

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

Abinash Gaya

Assistant Professor, Dept. of ECE, Centurion University, India

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 ϵ and permeability μ 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 ϵ and μ .

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

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

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,

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

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]

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

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

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

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

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

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

From all these, we get

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

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

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

For TE waves, we have

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

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

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

From these equations, we obtain

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

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

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

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

where

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

As explained before, m and n represent possible modes and it is shown as the TE_{mn} 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 γ vanishes. Therefore,

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

Since $l = \omega/f$, we have the cut-off wavelength,

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

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

The mode with the lowest cut-off frequency is called the *dominant mode*. Since TE₁₀ 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

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

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);

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

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 λ , the wavelength of a plane wave in the filling medium.

Phase velocity:

The phase velocity is

$$u_p = \frac{\omega}{\beta} > \frac{\omega}{k} = \frac{1}{\sqrt{\mu\epsilon}}$$

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

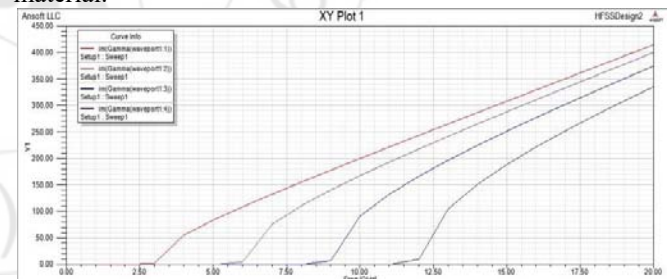


Figure 1: Plot of propagation constant (Gamma) vs. frequency for TE₁₀, TE₂₀, TE₀₁, TE and TM₁₁ using HFSS

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 $\exp(-j\beta z)$, has to be real and make $\exp(-j\beta z)$ imaginary

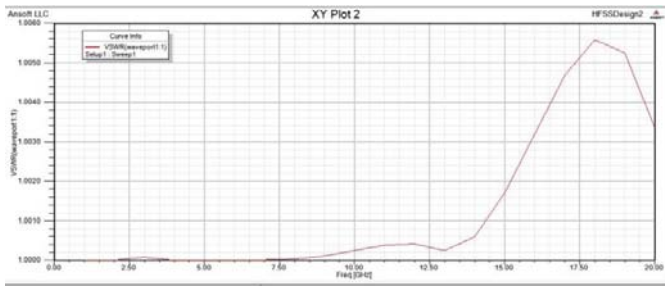


Figure 2: VSWR plot for wave port 1 to 1

3. Field Analysis

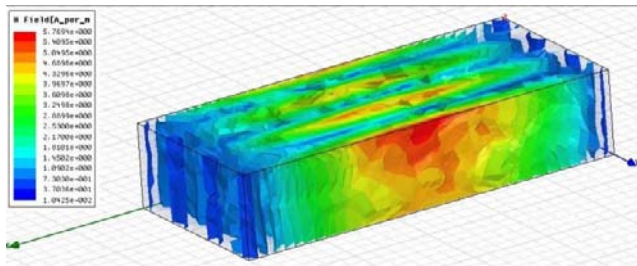


Figure 3: E-field patterns for first four modes

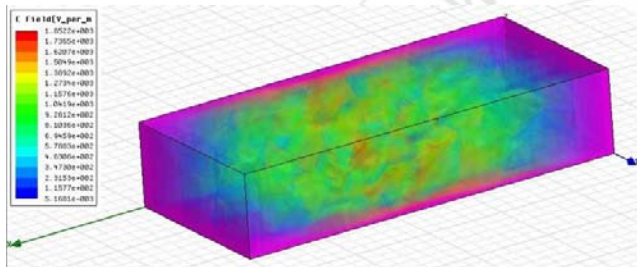


Figure 4: H-field patterns

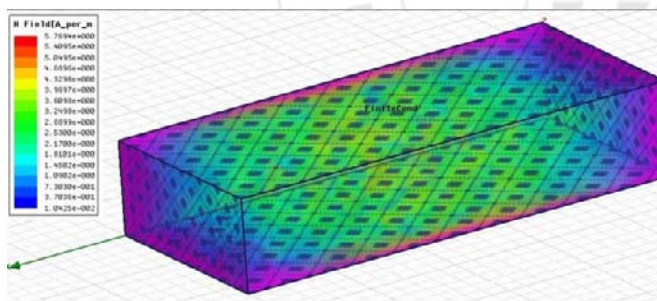


Figure 5: H-Field Patterns for First Four Modes

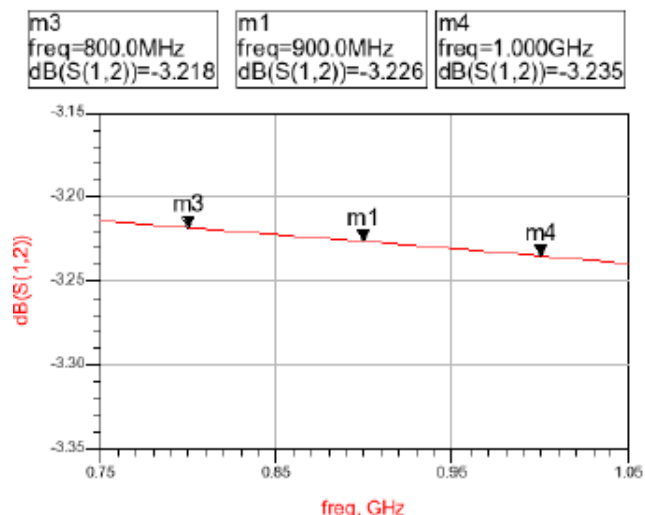


Figure 6: S parameter Characteristics for 3 TE modes

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

- [1] B.Glance; R.Trambarulo “ A Waveguide to Suspended Stripline Transition “ (Letters) , IEEE Transactions on Microwave Theory and Techniques ,Year: 1973, Volume: 21, Issue: 2 Pages: 117-118, DOI: 10.1109/TMTT.1973.1127938
- [2] Hatem Akel “Broadwall-Side Stripline-to-Waveguide Transition”2007 Asia-Pacific Microwave Conference Year: 2007 Pages: 1 - 4, DOI: 10.1109/APMC.2007.4554663
- [3] G. Arun Kumar; D. R. Poddar “Broadband Rectangular Waveguide to Suspended Stripline Transition Using Dendritic Structure “IEEE Microwave and Wireless Components Letters Year: 2016, Volume: 26, Issue: 11,Pages: 900 - 902, DOI: 10.1109/LMWC.2016.2615009
- [4] Jun Dong; Hao Peng; Yu Liu; Haodong Lin; Tao Yang "Broadband suspended stripline to air-filled rectangular waveguide transition “Electronics Letters Year: 2015, Volume: 51, Issue: 23, Pages: 1886 - 1888, DOI: 10.1049/el.2015.2743
- [5] Young-Gon Kim; Sun-Young Song; Kang Wook Kim "A Compact Wideband Ring Coupler Utilizing a Pair of Transitions for Phase Inversion"IEEE Microwave and Wireless Components Letters Year: 2011, Volume: 21, Issue: 1 Pages: 25 - 27, DOI: 10.1109/LMWC.2010.2089438