EXP NO: 7 STUDY OF FIELD PATTERNS OF VARIOUS MODES INSIDE A RECTANGULAR WAVEGUIDE

7.1.1 OBJECTIVE

Study of field patterns of various modes inside a rectangular waveguide.

7.1.2 REQUIREMENT:

You have to install a LabVIEW Run time Engine on your computer to run the exe file in order to perform the experiment. The Run Time Engine can be downloaded from the following link: http://joule.ni.com/nidu/cds/view/p/id/1101/lang/en

7.1.3 INTRODUCTION:

This experiment provides the field patterns of various modes inside a rectangular waveguide. This gives the basic idea of the change in the field pattern; that is, electric and magnetic field patterns with the change in modes inside a rectangular waveguide. 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 waveguide.

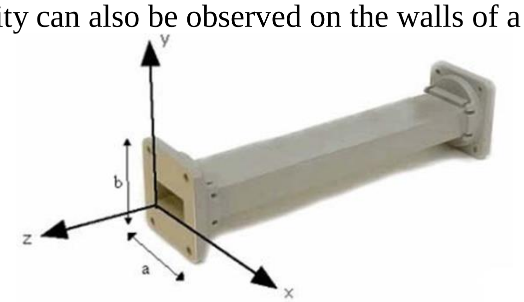


Fig.1 Rectangular Waveguide

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 cable, 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.

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’

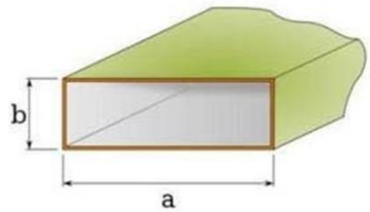


Fig. 2 Waveguide structure with dimension ‘a’ and ‘b’

***Modes*:** Electromagnetic waveguides are 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 eigen functions 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

Waveguide propagation modes depend on the operating wavelength and polarization and the shape and size of the guide. The modes of the waveguide are typically classified into following types:

- 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 component 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.

Field Equations: For TE_{mn} mode, the field equations for a rectangular wave guide are:

$$E_x = \frac{j\omega\mu}{h^2}\left(\frac{n\pi}{b}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$E_y = \frac{-j\omega\mu}{h^2}\left(\frac{m\pi}{a}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$$

$$E_z = 0$$

$$H_x = \frac{j\beta}{h^2}\left(\frac{m\pi}{a}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$$

$$H_y = \frac{j\beta}{h^2}\left(\frac{n\pi}{b}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$H_z = \cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

For TE_{mn} mode, the field equations for a rectangular waveguide are:

$$E_x = \frac{-j\beta}{h^2}\left(\frac{m\pi}{a}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$E_y = \frac{-j\beta}{h^2}\left(\frac{n\pi}{b}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$$

$$E_z = \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$H_x = \frac{j\omega\varepsilon}{h^2}\left(\frac{n\pi}{b}\right)\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)$$

$$H_y = \frac{-j\omega\varepsilon}{h^2}\left(\frac{m\pi}{a}\right)\cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)$$

$$H_z = 0$$

7.1.4 Procedure:

- **Download the run time engine from this link** http://joule.ni.com/nidu/cds/view/p/id/1101/lang/en
- **Click to begin experiment**

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

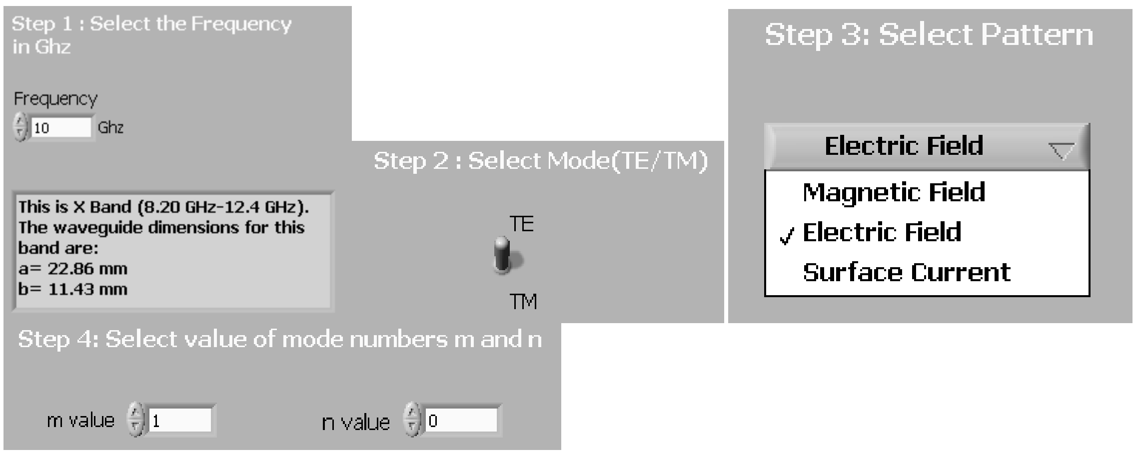
Step 2: Select the type of mode, i.e. either Transverse Electric (TE) or Transverse magnetic (TM). Step 3: Select pattern:

- ❖ Electric Field: Select this to view the electric field pattern of the given mode.

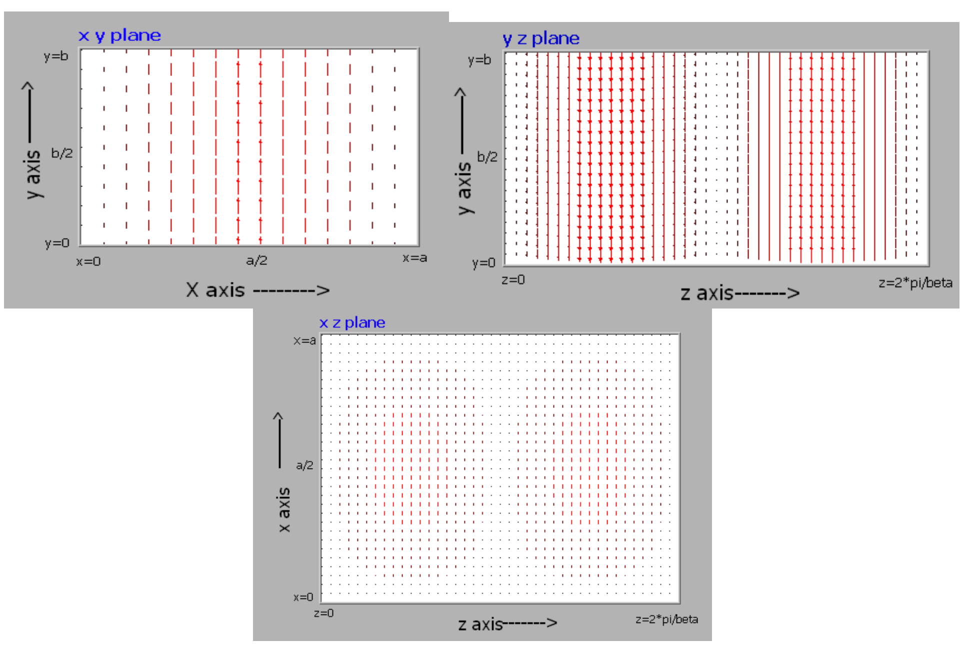
- ❖ Magnetic Field: Select this to view the magnetic field pattern of the given mode.
- ❖ Surface Current: Select this option to view the surface current density for TE10mode.

Step 4: Enter the values of m and n to obtain the field pattern, where m stands for number 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.



Step 5: View Pattern



Observations

1. Plot the electric and magnetic field patterns for TE_{11} mode in X-band inside a rectangular waveguide. Observe and explain the field patterns with proper reasons.
2. Plot the electric and magnetic field patterns for TM_{11} mode and also check for TM_{10} mode and check if the mode exists.

7.1.5 Pre Lab Questions

1. Which mode is dominant in rectangular waveguide (x > y)?
2. A waveguide section in a microwave circuit will act as a ____________ filter.
3. Degenerate modes in a waveguide are characterized by ___________cut off frequencies and field distributions
4. The cut-off frequencies of the dominant mode and the next higher order mode in a designated waveguide are fc_1 and fc_2 respectively. The typical operating frequency range for this waveguide is ________< f < ________
5. What is the cut off wavelength for TE_{20} mode for a standard rectangular waveguide**?**

7.1.6 Post Lab Questions

1. Which of the following modes is not present in a rectangular waveguide (x > y)?
2. With the change in the frequency band, dimensions of the waveguide will __________
3. In a rectangular waveguide, for TM_{m1} mode where $m \neq 0$, the number of contours in magnetic field pattern in xy plane is __________ to the value of m.
4. In a rectangular waveguide, for TE_{20} mode electric field and magnetic field components are perpendicular in _____ planes.
5. If in a rectangular waveguide for which a = 2b, the cut-off frequency for TE_{02} mode is 12 GHz. Calculate the cut-off frequency for TM_{11} mode.

7.1.7 Result

From the experiment, we can observe the field patterns of various modes inside a rectangular Wave guide in xy, yz and zx planes. This also shows the current density variation inTE_{10}mode in all three planes. Here, one can observe the field patterns for various frequency bands. One can correlate the above mentioned field equations with the field patterns of various modes and can develop better understanding of the modes of the rectangular waveguides.

EXP NO: 7.2 ANALYSIS OF FIELD PATTERNS OF VARIOUS MODES INSIDE A RECTANGULAR CAVITY

7.2.1 OBJECTIVE

Study of field patterns of various modes inside a rectangular cavity

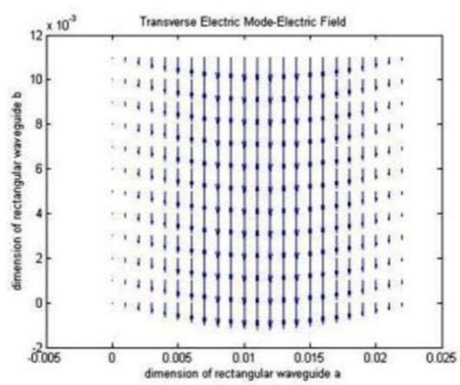
7.2.2 REQUIREMENT:

You have to install a LabVIEW Run time Engine on your computer to run the exe file in order to perform the experiment. The Run Time Engine can be downloaded from the following link: http://joule.ni.com/nidu/cds/view/p/id/1101/lang/en

7.2.3 INTRODUCTION:

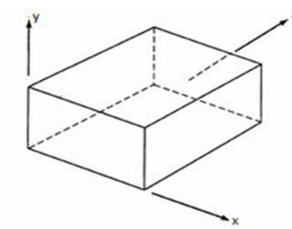
This gives the basic idea of the field pattern; that is, electric and magnetic field patterns for various modes inside a rectangular cavity resonator. One can observe the field patterns of various modes in xy, xz and yz planes for different frequency bands. Surface current density can also be observed on the walls of a rectangular cavity resonator.

Field Pattern for dominant mode (TE_{101}) along xy plane



About the experiment:

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 rectangular cavity, modes are designated as TE_{mnp} or TM_{mnp} , where m, n, p are the number of half 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

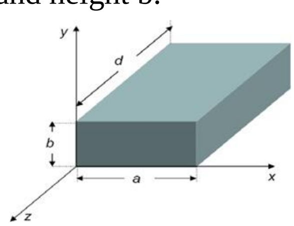


In this experiment, a rectangular cavity of dimension x=a, y =b and z=d has been considered. The dimensions of the cavity depend on the frequency band in which we are observing the field pattern. For example, in X Band (8-12GHz), the U.S. standard waveguide WR-90 has inner width of 2.286 cm ('a'), an inner height of 1.106 cm ('b') and the dimension in z direction, d is usually an odd multiple of the guide wavelength (λ_g).

Electromagnetic waves propagating in open space travel out in all directions. As we know 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. By definition, a resonant cavity is any space completely enclosed by conducting walls that can contain oscillating electromagnetic fields and possess resonant properties. 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 cavity. Resonant cavities have a very high Q and can be built to handle relatively large amounts of power. They are used principally at frequencies in the microwave range and can act as a resonator above a certain frequency, known as the cut-off frequency. This cut-off frequency of the cavity depends upon its dimensions.

<u>Rectangular Cavity</u>

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 b.



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 eigen- functions of the equation system. Each mode is therefore characterized by an eigen-value, 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 following types:
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.

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, n and p) and the dimensions (a, b and d) of the cavity. The electric field and magnetic field pattern are different for various modes in different cavities .The electric field component of an EM wave is characterized by E_x, E_y and E_z components of the wave. Similarly the magnetic field component of an EM wave is characterized by H_x, H_y and H_z components of the wave.
For TE_{mnp} mode, the field equations for a rectangular cavity are:

$$E_x = \left(\frac{j\omega\mu}{h^2}\right)\left(\frac{n\pi}{b}\right)H_0 \cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)\sin(\frac{p\pi}{d}z)$$

$$E_y = -\left(\frac{j\omega\mu}{h^2}\right)\left(\frac{m\pi}{a}\right)H_0 \sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)\sin(\frac{p\pi}{d}z)$$

$$E_z = 0$$

$$H_x = -(\frac{1}{h^2})\left(\frac{m\pi}{a}\right)\left(\frac{p\pi}{d}\right)H_0 \sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)\cos(\frac{p\pi}{d}z)$$

$$H_y = -\left(\frac{1}{h^2}\right)\left(\frac{n\pi}{b}\right)\left(\frac{p\pi}{d}\right)H_0 \cos(\frac{m\pi}{a}x)\sin\left(\frac{n\pi}{b}y\right)\cos(\frac{p\pi}{d}z)$$

$$H_z = H_0 \cos(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)\sin(\frac{p\pi}{d}z)$$

Where m=0,1,2..., n=0,1,2...., p=1,2,3... and m=n≠0 and $h^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$

For TM_{mnp} mode, the field equations for a rectangular cavity are:

$$E_x = -(\frac{1}{h^2})\left(\frac{m\pi}{a}\right)\left(\frac{p\pi}{d}\right)E_0 \cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)\sin(\frac{p\pi}{d}z)$$

$$E_y = -\left(\frac{1}{h^2}\right)\left(\frac{n\pi}{b}\right)\left(\frac{p\pi}{d}\right)E_0 \sin(\frac{m\pi}{a}x)\cos\left(\frac{n\pi}{b}y\right)\sin(\frac{p\pi}{d}z)$$

$$E_z = E_0 \sin(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)\cos(\frac{p\pi}{d}z)$$

$$H_x = \left(\frac{j\omega\epsilon}{h^2}\right)\left(\frac{n\pi}{b}\right)E_0 \sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)\cos(\frac{p\pi}{d}z)$$

$$H_y = -\left(\frac{j\omega\epsilon}{h^2}\right)\left(\frac{m\pi}{a}\right)E_0 \cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)\cos(\frac{p\pi}{d}z)$$

$$H_z = 0$$

Where m=1,2..., n=1,2...., p=0,1,2,3... and $h^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$

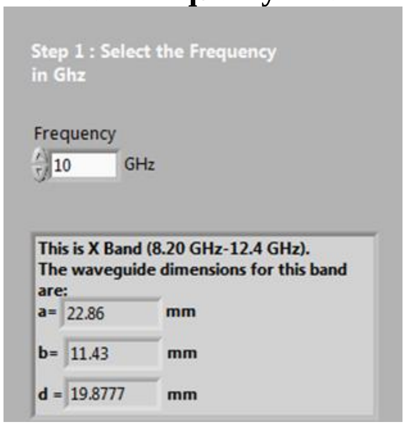
The resonant frequency for TE_{mnp} and TM_{mnp} modes is same and is given by

$$(f_r)_{mnp} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

7.2.4 Procedure

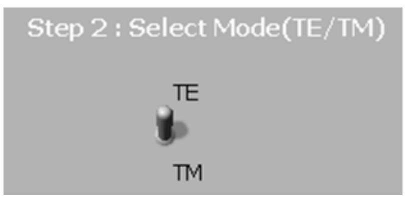
Step 1: Select the frequency band in which you wish to see the field pattern.

Enter the frequency in GHz



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

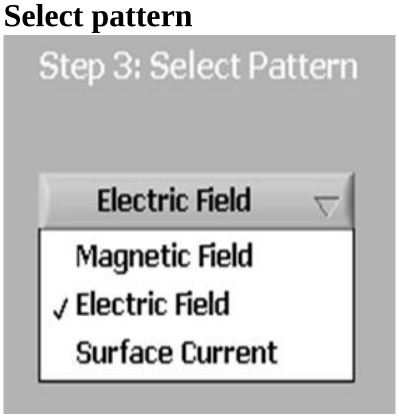
Select Mode (TE/TM)



Step 3: Select Pattern:

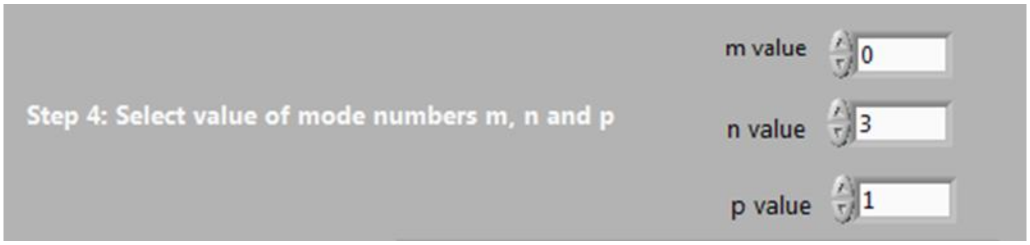
i) Electric Field: Select this to view the electric field pattern of the given mode.
ii) Magnetic Field: Select this to view the magnetic field pattern of the given mode.
iii) Surface Current: Select this option to view the surface current density for TE_{10}mode.

Select pattern



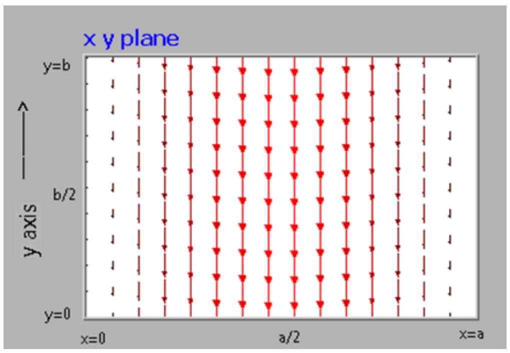
Step 4: Enter the values of m, n and p to obtain the field pattern, where m stands for no. of half waves of electric or magnetic intensity in the X- direction, n stands for number of half waves in

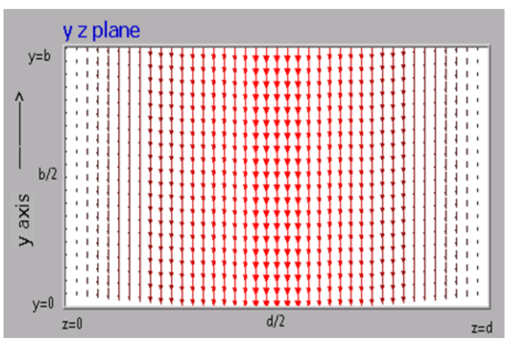
the y direction and p stands for number of half waves in the z direction.

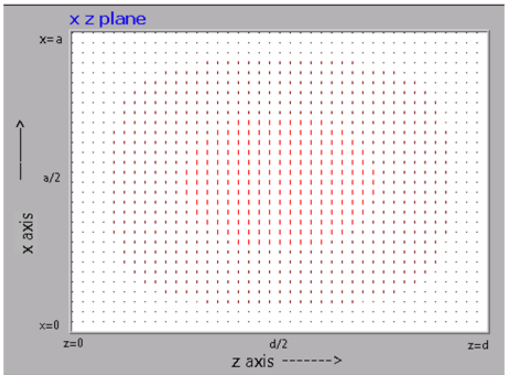


Step 5: Run the VI up to see the desired field pattern in XY, YZ and XZ planes. In case, you wish to see the other field pattern then click stop and repeat steps 1-4 before running the program again.

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:







7.2.5 Prelab Questions

1. Mention the uses of rectangular waveguides
2. What are the various modes of propagation in rectangular waveguides?
3. Express the wave equation that a wave should obey inside a rectangular waveguide.
4. Define dominant mode
5. Write the formula to determine the cutoff frequency.

7.2.6 Post lab Questions

6. Discuss the working of TE mode
7. Explain the wave propagation in TM mode
8. Discuss on attenuation in lossy waveguide
9. What is the principle of waveguide cavities?
10. What do you mean by resonant frequency?

7.2.7 Result:

From the experiment, we can observe the field patterns of various modes inside a rectangular waveguide in xy, yz and zx planes.