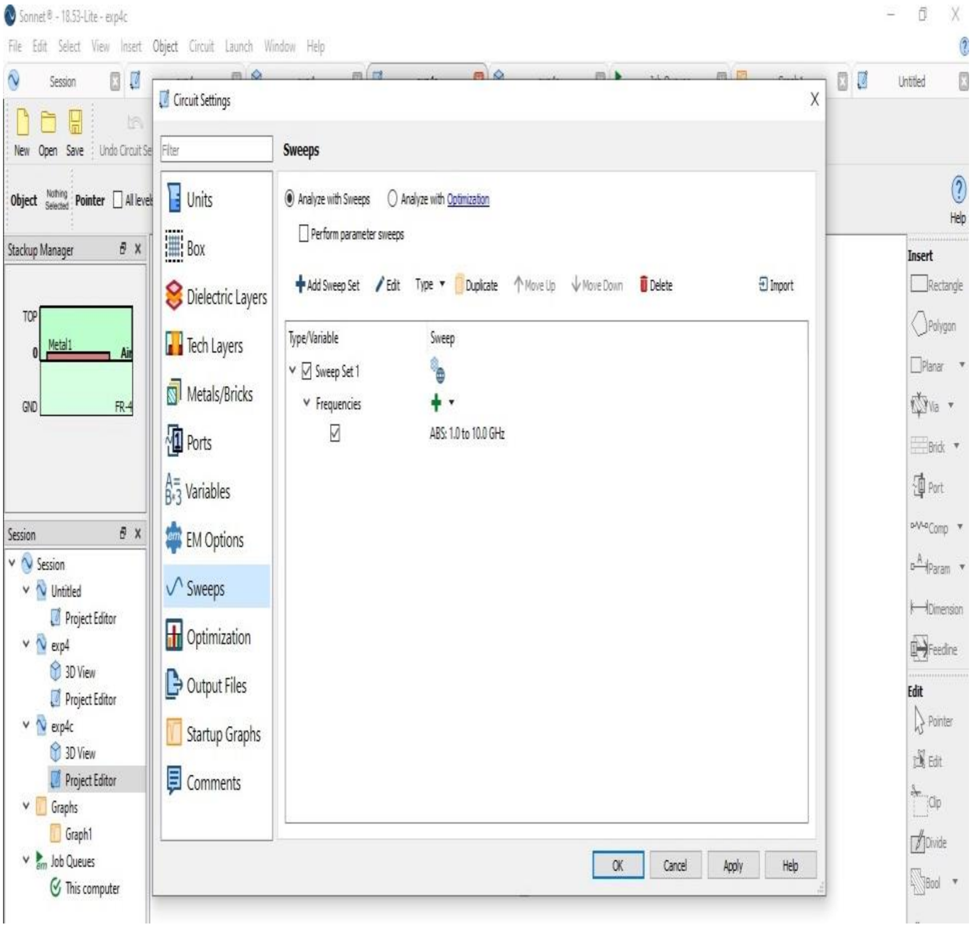
Experiment No: 4	**Design a 50Ω microstrip line in SONNETLite™ software**
Aim:	To calculate the specifications of a 50Ω microstrip transmission line and implement it using SONNET software. The objective of this experiment is to explore the Sonnet (EM solver) software features.
Theory:	Microstrip is a commonly used transmission line configuration in mixed signal Printed Circuit Board (PCB) designs. For initial transmission line calculations, we require multiple equations. Most practical PCB circuits are quite complex and quickly exceed the limitations of the equations. For a more complete understanding of transmission line-based circuits, an electromagnetic (EM) model is required. Sonnet is a useful tool for Planar EM Simulation. It uses a Method of Moment analysis technique to generate frequency domain data for transmission line structures. Microstrip transmission lines consist of a conductive strip of width "w" and thickness "t" and a wider ground plane, separated by a dielectric layer (a.k.a. the "substrate") of thickness "h" as shown in the Figure below. 
Problem Statement	Design a 50Ω microstrip line on a dielectric substrate having, height = 2mm and ε_r = 4.12

Procedure

1. Open sonnet software. In sonnet Task bar click on project and select New Geometry.



2. Now we see the Sonnet Project Editor window on which we have to draw the transmission line geometry according to calculations. In the Sonnet Project click on settings. A circuit settings window will appear as follows.



Circuit Settings

Sweeps

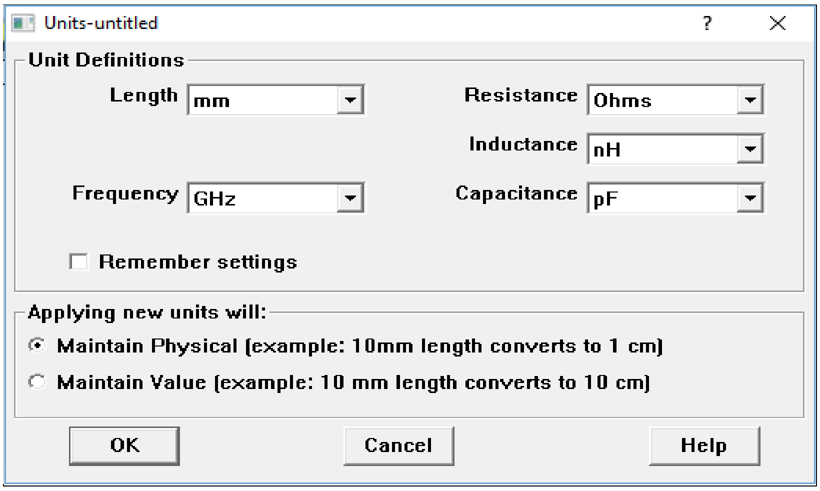
● Analyze with Sweeps ○ Analyze with Optimization

☐ Perform parameter sweeps

☑ Sweep Set 1

Frequencies ☑ ABS: 1.0 to 10.0 GHz

3. Specify units: In the Sonnet Project Editor window under the circuit click on units. Chose Length and Frequency unit. (Note-If you chose Length unit in mm then you have to enter all dimensions in mm)



Units-untitled

Unit Definitions

Length: mm

Frequency: GHz

Resistance: Ohms

Inductance: nH

Capacitance: pF

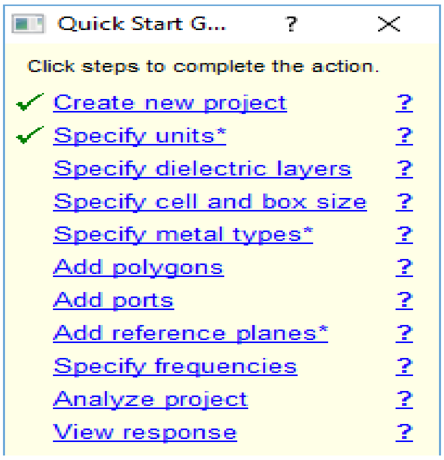
☐ Remember settings

Applying new units will:

● Maintain Physical (example: 10mm length converts to 1 cm)

○ Maintain Value (example: 10 mm length converts to 10 cm)

4. After completing the step, we observe mark on Quick Start Guide window corresponding to the completed steps.

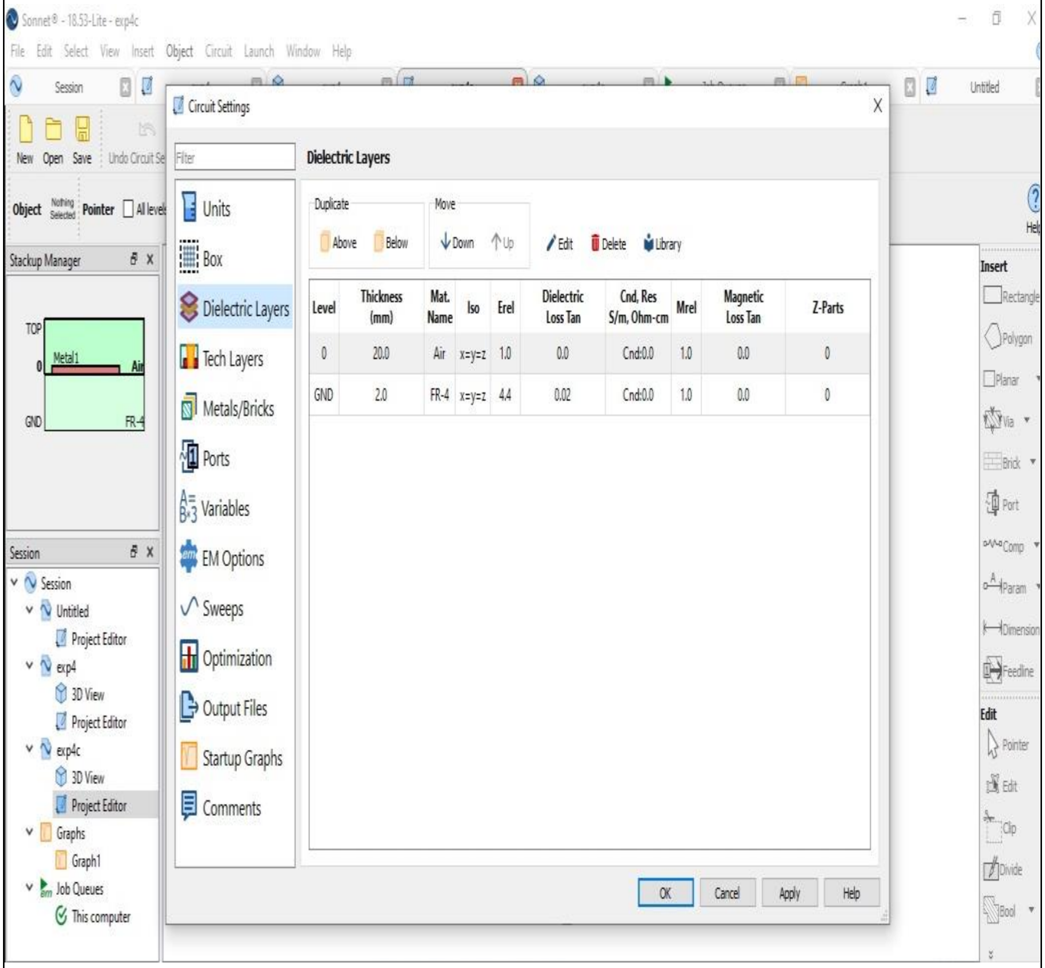


Quick Start G...

Click steps to complete the action.

- ✓ Create new project ?
- ✓ Specify units* ?
- Specify dielectric layers ?
- Specify cell and box size ?
- Specify metal types* ?
- Add polygons ?
- Add ports ?
- Add reference planes* ?
- Specify frequencies ?
- Analyze project ?
- View response ?

5. **Specify dielectric layers:** In the Sonnet Project Editor window under settings click on dielectric layers. We design the microstrip line on the substrate (Normally FR-4 substrate is used) and for simulating the design we assume that the substrate is inside an imaginary box that is filled with air. In the dielectric layer, we specify the type of material and their height.

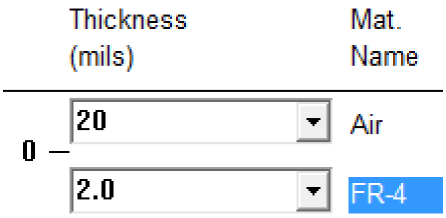


Dielectric Layers

Level	Thickness (mm)	Mat. Name	Iso	Erel	Dielectric Loss Tan	Cnd, Res S/m, Ohm-cm	Mrel	Magnetic Loss Tan	Z-Parts
0	20.0	Air	x=y=z	1.0	0.0	Cnd:0.0	1.0	0.0	0
GND	2.0	FR-4	x=y=z	4.4	0.02	Cnd:0.0	1.0	0.0	0

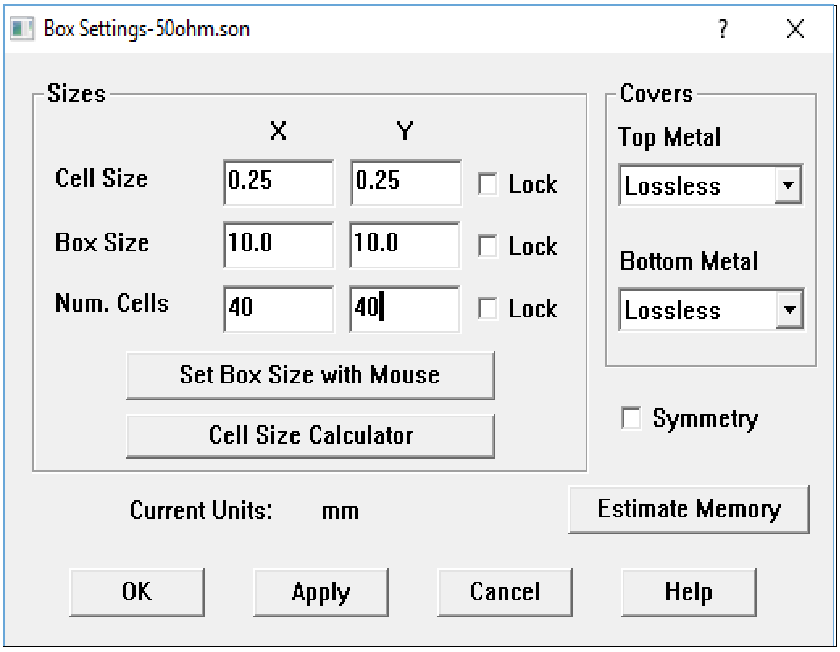
Click on the material Name. i.e. is unnamed and renamed as Air and enter thickness 20(it accepts 20mm because we have specified the Length unit as 'mm').

Similarly double click on unnamed and click on Select dielectric from library. Now select FR-4 as a dielectric material and click on OK.



Thickness (mils)	Mat. Name
20	Air
2.0	FR-4

5. **Specify cell and box size:** We will define the analysis box next. This sets the X*Y size of the dielectric layers. To access this dialog box click Circuit > Box



Box Settings-50ohm.son

Sizes

	X	Y	
Cell Size	0.25	0.25	☐ Lock
Box Size	10.0	10.0	☐ Lock
Num. Cells	40	40	☐ Lock

Covers

Top Metal: Lossless

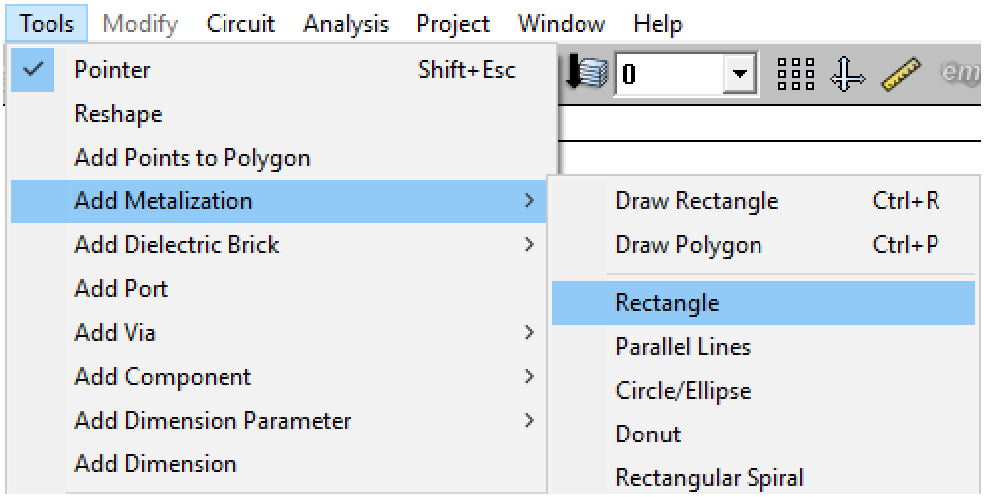
Bottom Metal: Lossless

☐ Symmetry

Current Units: mm

In this example we will use a 10 x 10 mm box size (grid). The idea is to have a large enough PCB size to allow for your circuit and use a fine enough grid to handle the dimensions you plan to use. **The grid size is inversely proportional to your model size, so it must be selected carefully.**

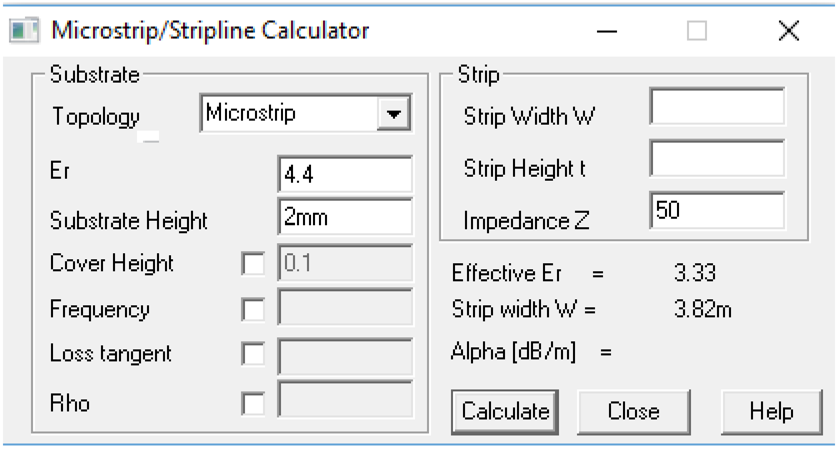
6. **Adding a Rectangle**: The impedances are converted into a transmission line and each transmission line is drawn using a Rectangle made up of metal.
   Go to Insert > Metallization > Rectangle



Enter the Rectangular attributes i.e. its width and Height.

Width Calculation:

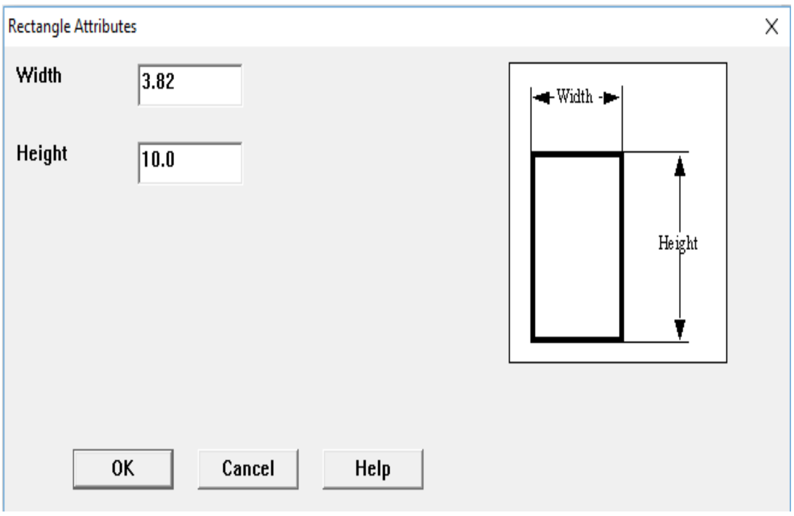
- Width is calculated by using APLAC calculator.
- Open APLAC software >In Aplac Editor Window under Tools> Select Microstrip Calculator.
- In Microstrip Calculator enter substrate Er (4.4 for FR-4 substrate), substrate Height (2mm) and enter the Impedance of transmission line.
- Click on Calculate.


Microstrip/Stripline Calculator

Substrate
Topology: Microstrip
Er: 4.4
Substrate Height: 2mm
☐ Cover Height: 0.1
☐ Frequency
☐ Loss tangent
☐ Rho

Strip
Strip Width W
Strip Height t
Impedance Z: 50

Effective Er = 3.33
Strip width W = 3.82m
Alpha [dB/m] =

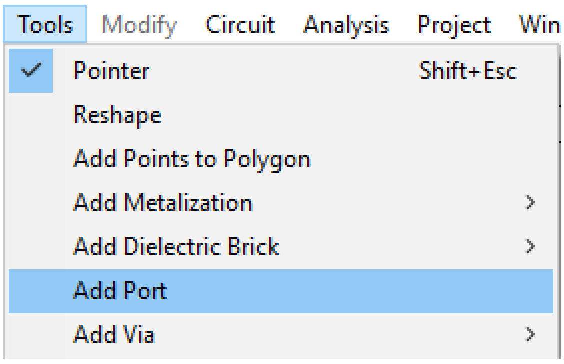


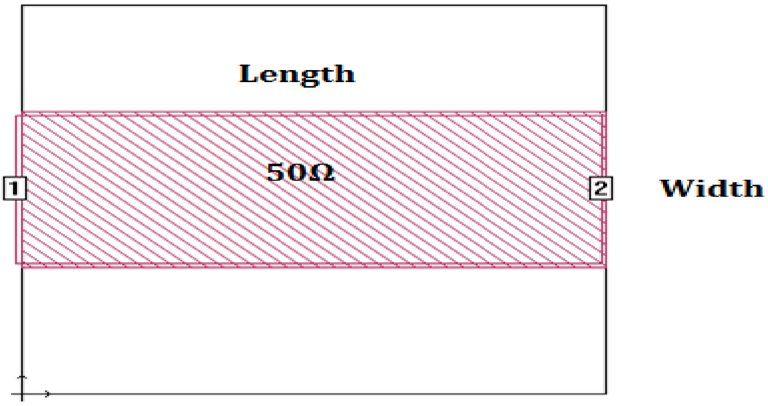
Rectangle Attributes

Width 3.82

Height 10.0

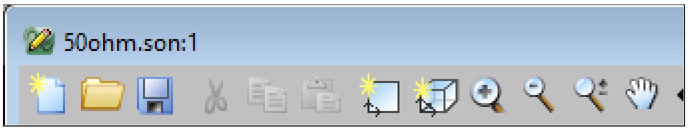
7. **Add Ports:** In Sonnet Project Editor window >under Insert >select Add ports and drag the port (input port) at the left edge of the 50 Ω transmission line. Similarly, select the port (output port) and drag it at the right edge of the 50Ω transmission line.

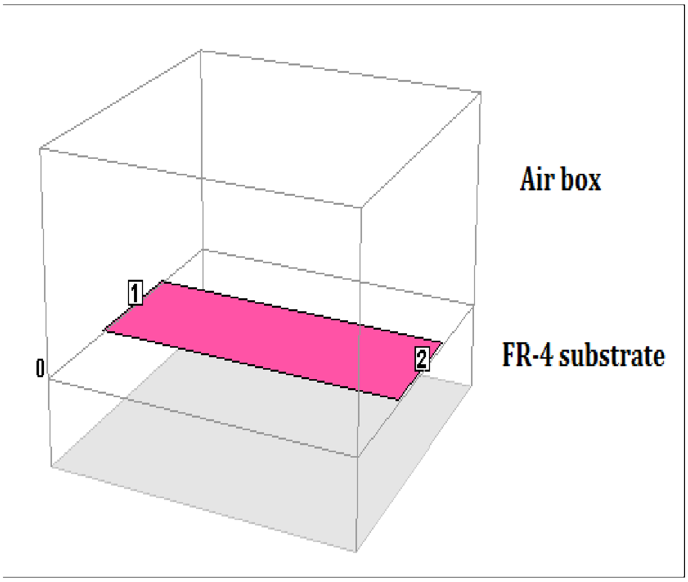




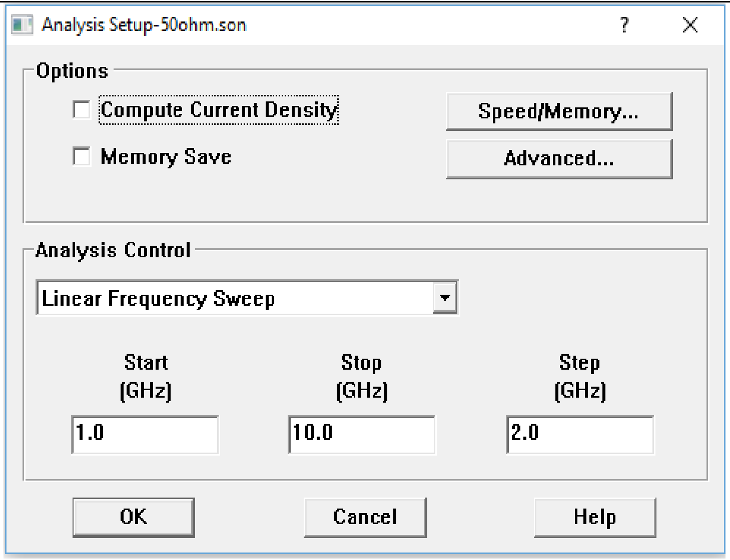
(Note: Take any length for a 50Ω transmission line. Here we adjust the length according to the length of box).

We can also observe the 50Ω line in 3D by clicking on view 3D.





8. **Specify Frequency:** In the Sonnet Project Editor window >under Settings> click on
   Sweeps.
   In Analysis Setup under Analysis Control select Linear Frequency Sweep and enter the Star, stop and give Step frequencies.


Analysis Setup-50ohm.son

Options

☐ Compute Current Density

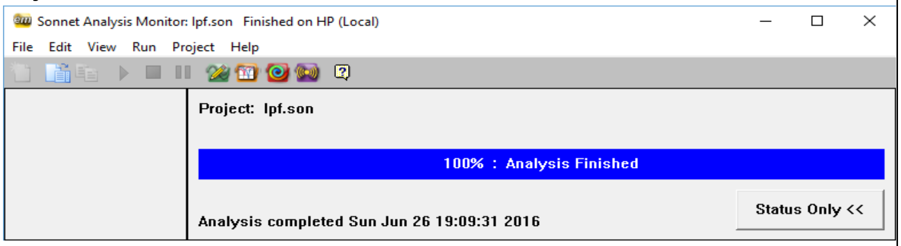
☐ Memory Save

Analysis Control

Linear Frequency Sweep

Start [GHz]	Stop [GHz]	Step [GHz]
1.0	10.0	2.0

8. **Analyze and View Response**: In Sonnet Project Editor window> Launch > click on Analyze> save > run
9. **To view graphs:** click on the graph > click on curves> then add S_{12}, S_{21} and S_{22} parameters by clicking on S_{11} and then edit it. We get the following window. If there is no error then we get a message as 100% Analysis Finished


Sonnet Analysis Monitor: lpf.son Finished on HP (Local)

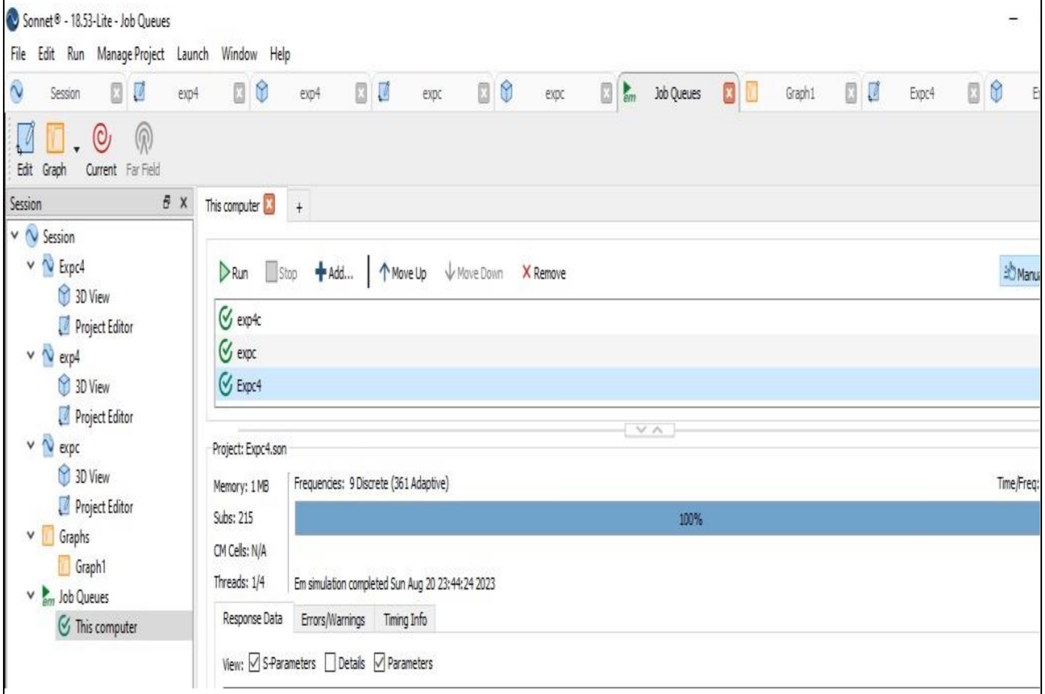
Project: lpf.son

100% : Analysis Finished

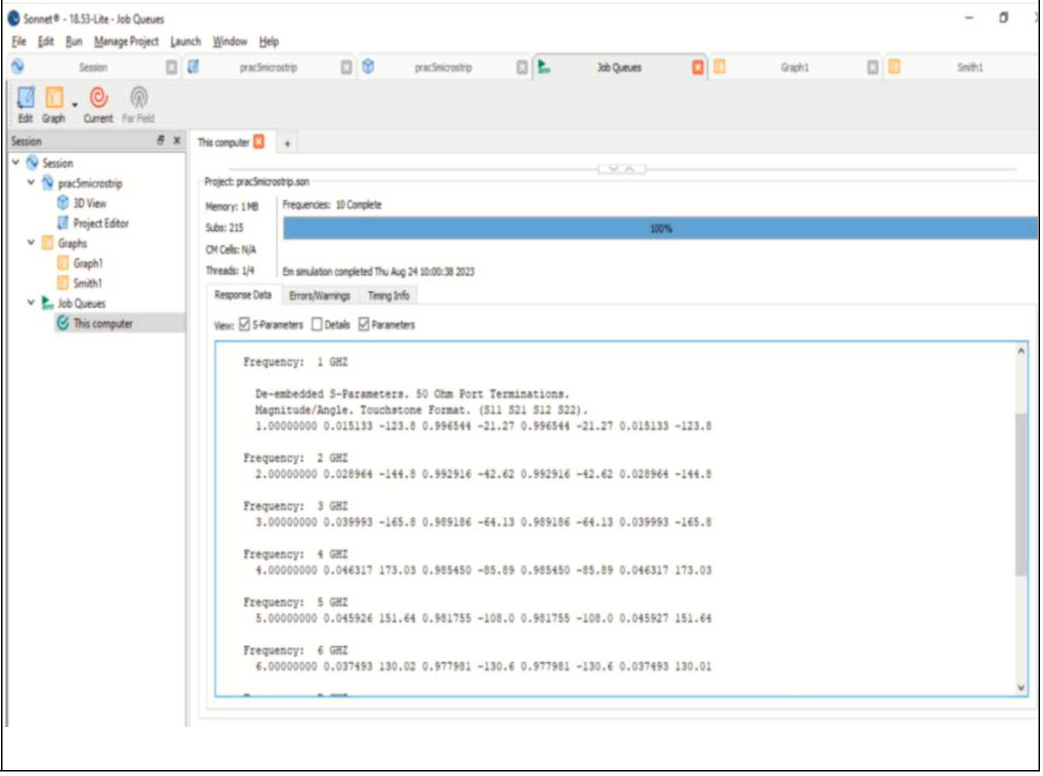
Analysis completed Sun Jun 26 19:09:31 2016

View Response: In Sonnet Analysis Monitor > click on View Response. (Note: If you are using Sonnet software student version setup then it will simulate file having maximum size of 1MB, so if you run a file that is greater than 1MB then it will give an error. To solve this problem, adjust the size of the air box and substrate (make cell size coarse) so that the area of simulation will be reduced. Otherwise, register the Sonnet Lite software which will allow you to simulate a maximum of 32MB of file.)

10. By default a cartesian graph of S_{11} in dB will be plotted in the Response Viewer. We can change the displayed data type by double clicking on the quantity in the left legend and selecting the command Edit curve group.



Project: Expc4.son
Memory: 1 MB
Frequencies: 9 Discrete (361 Adaptive)
Subs: 215
CM Cells: N/A
Threads: 1/4
Em simulation completed Sun Aug 20 23:44:24 2023
View: ☑ S-Parameters ☐ Details ☑ Parameters



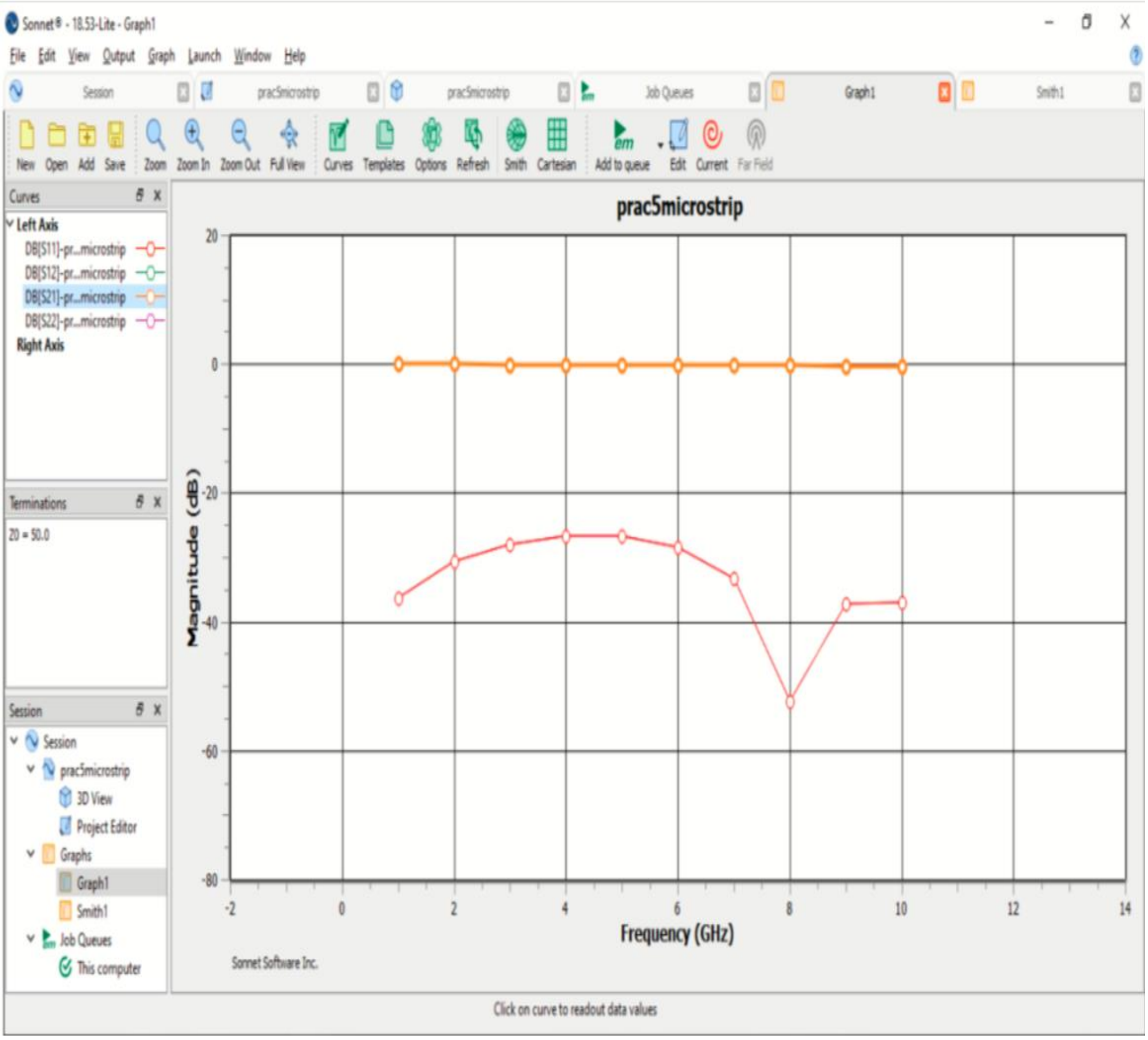
Project: pracSmicrostrip.son
Memory: 1 MB
Frequencies: 10 Complete
Subs: 215
CM Cells: N/A
Threads: 1/4
Em simulation completed Thu Aug 24 10:00:38 2023
View: ☑ S-Parameters ☐ Details ☑ Parameters

```
Frequency:  1 GHZ

  De-embedded S-Parameters. 50 Ohm Port Terminations.
  Magnitude/Angle. Touchstone Format. (S11 S21 S12 S22).
  1.00000000 0.015133 -123.8 0.996544 -21.27 0.996544 -21.27 0.015133 -123.8

Frequency:  2 GHZ
  2.00000000 0.028964 -144.8 0.992916 -42.62 0.992916 -42.62 0.028964 -144.8

Frequency:  3 GHZ
  3.00000000 0.039993 -165.8 0.989186 -64.13 0.989186 -64.13 0.039993 -165.8

Frequency:  4 GHZ
  4.00000000 0.046317 173.03 0.985450 -85.89 0.985450 -85.89 0.046317 173.03

Frequency:  5 GHZ
  5.00000000 0.045926 151.64 0.981755 -108.0 0.981755 -108.0 0.045927 151.64

Frequency:  6 GHZ
  6.00000000 0.037493 130.02 0.977981 -130.6 0.977981 -130.6 0.037493 130.01
```

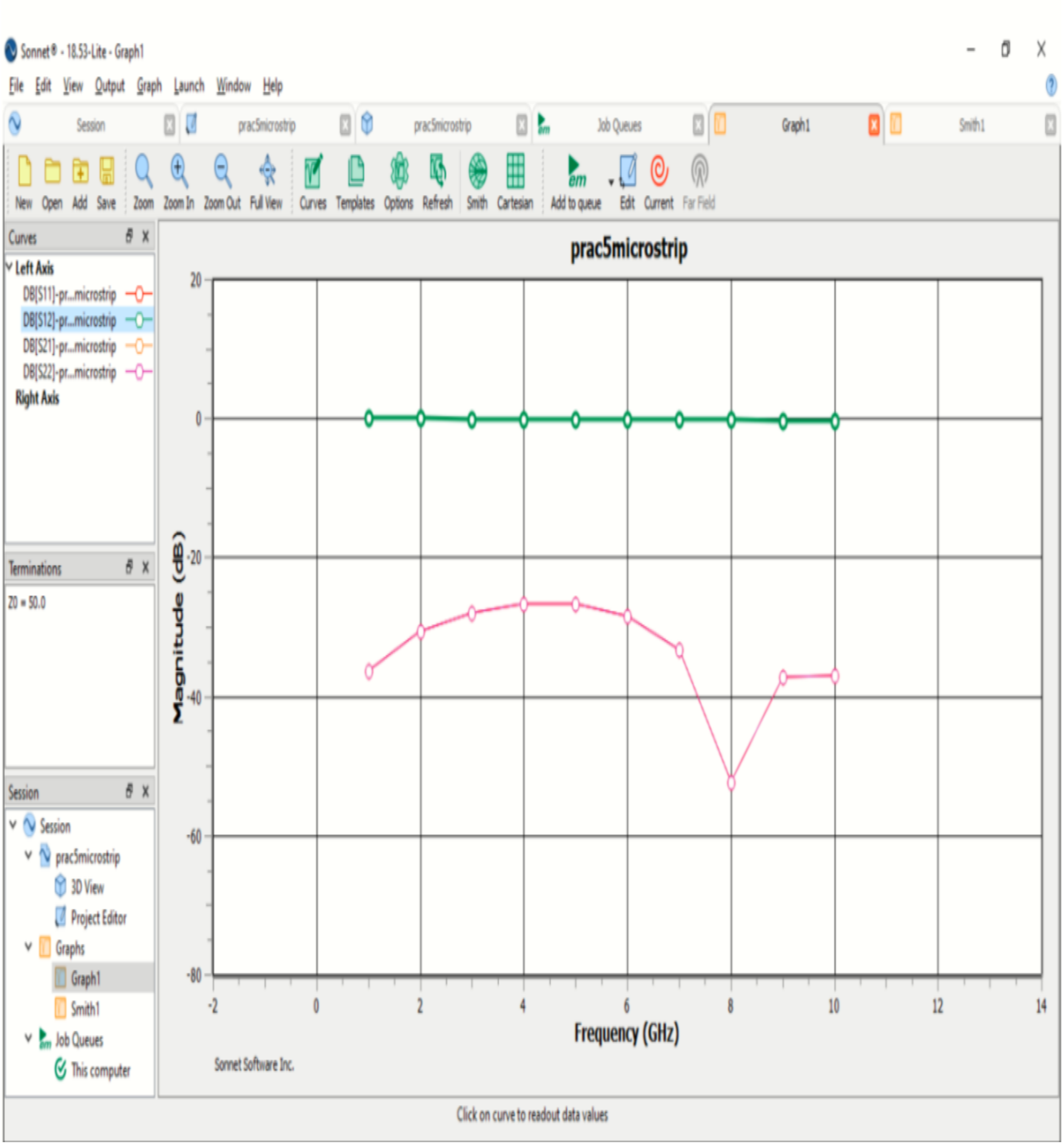
Observations	
Result Analysis and Conclusion	
Post Experiment Quiz	1. What is the effect of the frequency on the S-parameters? 2. Why Microstrip line is called as Asymmetric line?

Output:

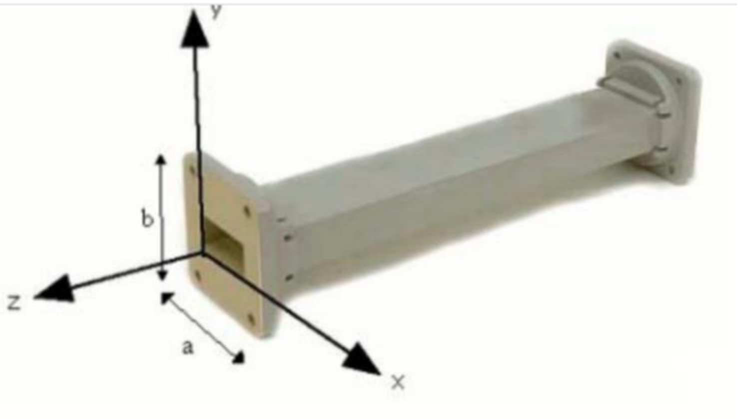
S_{12} and S_{21} Parameters:



S_{12} and S_{21} Parameters:



Experiment No :6	**Study of field pattern of various modes inside a Rectangular waveguide.**

Aim	Study of field patterns of various modes inside a rectangular waveguide.
Theory	Electromagnetic waves propagating in open space travel out in all directions. The power intensity of these waves decreases as the distance increases - it is proportional to the power of the source divided by the square of the distance. The waveguide operates by confining the electromagnetic wave inside a metallic structure so that it does not spread out, and losses resulting from this effect are eliminated. In electromagnetics, the term waveguide may refer to any linear structure that guides electromagnetic waves between two endpoints. Typically a waveguide is thought of as a transmission line comprising a hollow conducting tube, which may be rectangular or circular within which electromagnetic waves are propagated. Unlike coaxial cables, there is no centre conductor within the waveguide. Signals propagate within the confines of the metallic walls that act as boundaries. The signal is confined by total internal reflection from the walls of the waveguide. Waveguides are used principally at frequencies in the microwave range. Waveguides will only carry or propagate signals above a certain frequency, known as the cut-off frequency. Below this, the waveguide is not able to carry the signals. The cut-off frequency of the waveguide depends upon its dimensions.  Fig.1 Rectangular Waveguide **Rectangular Waveguide** A rectangular waveguide is a hollow metallic tube with a rectangular cross section. The conducting walls of the waveguide confine the electromagnetic fields and thereby guide the electromagnetic wave. The rectangular waveguide is basically characterized by its dimensions i.e., length 'a' and breadth 'b'.

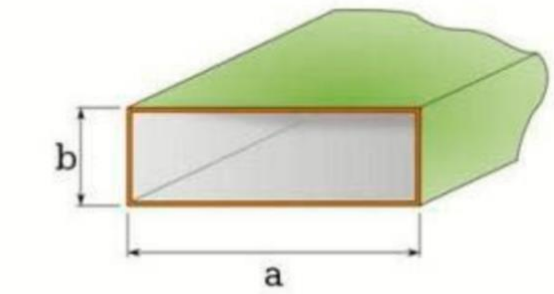


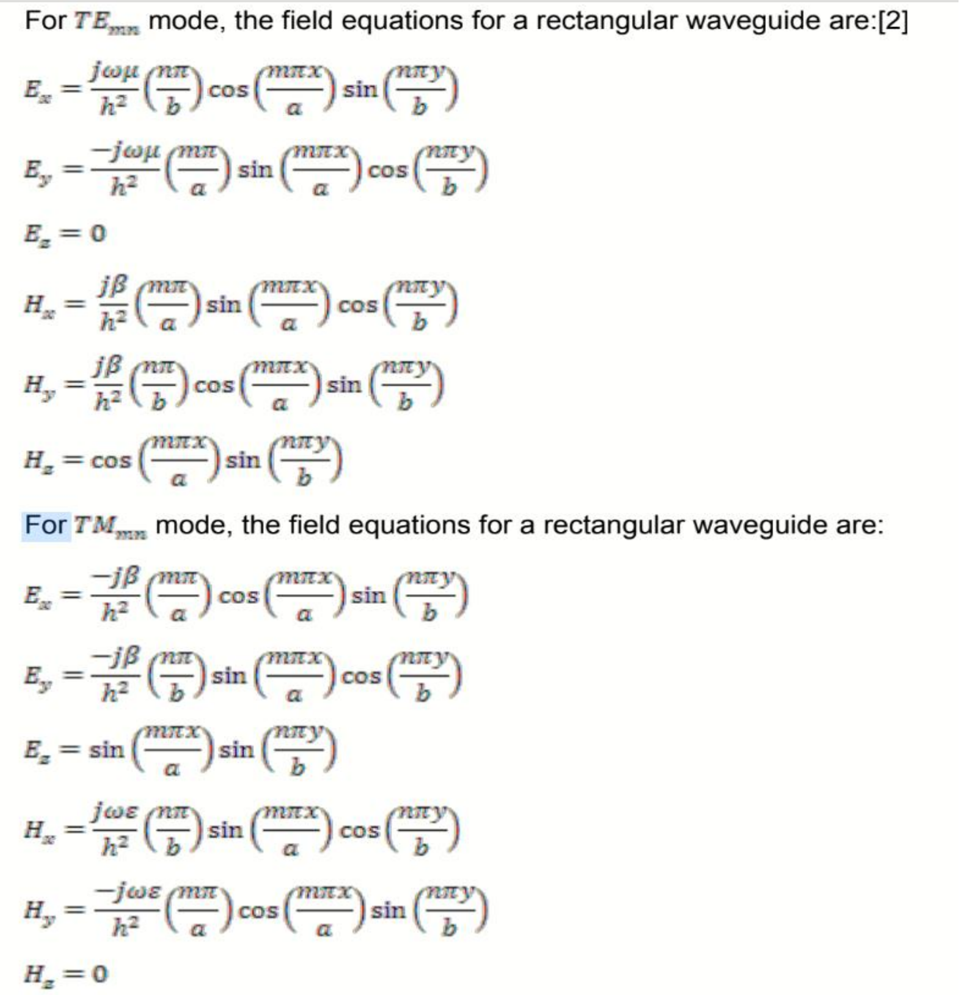
Fig. 2 Waveguide structure with dimension 'a' and 'b'

Modes:

Electromagnetic waveguides are analysed by solving Maxwell's equations, or their reduced form, the electromagnetic wave equation, with boundary conditions determined by the properties of the materials and their interfaces. These equations have multiple solutions, or modes, which are eigenfunctions of the equation system. Each mode is therefore characterized by an eigenvalue, which corresponds to a cutoff frequency below which the mode cannot exist in the guide

- TE modes (Transverse Electric) have no electric field component in the direction of propagation.
- TM modes (Transverse Magnetic) have no magnetic field component in the direction of propagation.
- TEM modes (Transverse Electromagnetic) have neither electric nor magnetic field components in the direction of propagation.

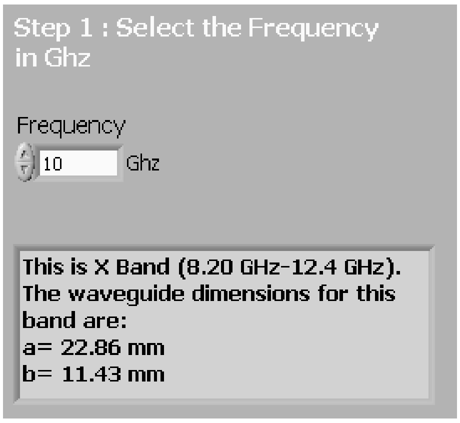
Field Theory: As we know, an electromagnetic field is comprised of electric and magnetic fields which are perpendicular to each other. These fields have different patterns for each mode. These patterns depend upon the mode numbers (m and n) and the dimensions ('a' and 'b') of the waveguide. The electric field and magnetic field pattern are different for various modes in different waveguides. The electric field component of an EM wave is characterized by Ex, Ey and Ez components of the wave. Similarly, the magnetic field component of an EM wave is characterized by Hx, Hy and Hz components of the wave. These components are usually plotted on an XY plane which shows the field pattern for both the fields.

	 For TE_{mn} mode, the field equations for a rectangular waveguide are:[2] $E_x = \frac{j\omega\mu}{h^2}\left(\frac{n\pi}{b}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ $E_y = \frac{-j\omega\mu}{h^2}\left(\frac{m\pi}{a}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$ $E_z = 0$ $H_x = \frac{j\beta}{h^2}\left(\frac{m\pi}{a}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$ $H_y = \frac{j\beta}{h^2}\left(\frac{n\pi}{b}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ $H_z = \cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ For TM_{mn} mode, the field equations for a rectangular waveguide are: $E_x = \frac{-j\beta}{h^2}\left(\frac{m\pi}{a}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ $E_y = \frac{-j\beta}{h^2}\left(\frac{n\pi}{b}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$ $E_z = \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ $H_x = \frac{j\omega\varepsilon}{h^2}\left(\frac{n\pi}{b}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$ $H_y = \frac{-j\omega\varepsilon}{h^2}\left(\frac{m\pi}{a}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$ $H_z = 0$
Procedure	Step 1: Select the frequency band in which you wish to see the field pattern. Step 2: Select the type of mode, i.e., either Transverse Electric (TE) or Transverse Magnetic (TM). Step 3: Select Pattern: i) Electric Field: Select this to view the electric field pattern of the given mode. ii) Magnetic Field : Select this to view the magnetic field pattern of the given mode. iii) Surface Current: Select this option to view the surface current density for TE10 mode. Step 4: Enter the values of m and n to obtain the field pattern, where m stands for no.of half waves of electric or magnetic intensity in the X-direction, and n stands for number of half waves in the y direction if the propagation of wave is in z direction.

Step 5: Run the VI up to see the desired field pattern in XY, YZ and XZ planes. In case, you wish to see the other field pattern then click stop and repeat steps 1-4 before running the program again.

You may see the the following example for your reference, where appropriate buttons are selected in order to observe the electric field pattern of TE10 mode in X-band:

a) **Enter the frequency in GHz**

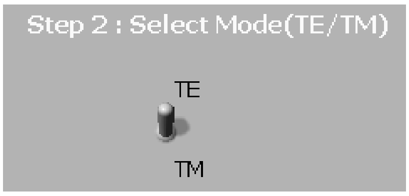


Step 1 : Select the Frequency in Ghz

Frequency: 10 Ghz

This is X Band (8.20 GHz-12.4 GHz).
The waveguide dimensions for this band are:
a= 22.86 mm
b= 11.43 mm

b) **Select Mode (TE/TM)**



Step 2 : Select Mode(TE/TM)

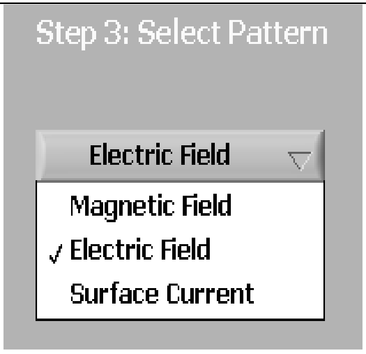
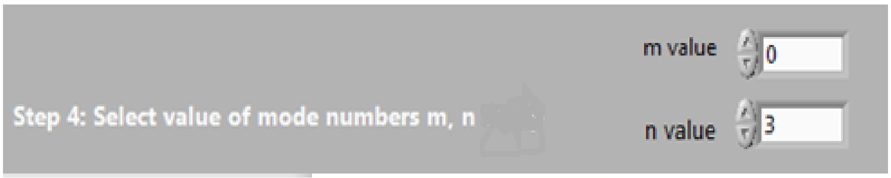
c) **Select pattern**

i) Electric Field: Select this to view the electric field pattern of the given mode.

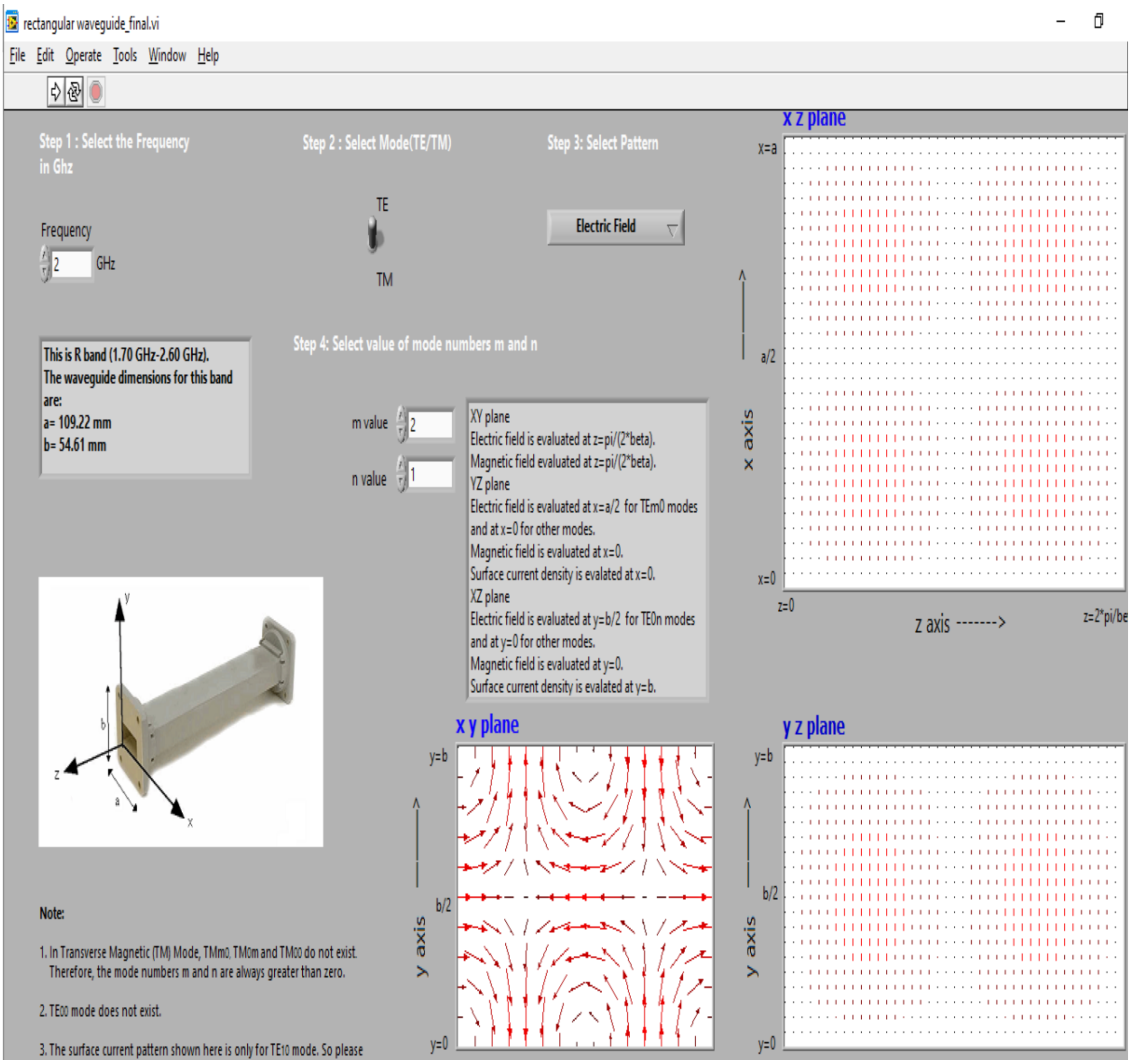
ii) Magnetic Field: Select this to view the magnetic field pattern of the given mode.

iii) Surface Current: Select this option to view the surface current density for TE10 mode.

d) Select pattern

	 Step 3: Select Pattern Electric Field
	<u>Step 4:</u> Enter the values of m and n to obtain the field pattern, where m stands for no. of half waves of electric or magnetic intensity in the X-direction, n stands for number of half waves in the y direction.  Step 4: Select value of mode numbers m, n m value 0 n value 3
<u>Observation</u>	**1. Cut off frequency** **2. Propagating Modes** **3. Non-Propagating Modes**
<u>Result Analysis and Conclusion</u>	

Output



Step 1 : Select the Frequency in Ghz

Frequency 2 GHz

Step 2 : Select Mode(TE/TM)

TE
TM

Step 3: Select Pattern

Electric Field

This is R band (1.70 GHz-2.60 GHz).
The waveguide dimensions for this band are:
a= 109.22 mm
b= 54.61 mm

Step 4: Select value of mode numbers m and n

m value 2

n value 1

XY plane
Electric field is evaluated at z=pi/(2*beta).
Magnetic field evaluated at z=pi/(2*beta).
YZ plane
Electric field is evaluated at x=a/2 for TEm0 modes and at x=0 for other modes.
Magnetic field is evaluated at x=0.
Surface current density is evalated at x=0.
XZ plane
Electric field is evaluated at y=b/2 for TE0n modes and at y=0 for other modes.
Magnetic field is evaluated at y=0.
Surface current density is evalated at y=b.

Note:

1. In Transverse Magnetic (TM) Mode, TM_{m0}, TM_{0m} and TM_{00} do not exist. Therefore, the mode numbers m and n are always greater than zero.

2. TE_{00} mode does not exist.

3. The surface current pattern shown here is only for TE_{10} mode. So please

Figure 1. Mode TE_{21}

Experiment No. :7	**Study of field pattern of various modes inside a rectangular waveguide cavity.**
Aim	Study of field patterns of various modes inside a rectangular cavity.
Theory:	This gives the basic idea of the field pattern; that is, electric and magnetic field patterns for various modes inside a rectangular cavity resonator. One can observe the field patterns of various modes in xy, xz and yz planes for different frequency bands. Surface current density can also be observed on the walls of a rectangular cavity resonator.  This Experiment provides the field patterns of various modes inside a rectangular cavity. The conducting walls of the cavity confine the electromagnetic fields inside the structure and hence the cavity acts as a resonator. A number of distinct field configurations or modes can exist in cavities. In the rectangular cavities, modes are designated as TE_{mnp} or TM_{mnp} , where m, n, p are the number half-wave wave variations in x, y, z directions respectively. In this Experiment, you can get better understanding of how the field patterns vary with the parameters m, n and p for Transverse Electric (TE) and Transverse Magnetic (TM) modes in xy, yz and xz planes for different frequency bands. The surface current density plot for the TE and TM modes can also be observed on the walls of the rectangular cavity. The figure below shows the planes of a rectangular cavity. Rectangular Cavity A rectangular cavity is a hollow metallic tube with a rectangular cross section. It can be simply described as a rectangular waveguide which is shorted at both ends. The conducting walls of the waveguide confine the electromagnetic fields and hence standing waves are created which leads to resonant phenomenon. The rectangular cavity is basically characterized by its dimensions i.e., length d, breadth a and height. Modes: Like waveguides, cavities are also analyzed by solving

Maxwell's equations, or their reduced form, the electromagnetic wave equation, with boundary conditions determined by the properties of the materials and their interfaces. These equations have multiple solutions, or modes, which are eigenfunctions of the equation system. Each mode is therefore characterized by an eigenvalue, which corresponds to a cutoff frequency below which the mode cannot exist in the guide.

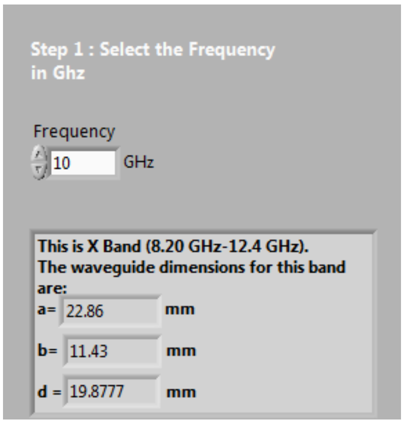
These resonant modes depend on the operating wavelength and the shape and size of the cavity. The modes of the cavity are typically classified into the following types:

1. TE modes (Transverse Electric) have no electric field component in the direction of propagation.

2. TM modes (Transverse Magnetic) have no magnetic field component in the direction of propagation.

Procedure

Step 1: Select the frequency band in which you wish to see the field pattern. **Enter the frequency in GHz**



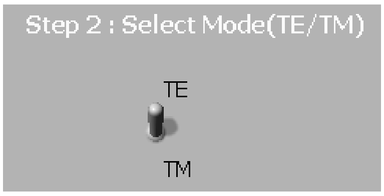
Step 1 : Select the Frequency in Ghz

Frequency 10 GHz

This is X Band (8.20 GHz-12.4 GHz).
The waveguide dimensions for this band are:
a= 22.86 mm
b= 11.43 mm
d = 19.8777 mm

Step 2: Select the type of mode, i.e., either Transverse Electric (TE) or Transverse Magnetic (TM).

Select Mode (TE/TM)



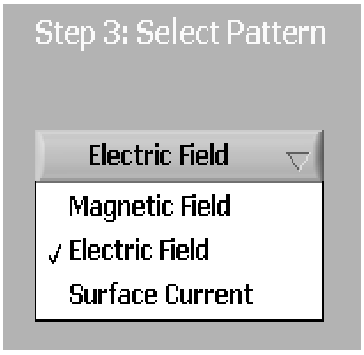
Step 3: Select Pattern:

1. Electric Field: Select this to view the electric field pattern of the

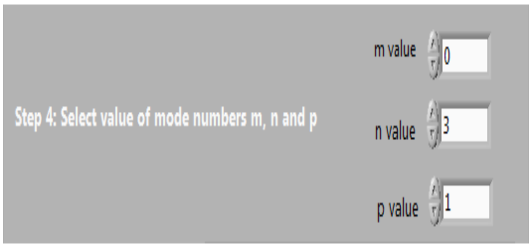
given mode.

2. Magnetic Field: Select this to view the magnetic field pattern of the given mode.
3. Surface Current: Select this option to view the surface current density for TE10 mode.

Select pattern



Step 4: Enter the values of m, n and p to obtain the field pattern, where m stands for no. of half waves of electric or magnetic intensity in the X-direction, n stands for number of half waves in the y direction and p stands for number of half waves in the z direction.

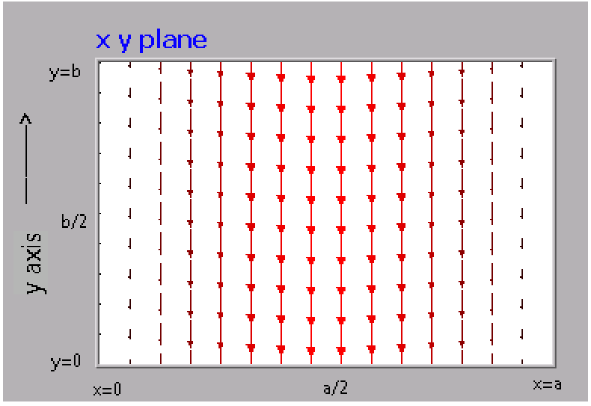

Step 4: Select value of mode numbers m, n and p

m value 0
n value 3
p value 1

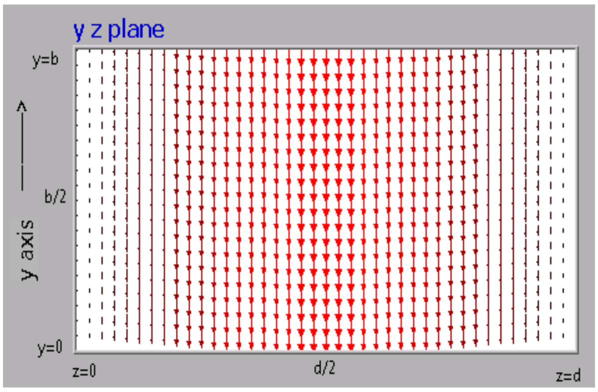
Step 5: Run the VI up to see the desired field pattern in XY, YZ and XZ planes. In case, you wish to see the other field pattern then click stop and repeat steps 1-4 before running the program again.

You may see the following example for your reference, where appropriate buttons are selected in order to observe **the electric field pattern** of TE_{101} mode in X-band:

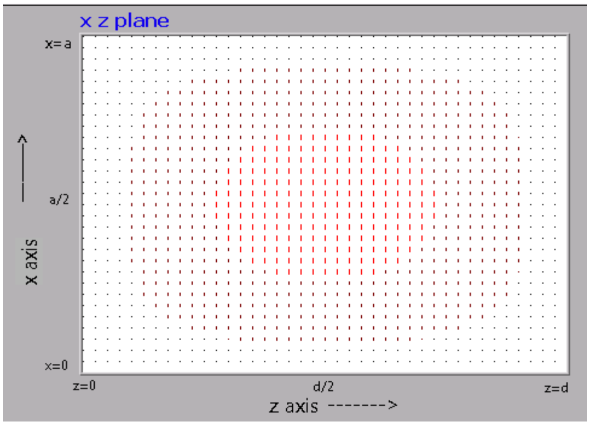
View the pattern in XY plane



YZ plane

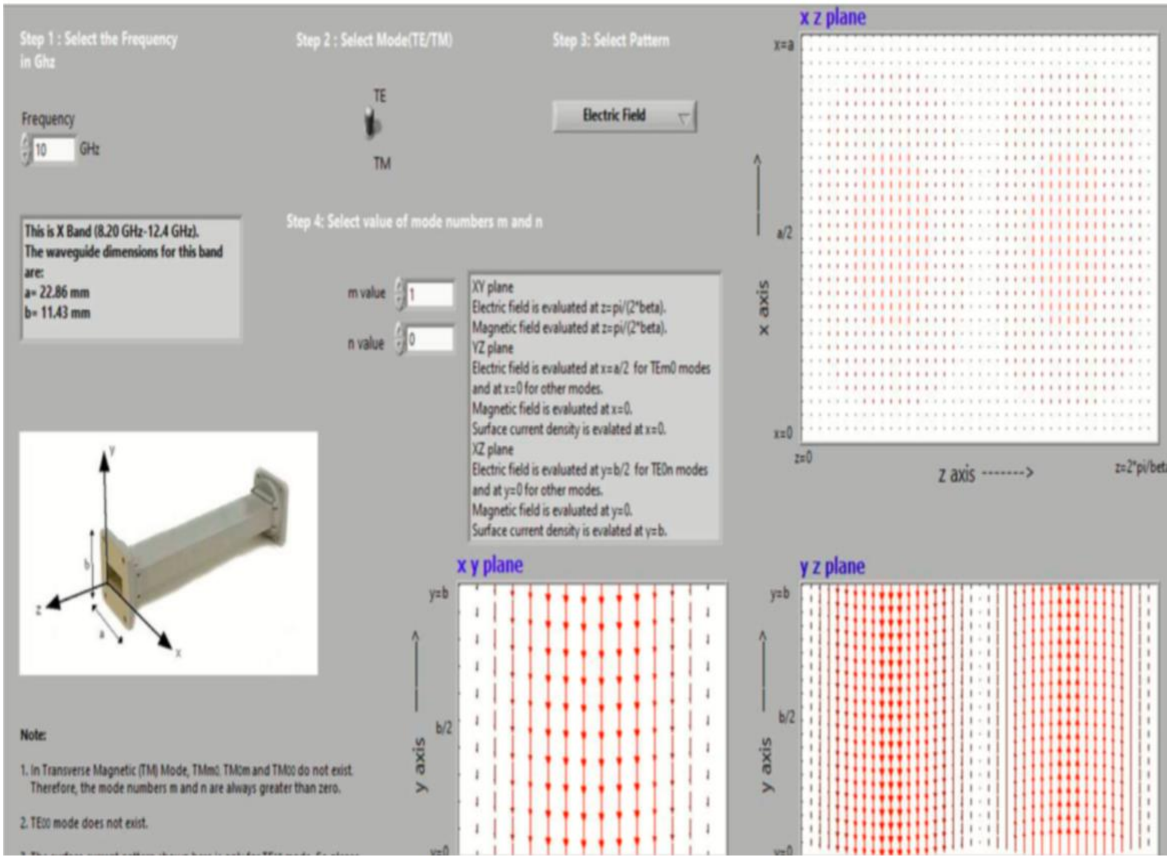


XZ plane



Observations:	Cutoff Frequency: Mode
Result Analysis and Conclusion:	
Post Experiment Quiz	1) What do mean by cavity resonator? 2) How Rectangular cavity resonator different than a rectangular waveguide?

Output:



Step 1 : Select the Frequency in Ghz

Frequency 10 GHz

Step 2 : Select Mode(TE/TM)

Step 3: Select Pattern

Step 4: Select value of mode numbers m and n

m value 1

n value 0

This is X Band (8.20 GHz-12.4 GHz).
The waveguide dimensions for this band are:
a= 22.86 mm
b= 11.43 mm

XY plane
Electric field is evaluated at z=pi/(2*beta).
Magnetic field evaluated at z=pi/(2*beta).
YZ plane
Electric field is evaluated at x=a/2 for TEm0 modes and at x=0 for other modes.
Magnetic field is evaluated at x=0.
Surface current density is evalated at x=0.
XZ plane
Electric field is evaluated at y=b/2 for TE0n modes and at y=0 for other modes.
Magnetic field is evaluated at y=0.
Surface current density is evalated at y=b.

Note:

1. In Transverse Magnetic (TM) Mode, TMm0, TM0m and TM00 do not exist. Therefore, the mode numbers m and n are always greater than zero.

2. TE00 mode does not exist.

Experiment. No:8	**Introduction to Microwave Components.**
Aim	To study Microwave Components
Theory	Microwaves are electromagnetic waves (E.M. Waves) having wavelength in the micron range. Though microwave frequencies refer to those from 1GHz to 10^6GHz but generally used for those wavelengths measured in centimeters, roughly from 10cm to 1cm (3 to 30 GHz) and the waves having wavelengths less than 1cm corresponds to higher frequencies (> 30 GHz) are called millimeter waves (mm waves).

MICROWAVE FREQUENCIES

Relationship between the frequency (f) and the wavelength (λ) of an E.M. wave is $c = f\lambda$

Where, c is velocity of electromagnetic radiation, usually called the speed of light.

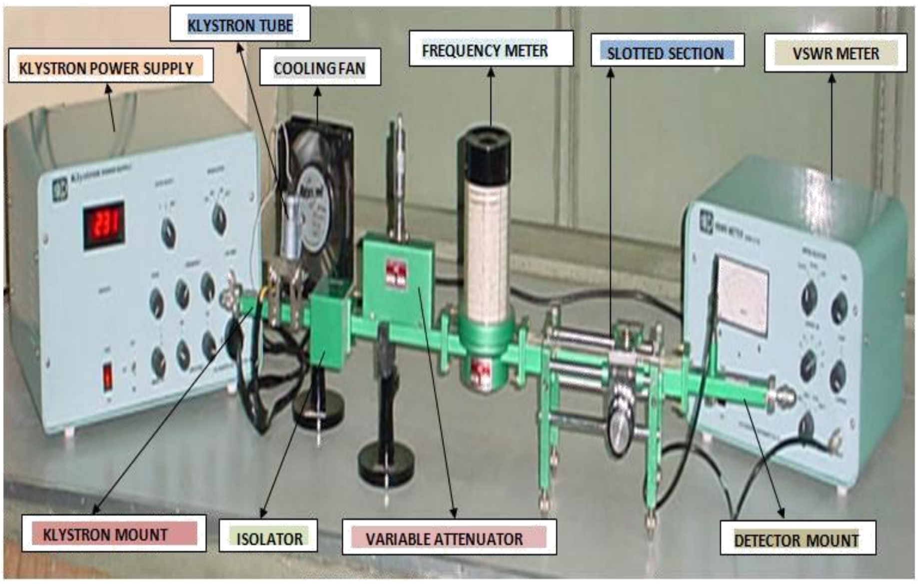
TABLE 1.1 IEEE MICROWAVE FREQUENCY BANDS

DESIGNATION	FREQUENCY RANGE IN GHZ
L-Band	1.0 to 2.0
S-Band	2.0 to 4.0
C-Band	4.0 to 8.0
X-Band	8.0 to 12.0
Ku-Band	12.0 to 27.0
K- Band	18.0 to 27.0
Ka-Band	27.0 to 40.0
Millimeter	40.0 to 300
Sub-Millimeter	300 and above.

MICROWAVE SYSTEMS:

Usually, a microwave system consists of a transmitter sub-system, consisting of a microwave oscillator, waveguide, transmission antenna, and a receiver sub-system; that includes a receiving antenna, waveguide microwave detector, power and frequency meter. The intermediate region between the transmitter and receiver, as well as the inner hollow space of the waveguide, may be filled up with air or dielectric medium. The electromagnetic wave traverses with the speed of light through air.

MICROWAVE TEST BENCH



Description Of Microwave Bench:

The Measurement Techniques in Microwave frequencies is vastly different from that of the more conventional techniques. At Low Frequency, it is convenient to measure voltage and current and use them to calculate power. However, at Microwave frequencies, they are difficult to measure since they vary with position in a transmission line and hence, they are of little value in determining power. Therefore, at microwave frequencies, it is more desirable and simpler to measure power directly. At microwave frequencies, quantities measured are relative and is not necessary to know their absolute values, i.e., it is sufficient to know the ratio of two power rather than exact input or output powers. The parameter that can be conveniently measured at microwave frequencies are Frequency, Power, Attenuation, Voltage Standing Wave Ratio (VSWR), Phase, Impedance, Insertion Loss, Dielectric Constant Noise Factor.

The general set up for measurement of any parameter in microwaves is called microwave test bench. The microwave test bench incorporates a range of instruments capable of allowing all types of measurements that are usually required for a microwave engineer. The bench is capable of being assembled or disassembled in a number of ways to suit individual Experiments. A general block diagram of the test bench comprising of different components is shown below.

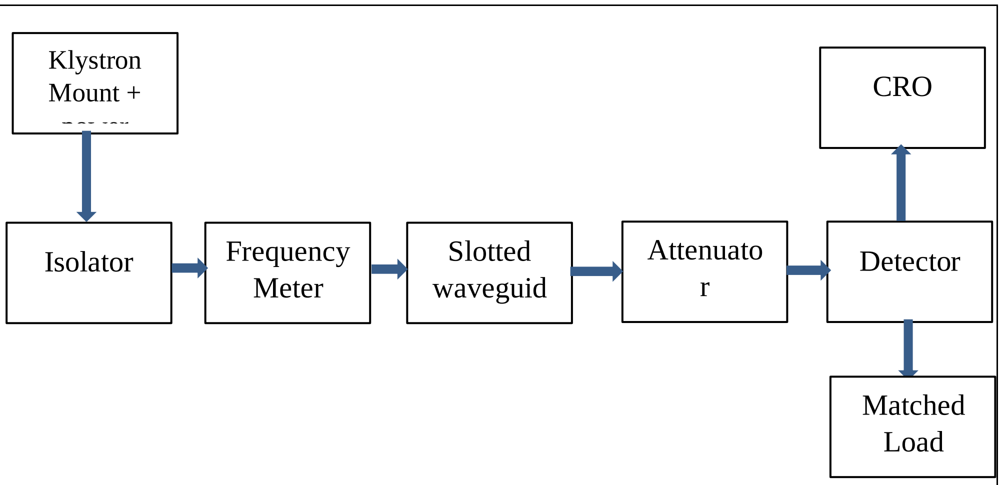


Figure 1. Microwave Bench

Klystron Power Supply:

Klystron Power Supply generates the voltage required for driving the Reflex Klystron Tube 2k25. It is a stable, regulated, and short-circuit-protected power supply. It has built in facility of square wave and saw tooth generators for amplitude and frequency modulation. The beam voltage ranges from 200V to 450V with a maximum beam current, of 50 mA. The provision is given to vary repeller voltage continuously from 270V DC to – 10V.

Gunn Power Supply:

Gunn Power Supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn oscillator and Pin Modulator. The supply voltage ranges from 0 to 12 V with a maximum current, of 1A.

Reflex Klystron Oscillator:

At high frequencies, the performance of a conventional vacuum tube is impaired due to transit time effects, lead inductance and inter-electrode capacitance. Klystron is a microwave vacuum tube employing velocity modulation and transit time in achieving its normal operation. The reflex type, known as reflex Klystron, has been most used source of microwave power in Laboratory. It consists of an electron gun producing a collimated electron beam. The electron beam is accelerated towards the reflector by a dc voltage V0, while passing through the positive resonator grids. The velocity of the electrons in the beam will be

$$V_{po} = \sqrt{\frac{2eV_0}{m}}$$

Where e and m being electronic charge and mass respectively. The repeller, which is placed at a short distance from the resonator grids, is kept at negative potential with respect to cathode, and consequently it retards and finally reflects the electrons which then turn back through the resonator grids.

Gunn Oscillator:

Gunn oscillator utilizes Gunn diode which works on the principle that when a d.c. voltage is applied across a sample of n type Gallium Arsenide (GaAs), the current oscillates at microwave frequencies. This does not need high voltage as it is necessary for Klystrons and therefore solid state oscillators are now finding wide applications. Normally, they are capable of delivering 0.5 watt at 10GHz, but as the frequency of operation is increased the microwave output power gets considerably reduced. Gunn oscillators can also be used as modulated microwave sources. The modulation is generally provided by means of a PIN diode. PIN diode is a device whose resistance varies with the bias applied to it. When waveguide line is shunted with PIN Diode and the diode is biased positively, it presents very high impedance thereby not affecting the line appreciably. However, it is negatively biased it offers a very low impedance; almost short-circuit thereby reflecting the microwave power incident on it. As impedance varies with bias, the signal is amplitude modulated as the bias varies. Since heavy power is reflected during negative biasing of PIN diode, so an isolator or an attenuator should invariably be used to isolate PIN diode avoid overloading of the latter.

Isolator:

The isolator is a two-port device. This device permits untenanted transmission in one direction (forward direction) but provides very high attenuation in the reverse direction (backward direction). This is generally used in between the source and the rest of the setup to avoid overloading of the source due to reflected power.

Variable Attenuator:

The attenuator is two-port device. The device that attenuates the signal is termed as attenuator. Attenuators are categorized into two categories, namely, fixed attenuators and variable attenuators. The attenuator used in the microwave setup is of variable type. The variable attenuator consists of a strip of absorbing material which is arranged in such a way that its profusion into the guide is adjustable. Hence, the signal power to be fed to the microwave setup can be set at the desired level. This type of attenuator is called a flap attenuator.

Frequency Meter:

Frequency meter is basically a absorption cavity resonator. The cavity is connected to a waveguide having been excited by a certain microwave source. The Cavity can be made to resonate at source frequency by adjusting its size by rotating the dial of frequency meter. At resonant frequency it sucks up some signal from the guide to maintain its stored energy. Thus if a power meter had been monitoring the signal power at resonating condition of the cavity it will indicate a sharp dip. The frequency can be read from the scale of direct reading frequency meter. If it is indirect reading frequency meter tuning can be achieved by a micrometer screw. The frequency can be obtained by using calibrating chart.

Slotted Section:

To sample the field with in a waveguide, a narrow longitudinal slot with ends tapered to provide smoother impedance transformation and thereby providing minimum mismatch, is milled in the center of the top of broader dimension of the waveguide. Such section is known as slotted waveguide section. The slot is generally so many wave length long to allow many minimum of standing wave pattern to be covered. The slot location is such that its presence does not influence the field configurations to any great degree. A probe is inserted through the slot senses the relative field strength of the standing wave pattern inside the waveguide. The probe is placed on a carriage plate which can be moved along the waveguide. The probe is connected to a crystal detector and the output is connected to indicating meter. For detector tuning a tuning plunger is provided instead of a Stub.

Crystal Detector:

The simplest and the most sensitive detecting element is a microwave crystal Diode. It is a nonlinear, nonreciprocal device that rectifies the received signal and produces, a current proportional to the power input. Since the current flowing through the crystal is proportional to the square law detection property of a crystal is valid at a low power levels (<10 mw). However, at high and medium power level (>10mw), the crystal gradually becomes a linear detector. Detector Mount is used for detection in which Crystal Detector is shunted in waveguide.

VSWR Meter:

Direct- reading VSWR meter is a low-noise voltage tuned amplifier calibrated in dB and VSWR for use with square law detectors. A typical SWR meter has a standard tuned frequency of 1 KHz at which the microwave signal is modulated. Clearly the source of power to be used while using SWR meter must be giving us a 1 KHz square wave modulated output. The band width facilitates single frequency measurements by reducing noise while the widest setting accommodates a sweep rate fast enough for oscilloscope presentation. The scale of VSWR meter is calibrated in VSWR and VSWR in db. It has two normal and one Expanded scale. In first normal scale VSWR from 1-3 can be measured and in the second normal scale, VSWR from 3 to 10 can be measured. To measure low VSWR (less than 1.3) Expanded scale is used. The dB scale is present along with the Expanded dB scale. Using the knob on the front panel choose the normal scale or Expanded scale. Using the knobs on the front panel can change the gain in the VSWR meter. Two knobs are present for changing gain from 0 to 10 db. Gain can also be changed by 0 to 10 dB in steps of 10 dB using another knob. While measuring VSWR, the gain should be either 50 or 60 db. for accurate measurement of VSWR. Both crystal and bolometer may be used in conjunction with the SWR meter. There is provision for high (2,500 – 10,000 ohm) and low (50-200 ohm) impedance crystal inputs. Input selector Switch is used to select the crystal or bolometer. This instrument is the basic piece of equipment in microwave measuring techniques and is used in measuring voltage peaks, valleys, attenuation, gain, and other parameters determined by the ratio of two signals.

Waveguides:

	A waveguide is a hollow metallic tube of a rectangular or circular cross-section used to guide an electromagnetic wave. Waveguides are used principally at microwave frequencies. In laboratories x band (8 to 12 GHz) range of frequencies are used. Therefore, standard X-band rectangular waveguides are used having an inner width, 0.4 in and an inner length, 0.9 in. In waveguides, the electric & magnetic fields are confined to the space within the guides. Thus, no power is lost through radiation, and even the dielectric loss is negligible, since the guides are normally air filled. However, there is some power loss as heat in the walls of the guides. It is possible to propagate several modes of Electromagnetic waves within a waveguide. A given wave-guide has a definite cutoff frequency for each allowed mode and behaves as a high pass filter. The dominant mode in rectangular waveguides is TE10 mode.
Post Experiment Quiz	1. Mention the frequency band for a millimeter wave. 2. List some of IEEE microwave frequency bands. 3. List some of characteristic feature of microwave. 4. List some of the application of microwave technology.

Experiment No:9	**Study the modes of Reflex Klystron.**
Aim	To study the relationship between repeller voltage and output power of Reflex Klystron.
Components Required	Klystron tube**,** Klystron power supply, Klystron Mount, Circulator, Variable Attenuator, Frequency meter, Slotted section, Matched load, CRO, Cables, and accessories.
Theory	Reflex Klystron is one of the most commonly used microwave (low power) generators. It converts D.C. power into microwave power. It uses velocity modulation to transform a continuous electron beam into microwave power. The electron beam emitted is accelerated towards the anode cavity. After passing the gap in the cavity, electrons travel towards the repeller electrode which is at a high negative potential (V_r). Thus electrons never reach the repeller because of the negative field and return back towards the gap. While returning due to the change in velocities, bunching of electrons occurs. As the electron bunches pass through the resonator, they interact with voltage at resonator grids. If the bunches pass the grid at such time that the electrons are slowed down by the voltage, energy will be delivered to the resonator and the klystron will oscillate. In general, oscillation will occur for the following conditions: $t_o = [n + \frac{3}{4}] T = NT \qquad n = 0, 1, 2, 3, ...$ where T is the time period at the resonant frequency, 'to' is the time taken by the reference electron(A) to travel the space between the resonating cavity and the repeller electrode, and return to the cavity at positive peak voltage on forming the bunch. Thus by adjusting the repeller voltage for given dimensions of the reflex klystron, the bunching can be made to occur at N= ¾, 1 ¾, 2 ¾, etc. for modes n = 0, 1, 2, 3, …, respectively.

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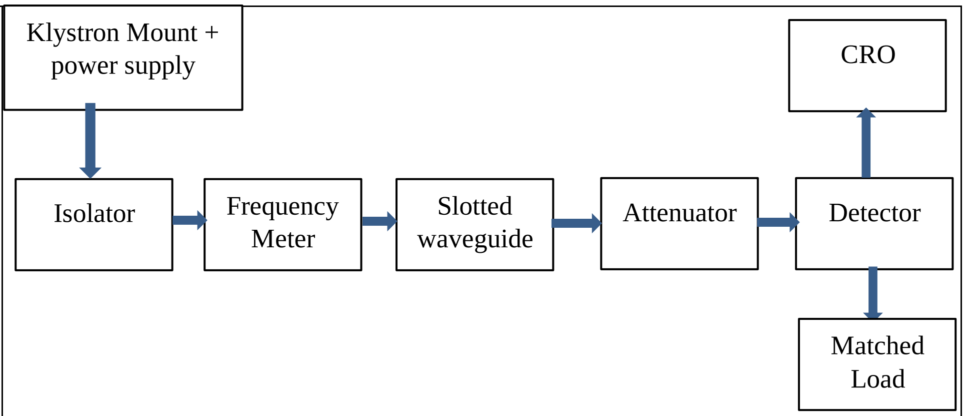

Figure 1. Microwave Bench setup for modes of Reflex Klystron
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<u>Procedure:</u>

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CAUTION: The RF power levels in the Experiments are not harmful, but an human eye may be damaged by low level of radiation. Do not look into the waveguide at any time when the equipment are on.

1. Arrange the bench setup as shown in figure. CRO probe is connected to the detector output.

2. Keep the control knobs of Klystron Power Supply as given:

Meter Switch - 'OFF'
Mod Switch - CW
Beam voltage knob - Fully anti-clockwise (i.e. minimum)
Reflector voltage - Fully clockwise (i.e., maximum)
Switch on the microwave source, cooling fan and CRO.

3. Now keep the beam voltage = 250V. Thus the Klystron source is set-up.

4. Slowly reduce the reflector voltage and read the output current for each reflector
voltage. Take the reflector voltage and output current values for at least 3 modes.

5. Plot the mode characteristics on a graph paper giving reflector voltage versus power.

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Observations:

Sr.	REPELLER VOLTAGE	OUTPUT CURRENT (uA)	Sr.	REPELLER VOLTAGE	OUTPUT CURRENT (uA)
No.	**(volts)**		**No.**	**(volts)**	
1	10	0	21	105	405
2	20	0	22	110	380
3	25	50	23	115	272
4	20	80	24	120	180
5	25	90	25	125	100
6	30	100	26	130	80
7	35	70	27	135	0
8	40	50	28	140	0
9	45	0	29	145	0
11	55	120	31	155	404
13	65	170	33	165	468
14	70	65	34	170	443
15	75	0	35	175	350
16	80	0	36	180	235
17	85	0	37	185	165
18	90	60	38	190	90
19	95	136	39	195	16
20	100	330	40	200	0

Conclusion:

Post Experiment Quiz:

1. What is velocity modulation?
2. Which mode number is most frequently used? Why?
3. What is transit time?

Experiment No 10: **Simulate a Rectangular waveguide in COMSOL Multiphysics® software**

Aim: To design and simulate a rectangular waveguide operating in an X band of frequency.

Problem Statement: Observe the traveling field pattern of the dominant mode inside an X-band waveguide. X band waveguides operate between frequency range 8 to 12 GHz. Their inner width is 2.286 cm and their inner height is 1.016 cm. Assume the waveguide walls are 8 mm thick.

Procedure:

1. Open COMSOL Multiphysics software. From the **File** menu, choose **New**. In the **New** window, click **Model Wizard**.

2. MODEL WIZARD

1. In the **Model Wizard** window, click **3D**.
2. In the **Select physics** tree, select **Radio Frequency > Electromagnetic Waves, Frequency Domain (emw)**.
3. Click **Add**. Click **Study**.
4. In the **Select study** tree, select **Preset Studies>Frequency Domain**
5. Click **Done**.

3. GLOBAL DEFINITION

1. On the **Home** toolbar, click **Parameters**.
2. In the **Settings** window for Parameters, locate the **Parameters** section.
3. In the table, enter the following settings:

Name	Expression	Value	Description
i_w	2.286[cm]	0.02286 m	Inner_width
i_h	1.016[cm]	0.01016 m	Inner_height
T	8[mm]	0.008 m	Thickness
F	8.3[GHZ]	8.3E9 Hz	Frequency

4. GEOMETRY

1. In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry**
2. In the **Settings** window for Geometry, locate the **Units** section.
3. From the **Length unit** list, choose **cm.**

Block 1(blk1)

1. On the **Geometry** toolbar, click **Block**.
2. Locate the **Size and Shape** section. In the **Width** text field, type i_w.
3. In the **Depth** text field, type 8[cm].
4. In the **Height** text field, type i_h
5. Locate the **Position** section. From the **Base** list, choose **Center**.

Block 2(blk2)

1. On the **Geometry** toolbar, click **Block**.
2. Locate the **Size and Shape** section. In the **Width** text field, type **i_w+t**
3. **In** the **Depth** text field, type **8[cm].**
4. In the **Height** text field, type **i_h+t**
5. Locate the **Position** section. From the **Base** list, choose **Center**.
6. Click the **Build All Objects** button.

4. ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EMW)

In the **Model Builder** window, under **Component 1 (comp1)** click **Electromagnetic Waves, Frequency Domain (emw)**.

Port 1

1. On the **Physics** toolbar, click **Boundaries** and choose **Port**.
2. Select Boundary 7 only.
3. In the **Settings** window for Port, locate the **Port Properties** section.
4. In **Type of port** select **Rectangular.**
5. From the **Wave excitation at this port** list, choose **On**.

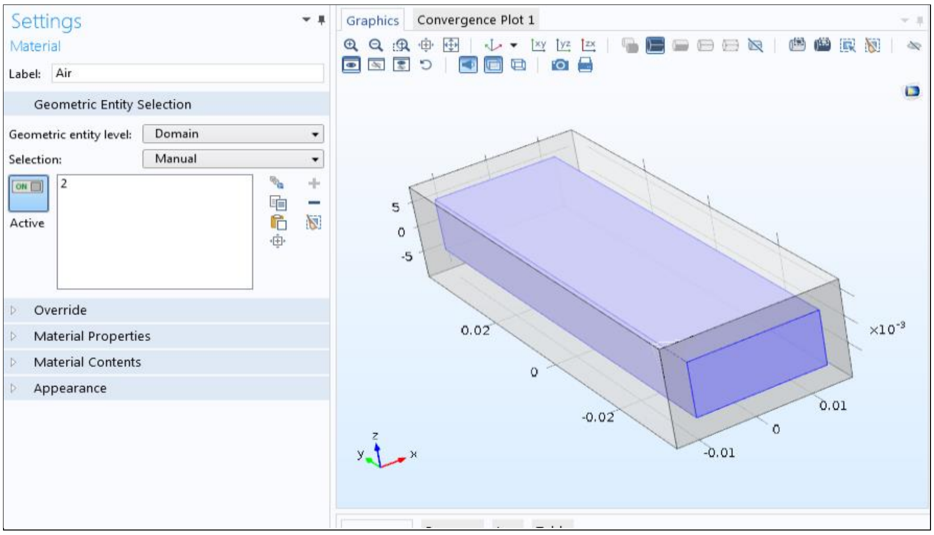
Port 2

1. On the **Physics** toolbar, click **Boundaries** and choose **Port**.
2. Select Boundary 10 only.
3. In the **Settings** window for Port, locate the **Port Properties** section.
4. In **Type of port** select **Rectangular.**

5. MATERIALS: Assign material properties to the model. First, apply air to all domains.

Add Material

1. On the **Home** toolbar, click **Add Material** to open the **Add Material** window.
2. Go to the **Add Material** window.
3. In the tree, select **Built-In>Air**.
4. Click **Add to Component** in the window toolbar.
5. Select **domain** in **geometric Entity Level.**
6. Select **domain 2. (as shown in fig.)**

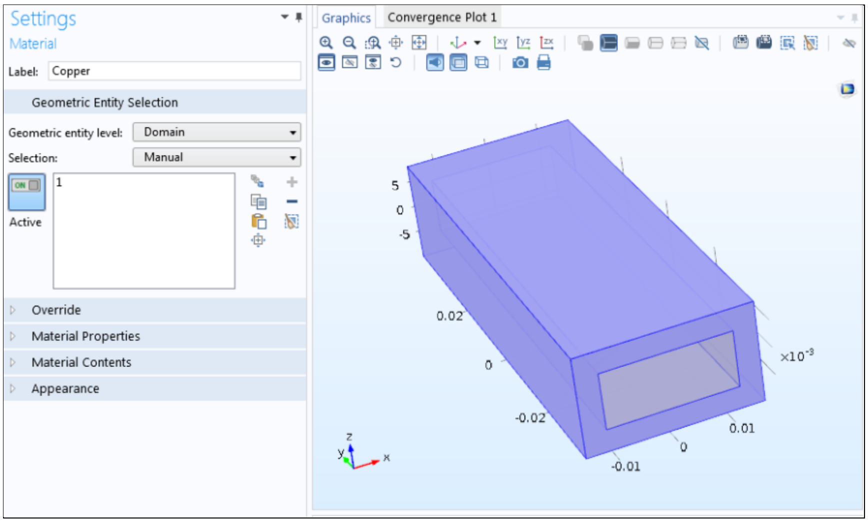


Settings
Material
Label: Air
Geometric Entity Selection
Geometric entity level: Domain
Selection: Manual
2
Active

Material : On the **Home** toolbar, click **Add Material** to close the **Add Material** window.

Material 2 (mat2)

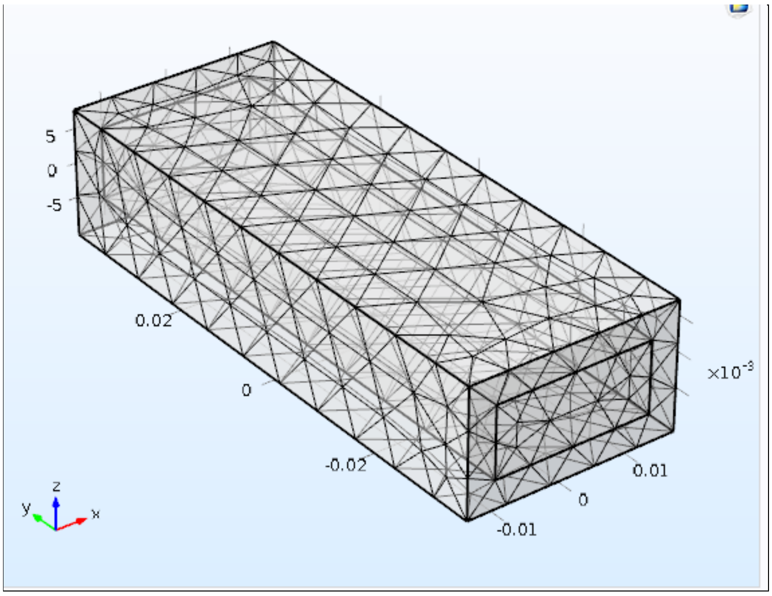
1. On the **Home** toolbar, click **Add Material** to open the **Add Material** window.
2. Go to the **Add Material** window.
3. In the tree, select **Built-In>copper**
4. Click **Add to Component** in the window toolbar.
5. Select **domain** in **geometric Entity Level.**
6. Select **domain 1 (as shown in fig.)**



Settings
Material
Label: Copper
Geometric Entity Selection
Geometric entity level: Domain
Selection: Manual
1
Active

6. MESH

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Build All**.



7. STUDY

Frequency Domain

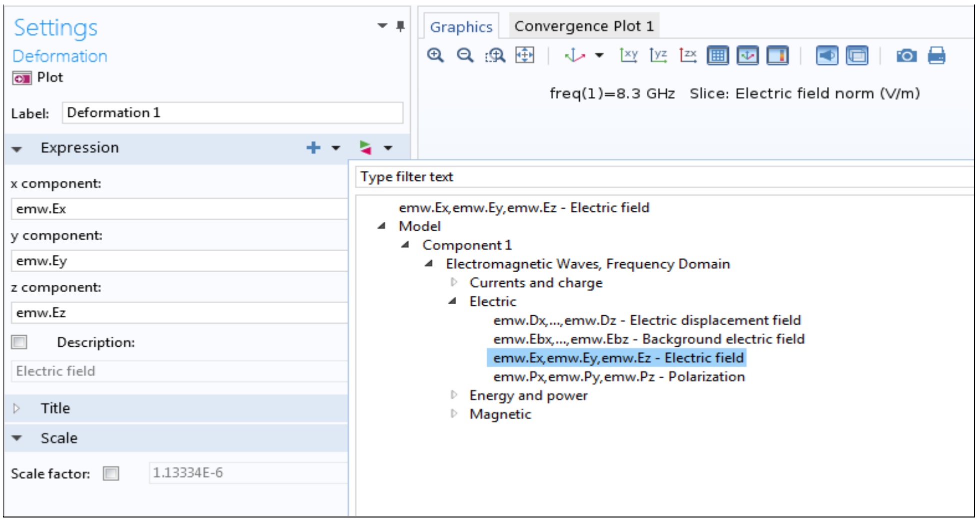
1. In the **Model Builder** window, under **Study 1** click **Step 1: Frequency Domain**.
2. In the **Settings** window for Frequency Domain, locate the **Study Settings** section.

3. In the **Frequencies** text field, type **f.**
4. On the **Home** toolbar, click **Compute**.

8. RESULTS

Electric Field (emw)

2. In the **Model Builder** window, expand the **Electric Field** node, then click **Multislice 1**.
1. In the **Settings** window **Disable** Multislice.
2. Right click Electric Field (emw), click on Slice.
3. In Slice **setting** window under Plane **Data**, select xy plane and number of planes 1.
4. Right click on **Slice, select Deformation.**
5. In Deformation **Setting** window, click on **Replace Expression.**
6. Under **Electromagnetic Waves, Frequency Domain > Electric > emw.Ex,emw.Ey, emw.Ez-Electric Field.**
7. Click on **plot.**



freq(1)=8.3 GHz Slice: Electric field norm (V/m)

Label: Deformation 1

x component: emw.Ex

y component: emw.Ey

z component: emw.Ez

☐ Description: Electric field

Scale factor: ☐ 1.13334E-6

Observation: Plot the electric and magnetic field patterns for TM_{11} mode and also check for TM_{10} mode and check if the mode exists.

Conclusion:

Post Experiment Quiz:

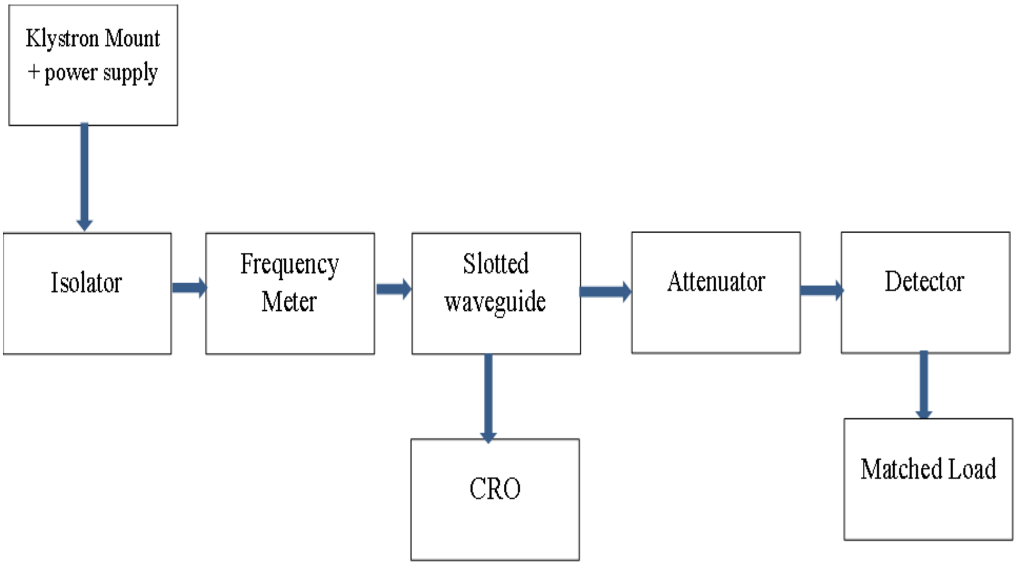
1. Explain dominant, propagating, and evanescent modes in rectangular waveguides.

Experiment No: 11	**Determine the frequency of operation & guided wavelength for the given rectangular waveguide.**
Aim:	To determine the frequency and guided wavelength in a rectangular waveguide working in dominant mode using frequency meter and slotted waveguide.
Components Required:	Klystron tube, Klystron power supply, Klystron Mount, Circulator, Variable Attenuator, Frequency meter, Slotted section, Matched load, CRO, Cables, and accessories.
Theory:	In general, a waveguide consists of a hollow metallic tube of a rectangular or circular shape used to guide an electromagnetic wave. Waveguides are used principally at frequencies in the microwave range. At frequency range X band from 8 to 12 GHz, for example, the U.S. standard rectangular waveguide WR-90 has an inner width of 2.286 cm (0.9 in.) and an inner height of 1.016 cm (0.4 in.); but its outside dimensions are 2.54 cm (1 in.) wide and 1.27 cm (0.5 in.) high. It is possible to propagate several modes of electromagnetic waves within a waveguide. These modes correspond to solutions of Maxwell's equations for particular waveguides. A given waveguide has a definite cutoff frequency for each allowed mode. If the frequency of the impressed signal is above the cutoff frequency for a given mode, the electromagnetic energy can be transmitted through the guide for that particular mode without attenuation. Otherwise, the electromagnetic energy with a frequency below the cutoff frequency for that particular mode will be attenuated to a negligible value in a relatively short distance. The dominant mode in a particular guide is the mode having the lowest cutoff frequency. For a rectangular waveguide, the dominant mode is TE_{10} mode. In order to excite a TE_{10} mode in one direction of the guide, the exciting probe is placed at the center of the waveguide. The operating wavelength is a function of the guided wavelength and the lower cutoff wavelength. Guided wavelength is always longer than the wavelength would be in free space. $1 / \lambda o^2 = (1 / \lambda g^2) + (1 / \lambda c^2)$ ---------- (1) where $\lambda = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}}$

λo = Free space wavelength
m, n = Mode number
λ g = Guided wavelength
λ c = Cut off wavelength
a = Broad dimension of waveguide
b = Narrow dimension of waveguide
Thus, for dominant TE$_{10}$ mode λ c = 2a.

Procedure:

CAUTION: The RF power levels in the experiments are not harmful, but a human eye may be damaged by low levels of radiation. Do not look into the waveguide at any time when the equipments are on.



1. Keep the control knobs of Klystron Power Supply as below:

Meter Switch - ‘OFF’
Mod Switch - AM
Beam voltage knob - Fully anti-clockwise (i.e minimum)
Reflector voltage - Fully clockwise (i.e maximum)
Switch on the microwave source, cooling fan, and CRO.

2. Now slowly reduce the reflector voltage and increase the beam voltage until you get a perfect square wave. Thus, the Klystron source is set up.

3. Tune the frequency meter knob to get the ‘dip’ on the CRO scale and note down the resonating length directly. From the chart find the corresponding operating frequency. After taking the reading de-tune the frequency meter.

4. Attach the CRO probe to the slotted waveguide output.

	5. Move the probe along with the slotted line, the output in CRO will vary. Move the probe to a minimum deflection position. Note and record the probe position (d1). (You can take the reading of maximum deflection position too.) 6. Move the probe to the next minimum position and record the probe position (d2) again. 8. Calculate the guided wavelength as twice the distance between successive minimum (or maximum) positions obtained as above. $\lambda g = 2 (d2 – d1)$ where (d2 – d1) is the difference between two successive minimum or maximum. 7. Measure the waveguides inner broad dimension 'a' and find λc. Thus, calculate the frequency of operation. 8. Verify with frequency obtained by frequency meter.
Observations:	(1) Calculate frequency using frequency meter: Frequency meter reading = 20.38cm Frequency from chart (fo) = 8.34GHz (2) Calculate frequency using a slotted waveguide: d1 (first min/max) =11.5cm d2 (second min/max) = 14.42cm $\lambda g = 2 (d2 – d1) = 5.72$cm a (broad dimension of waveguide) = 2.3cm $\lambda c = 2a = 4.6$cm $\lambda o = 3.5846$ (from 1) $fo = C/\lambda o = 8.3691$GHz
Conclusion:	
Post Experiment Quiz	1. What type of frequency meter used in microwave test bench? 2. Explain the principle of frequency meter?

Experiment No: 12	**Measurement of Voltage Standing Wave Ratio (V.S.W.R.) and Reflection Coefficient.**
Aim:	To determine the Voltage Standing Wave Ratio (V.S.W.R.) and Reflection Coefficient using frequency meter and slotted waveguide.
Components Required:	Klystron tube, Klystron power supply, Klystron Mount, Circulator, Variable Attenuator, Frequency meter, Slotted section, Matched load, CRO, Cables, and accessories.
Theory:	When a continuous wave reaches the end of transmission line and portion of it is reflected back down the line, the resulting combination of the incident wave and the reflected wave is referred to as the standing wave pattern. Such a pattern is often identified by the voltage standing wave ratio (V.S.W.R.), determine as: V.S.W.R = $\sqrt{\frac{V\ Max}{V\ Min}}$ The purpose of this experiment is to examine some of the common methods of measuring Voltage Standing Wave Ratio. The instruments most commonly used to measure the V.S.W.R. is a slotted section of a transmission line. The use of this device can perhaps be most readily understood by considering an example. Suppose that the transmission line is terminated in a load that causes the voltage along the line to be distributed. If the slotted section of the line inserted in existing transmission line without changing the standing wave pattern, the voltage at any point along the section can be sampled by inserting probe into slot. For example, if the slot extends from a to b , the values max and min can be sampled and X and Y respectively. In the slotted section, there is a carriage which moves along the slot in the line. The detector converts alternating of voltage into a D.C. current which can be measured by the microammeter. Reflection co-efficient This is a complex number (written as "I" and pronounced as "gamma") which indicates the degree of reflection of the energy due to a mismatch. Numerically, it is the ratio of the voltage value of he reflected wave to the voltage value of the incident wave at the same point. Thus, if VI is the voltage of the incident wave and V_2 of the reflected wave, then the reflection coefficient is given by: S $= \frac{V1+V2}{V1-V2}$ Or

$$|\Gamma| \quad = \frac{S-1}{S+1}$$

Where $|\Gamma|$ is the amplitude of Γ

Procedure:

1. Get the depth of S.S tuner slightly more for maximum VSWR.
2. Move the probe along with slotted line until minimum is indicated.
3. Adjust the VSWR meter gain control knob and variable attenuator to obtain a reading of 3 dB in the normal dB scale (0 to 10 dB) of VSWR meter.
4. Move the probe to the left on slotted line until full scale deflection is obtained on 0- 10 dB scale. Note and record the probe position on slotted line let it be d1.
5. Repeat the step-3 and move the probe right along the slotted line until full scale deflection is obtained on 0 – 10 dB normal dB scale. Let it be d2.
6. Repeat the S.S tuner and termination by movable short.
7. Measure the distance between two successive minima positions of the probe, twice the distance is guide wavelength λg. 8. Compute SWR from the following equation

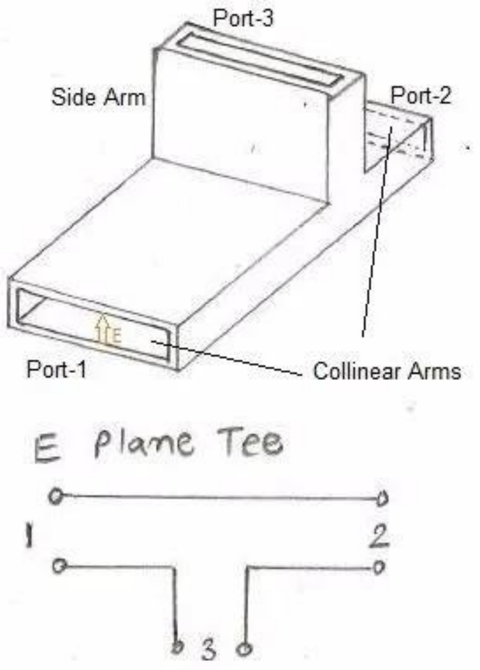
Observation:

Sr. No	$\mathbf{V_{max}}$	$\mathbf{V_{min}}$
1		

Conclusion:

Post Experiment Quiz:

1. What is min. value of VSWR?
2. What is range of reflection coefficient?
3. When do standing waves form?

Experiment No: 13	**Verify the characteristics of E-Plane Tee.**
Aim:	To Measure the power division in the E-Plane Tee.
Components Required:	Klystron tube, Klystron power supply, Klystron Mount, Circulator, Variable Attenuator, Frequency meter, Slotted section, Matched load, CRO, Cables, E-Plane Tee, VSWR meter and accessories.
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 port. Port1 and Port2, while the new one, Port3 is called as Side arm or E-arm. This 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.  $\begin{bmatrix} 0 & S12 & S13 \\ S21 & 0 & S23 \\ S31 & S32 & 0 \end{bmatrix}$ —— (1) $\begin{bmatrix} S11 & S12 & S13 \\ S12 & S11 & -S13 \\ S13 & -S13 & S33 \end{bmatrix}$ —— (2) In an E-Plane Tee, the axis of the side arm is parallel to the Electric Field (E) of the collinear arms which is a critical property of this device. If we carefully observe, the E-plane Tee is a 3-port device. In general, the input is given at port 3 and then

	the signal is obtained from port 1 and port 2. Properties of E-Plane Tee 1. In an E-Plane matrix, the output at ports 1 and 2 when input is fed at port 3 is out of phase by 180^0 therefore, we can say that $S_{23}= -S_{13}$ 2. Since port 3 is perfectly matched to the junction, we can say by the properties of the matched junction that $S_{33}=0$ 3. From the symmetric property Sij=Sji , so $S_{21}=S_{12}$ $S_{23}=S_{32}$ $S_{13}=S_{31}$
Procedure:	1. Connect the components and equipment as shown in figure, 2. Keep the control knob of klystron power supply as below: Modulation selection : AM Beam voltage knob : Fully anti-clockwise Reflector voltage knob : Fully clockwise Selector switch : Beam voltage 3. Keep the AM modulation control knob of amplitude &frequency at mid Position. 4. Switch on the klystron power supply. 5. Now vary the Beam voltage knob to 300V. Next change the selector knob to Beam Current. Observe the BEAM CURRENT 6. Now change the selector switch to Repeller voltage position. 7. Now decrease the Repeller voltage to minimum position. 8. Now observe the square wave form in CRO by varying either reflector voltage or adjusting the amplitude knob of AM. 9. Connect the slotted section output to detector mount, now measure the power on VSWR meter. 10. Now remove the detector mount from slotted section connect the E Plane Tee Port1 to slotted section. Terminate the Port 3, with matched termination 11. Now measure the power or voltage at Port 2 (P2) using VSWR meter. 12. Then remove the detector mount from Port 2, and connect to port 3, terminate the Port 2, with matched termination. Now measure the power at Port 3(P3) using on VSWR meter.

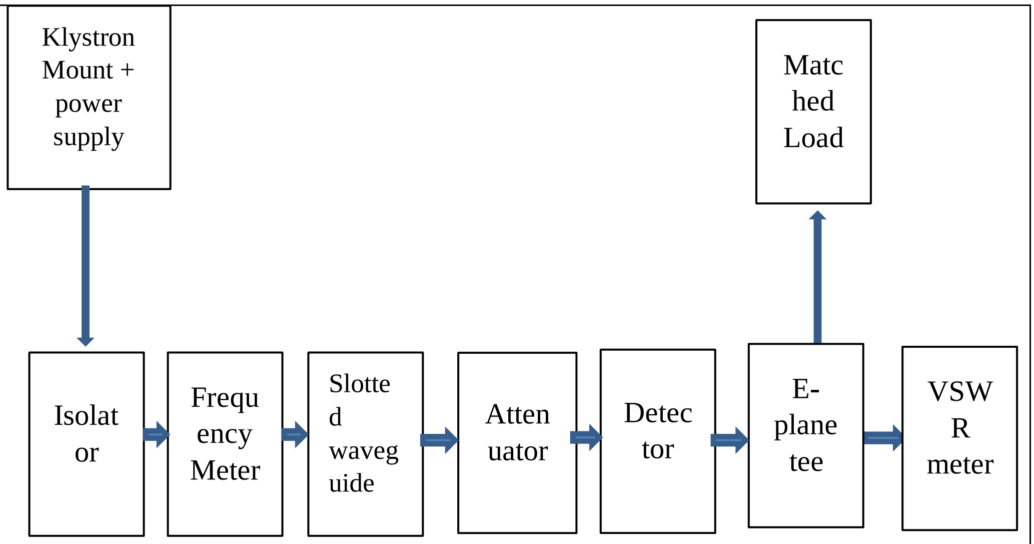


Figure 1. Microwave bench set for E-plane tee Power Measurement

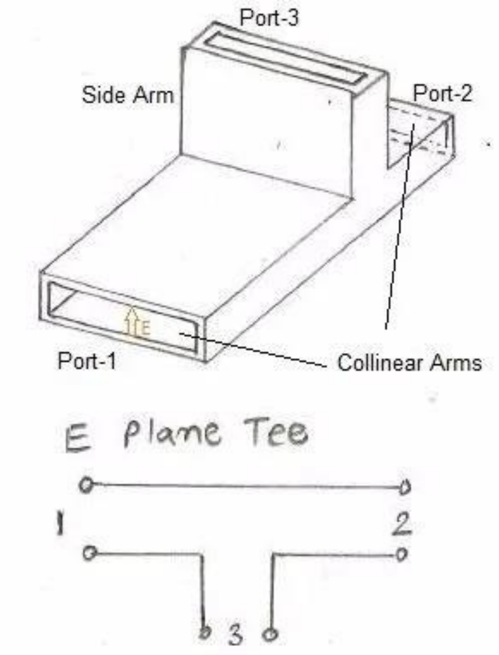
Observation Table

I/p power = 20db

Sr No.	i/p port	O/P port	Matched Termination	Power O/P P_{ij}
1	1	2	3	10
2	1	3	2	10
3	2	1	3	21.8
4	2	3	1	21.6
5	3	2	1	22.3
6	3	1	2	22.2

Post Experiment quiz:

1. What are the advantages of using an E-plane tee in microwave circuits?
2. How does an E-plane tee function as a power divider or combiner?
3. What factors influence the design of an E-plane tee?

Experiment No: 14	**Verify the characteristics of H-Plane Tee.**
Aim:	To Measure the power division in the H-Plane Tee.
Components Required:	Klystron tube**,** Klystron power supply, Klystron Mount, Circulator, Variable Attenuator, Frequency meter, Slotted section, Matched load, CRO, Cables, H-Plane Tee, VSWR meter and accessories.
Theory:	An H-plane Tee also known as a waveguide Tee is a device that connects a simple waveguide to a rectangular waveguide. Note that this waveguide already has two ports. The figure given below represents a basic H-plane Tee.  $\begin{bmatrix} 0 & S12 & S13 \\ S21 & 0 & S23 \\ S31 & S32 & 0 \end{bmatrix} \text{—— (1)}$ $\begin{bmatrix} S11 & S12 & S13 \\ S12 & S11 & -S13 \\ S13 & -S13 & S33 \end{bmatrix} \text{—— (2)}$ Figure 1. Microwave bench set for E-plane tee Power Measurement In an H-plane Tee, the axis of the side arm is parallel to the Magnetic Field (H) of the collinear arms which is a critical property of this device. From the diagram, we can say that the H-plane Tee is a 3-port device, the two ports are of the rectangular waveguide and the third port is due to the side arm.

	Properties of H-Plane Tee 1. H-Plane matrix, the output at ports 1 and 2 when input is fed at port 3 is same due to symmetry therefore, $S_{13}=S_{23}$ 2. Since port 3 is perfectly matched to the junction, we can say by the properties of the matched junction that $S_{33}=0$ 3. From the symmetric property Sij=Sji , so $S_{21}=S_{12}$ $S_{23}=S_{32}$ $S_{13}=S_{31}$
Procedure:	1. Connect the components and equipment as shown in figure, 2. Keep the control knob of klystron power supply as below: Modulation selection : AM Beam voltage knob : Fully anti-clockwise Reflector voltage knob : Fully clockwise Selector switch : Beam voltage 3. Keep the AM modulation control knob of amplitude &frequency at mid Position. 4. Switch on the klystron power supply. 5. Now vary the Beam voltage knob to 300V. Next change the selector knob to Beam Current. Observe the BEAM CURRENT 6. Now change the selector switch to Repeller voltage position. 7. Now decrease the Repeller voltage to minimum position. 8. Now observe the square wave form in CRO by varying either reflector voltage or adjusting the amplitude knob of AM. 9. Connect the slotted section output to detector mount, now measure the power on VSWR meter. 10. Now remove the detector mount from slotted section connect the E Plane Tee Port1 to slotted section. Terminate the Port 3, with matched termination 11. Now measure the power or voltage at Port 2 (P2) using VSWR meter. 12. Then remove the detector mount from Port 2, and connect to port 3, terminate the Port 2, with matched termination. Now measure the power at Port 3(P3) using on VSWR meter.

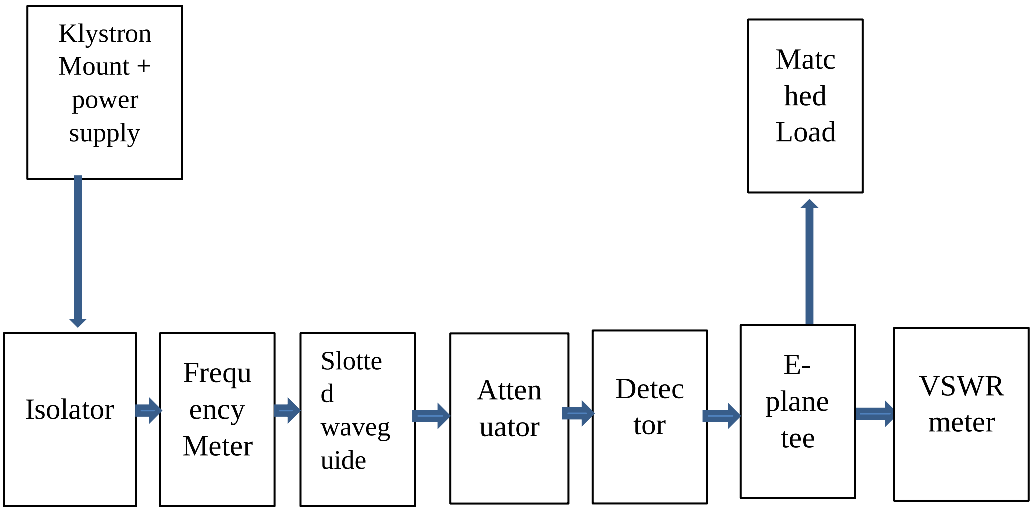


Figure 1. Microwave bench set for E-plane tee Power Measurement

Observation Table

P1 dB	P2 dB	P3 dB

Post Experiment quiz:

13. What are the advantages of using an H-plane tee in microwave circuits?
14. How does an H-plane tee function as a power divider or combiner?
15. What factors influence the design of an H-plane tee?