Transition Design of Strip line to a Rectangular Wave Guide with Frequency Response Analysis in TE Mode

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Abstract: ***This paper describes about the transition of a stripline to a rectangular wave guide with 3 different modes of propagation in TE mode. The mode selection with different cut off frequency has been mentioned here. Plot of propagation constant (Gamma) vs. frequency for TE10, TE20, TE01, TE and TM11 using HFSS has been simulated using HFSS. It has some unique characteristics that allow for wide range of application including slow and fast light, meta-material, low loss energy transmission, and sensing.***

Keywords: TE mode, Strip line Transition

1. Introduction

Rectangular waveguides are the one of the earliest type of the transmission lines. They are used in many applications. A lot of components such as isolators, detectors, attenuators, couplers and slotted lines are available for various standard waveguide bands between 1 GHz to above 220 GHz. [1,4]

A rectangular waveguide supports TM and TE modes but not TEM waves because we cannot define a unique voltage since there is only one conductor in a rectangular waveguide. The shape of a rectangular waveguide is as shown below. A material with permittivity e and permeability m fills the inside of the conductor.

A rectangular waveguide cannot propagate below some certain frequency. This frequency is called the cut-off frequency. [1] It has some unique characteristics that allow for wide range of application including slow and fast light, meta-material, low loss energy transmission, and sensing.

A. Rectangular waveguide mode :TE mode:

Consider again the rectangular waveguide below with dimensions a and b (assume a>b) and the parameters e and m.

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For TE waves $E_z = 0$ and Hz should be solved from equation for TE mode;

$$\nabla^2_{xy} H_z + h^2 H_z = 0$$

Since $H_z(x,y,z) = H_z^0(x,y)e^{-\gamma z}$, we get the following equation,

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + h^2\right) H_z^0(x,y) = 0$$

If we use the method of separation of variables, that is $H_z^0(x,y) = X(x).Y(y)$ we get,

$$\frac{1}{X(x)}\frac{d^2X(x)}{dx^2} = \frac{1}{Y(y)}\frac{d^2Y(y)}{dy^2} + h^2$$

Since the right side contains x terms only and the left side contains y terms only, they are both equal to a constant. Calling that constant as k_x^2, we get;[2]

$$\frac{d^2X(x)}{dx^2} + k_x^2 X(x) = 0$$

Here, we must solve for X and Y from the preceding equations. Also we have the following boundary conditions:

$$\frac{\partial H_z^0}{\partial x} = 0 (E_y = 0) \quad at\ x=0$$

$$\frac{\partial H_z^0}{\partial x} - 0 (E_y - 0) \quad at\ x=a$$

$$\frac{\partial H_z^0}{\partial y} = 0 (E_x = 0) \quad at\ y=0$$

$$\frac{\partial H_z^0}{\partial y} = 0 (E_x = 0) \quad at\ y=b$$

From all these, we get

$$H_z^0(x,y) = H_0 \cos\left(\frac{m\pi}{a}x\right)\cos\left(\frac{n\pi}{b}y\right) \text{ (A/m)}$$

From $k_y^2 = h^2 - k_x^2$, we have;

$$\boxed{h^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

For TE waves, we have

$$H_x^0 = -\frac{\gamma}{h^2}\frac{\partial H_z^0}{\partial x}$$

$$H_y^0 = -\frac{\gamma}{h^2}\frac{\partial H_z^0}{\partial y}$$

$$E_x^0 = -\frac{jw\mu}{h^2}\frac{\partial H_z^0}{\partial y}$$

From these equations, we obtain

$$E_x^0(x,y) = \frac{jw\mu}{h^2}\left(\frac{n\pi}{b}\right)H_0 \cos\left(\frac{m\pi}{a}x\right)\sin\left(\frac{n\pi}{b}y\right)$$

$$E_y^0(x,y) = -\frac{jw\mu}{h^2}\left(\frac{m\pi}{a}\right)H_0 \sin\left(\frac{m\pi}{a}x\right)\cos\left(\frac{n\pi}{b}y\right)$$

$$H_x^0(x,y) = \frac{\gamma}{h^2}\left(\frac{m\pi}{a}\right)H_0 \sin\left(\frac{m\pi}{a}x\right)\cos\left(\frac{n\pi}{b}y\right)$$

$$H_y^0(x,y) = \frac{\gamma}{h^2}\left(\frac{n\pi}{b}\right)H_0 \cos\left(\frac{m\pi}{a}x\right)\sin\left(\frac{n\pi}{b}y\right)$$

where

$$\gamma = j\beta = j\sqrt{w^2\mu\varepsilon - \left(\frac{m\pi}{a}\right)^2 - \left(\frac{n\pi}{b}\right)^2}$$

As explained before, m and n represent possible modes and it is shown as the TEmn mode. m denotes the number of half cycle variations of the fields in the x-direction and n denotes the number of half cycle variations of the fields in the y-direction. [2,3]

Here, the cut-off wave number is

$$k_c = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

and therefore,

$$\beta = \sqrt{k^2 - k_c^2}$$

2. Cut-Off Frequency Calculation

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. The cut-off frequency is at the point where g vanishes. Therefore,

$$f_c = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}\ (Hz)$$

Since *l=u/f*, we have the cut-off wavelength,

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}\ (m)$$

At a given operating frequency f, only those frequencies, which have f>fc will propagate. The modes with f<fc will not propagate. [5]

The mode with the lowest cut-off frequency is called the *dominant mode*. Since TE_{10} mode is the minimum possible mode that gives nonzero field expressions for rectangular waveguides,[5] it is the dominant mode of a rectangular waveguide with a>b and so the dominant frequency is

$$(f_c)_{10} = \frac{1}{2a\sqrt{\mu\varepsilon}}\ (Hz)$$

The wave impedance is defined as the ratio of the transverse electric and magnetic fields. Therefore, we get from the expressions for E_x and H_y (see the equations above);

$$Z_{TE} = \frac{E_x}{H_y} = \frac{jw\mu}{\gamma} = \frac{jw\mu}{j\beta} \Rightarrow Z_{TE} = \frac{k\eta}{\beta}$$

The guide wavelength is defined as the distance between two equal phase planes along the waveguide and it is equal to

$$\lambda_g = \frac{2\pi}{\beta} > \frac{2\pi}{k} = \lambda$$

This is thus greater than l, the wavelength of a plane wave in the filling medium.

Phase velocity:

The phase velocity is

$$u_p = \frac{w}{\beta} > \frac{w}{k} = \frac{1}{\sqrt{\mu\varepsilon}}$$

This is greater than the speed of the plane wave in the filling material.

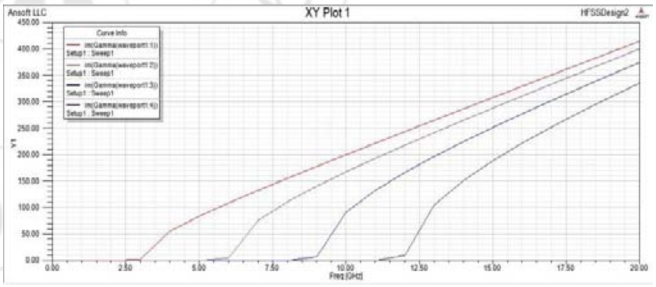

Figure 1: Plot of propagation constant (Gamma) vs. frequency for TE10, TE20, TE01, TE and TM11 using HFSS

Note that the mode propagates only when the propagation constant has is real and the operating frequency is greater than its cut-off frequency. As the traveling waves are functions of exp(-jβ z), has to be real and make exp(-jβ z) imaginary

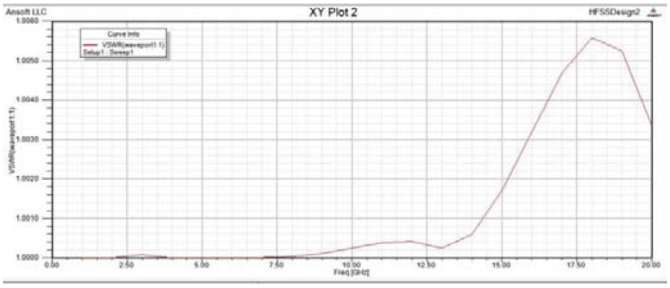

Figure 2: VSWR plot for wave port 1 to 1

3. Field Analysis

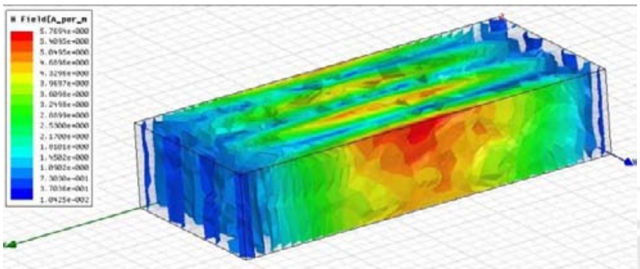

Figure 3: E-field patterns for first four modes

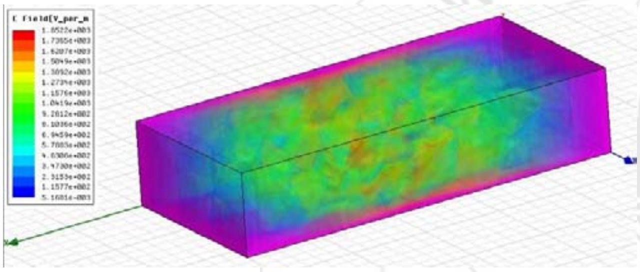

Figure 4: H-field patterns

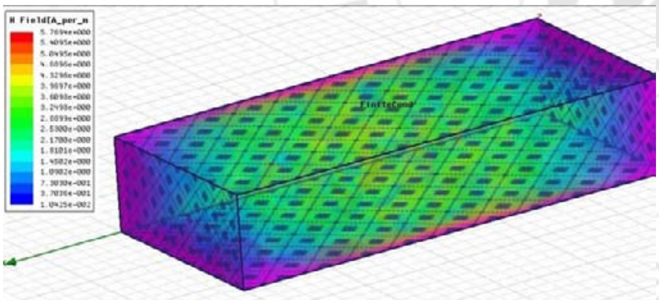

Figure 5: H-Field Patterns for First Four Modes

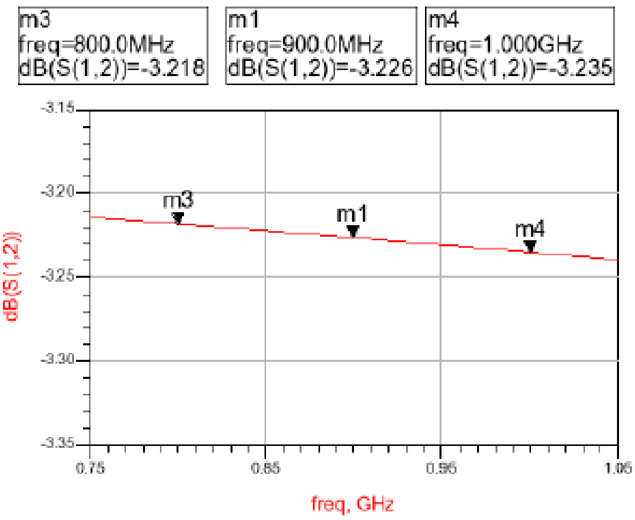

Figure 6: S parameter Characteristics for 3 TE modes

4. Conclusion

- The rectangular waveguide characteristics and field distribution for different modes has been simulated for one end open with a gamma factor .
- The analysis is for different parameters. The electric and magnetic fields strengths has been analysed inside a rectangular waveguide along with fundamental modal distributions.
- Theoretical analysis and simulation are carried out for rectangular waveguide and are shown with different mode conditions.

Reference

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