DESIGNING AND STUDYING THE CHARACTERISTICS OF RECTANGULAR WAVEGUIDE USING HFSS

1M. LAKSHMI RAVI TEJA, 2G.N.S BHAGYA SRI, 3V. DAMODHAR RAO

1,2Electronics and Communication Engineering, Institute of Aeronautical Engineering, Hyderabad, India
E-mail: 1lakshmi.ravi3003@gmail.com, 2smilingbaugi@gmail.com, 3vanjarapudamodhar@gmail.com

Abstract - The rectangular waveguide characteristics and field distribution for various modes in rectangular waveguide when the waveguide is in the free space is computed using HFSS software. The analysis is made for different parameters. The electric and magnetic fields strengths are analysed inside a rectangular waveguide along with fundamental modal distributions. Simulation analysis is carried out for X-band and for two unique sizes i.e., breadths a=32.86mm and 22.86mm and widths b=20.16mm and 10.16mm. Characteristics profiles are analysed and the performance of rectangular waveguide is studied. Simulations are carried out for waveguide and both results of different dimensions are compared. A HFSS simulation platform for the analysis of the aperture radiation from a dielectric i.e., air filled rectangular waveguide is depicted.

Keywords - Waveguide, HFSS, Propagation Constant, Impedance matching.

I. INTRODUCTION

Microwaves propagate through various microwave circuits, components and devices that act as section of microwave transmission lines that are extensively called waveguides. Any shape of cross section of waveguide can support electromagnetic waves. But since irregular shapes are hard to analyse and are rarely used, rectangular and circular waveguides have become more common waveguide cross-section may have any shape. Rectangular waveguide is most common.

Rectangular Waveguides are utilized to transfer electromagnetic energy or power from one point in the space to another efficiently. They are used as a part of numerous applications, for example, radars, isolators, attenuators and slotted lines. The electromagnetic waves propagating inside the waveguide might be described by reflections from the conducting walls. It is possible to propagate several modes of electromagnetic waves inside a rectangular waveguide. The rectangular waveguide is a transmission medium supports TE and TM modes. Because of the absence of a center conductor, the electromagnetic field supported by a waveguide must be TE or TM modes. For rectangular waveguide the dominant mode is TE10, which has the most minimal cut-off frequency.

As the communication technology improves higher frequency range available for the longer bandwidth. Analysis of transmission line is done by microwave and millimeter wave frequencies. Subsequently waveguide structures characterization is very important. It depends upon geometrical shape of the waveguide and property of the medium. The different theoretical formulas such as propagation constant, cut off frequency or wavelength and resistive profiles are determined.

The HFSS is a software package analysis modelling and analysis of 3-dimensional structures. HFSS uses a 3D full wave finite element method to compute the electrical behaviours of high frequency and high speed components. The HFSS is more precisely characterizes the electrical performance of components and effectively evaluates different parameters. It helps the user to observe and analyse various performance of electromagnetic properties of structures such as propagation constant, characteristic port impedance, generalised S-parameters and Y-parameters and etc., are normalised to specific port impedances. The HFSS software is designed for extracting modal parameters by simulating passive devices. It is necessary for designing high frequency and high speed components utilized as a part of advanced electronic devices. The HFSS simulated results are more precise and helpful before design and fabricating of real world components.

II. MATHEMATICAL MODELLING

Consider two hallow rectangular waveguides arranged in the rectangular co-ordinate system with its breadth along x-axis, width along y-axis, inner dimension a × b i.e., a=32.86mm and 22.86mm and b= 20.16mm and 10.16mm, loaded with an air as a dielectric. In rectangular waveguide the electric and magnetic fields are confined to space within the waveguides. The electromagnetic waves are propagating in the "z" direction. Or else the z-component of the magnetic field, Hz must exist in order to have energy transmission in the rectangular waveguide. The electromagnetic wave inside a waveguide can have an infinite number of patterns which are called modes. The TE_{mn} mode in a rectangular waveguide are characterised by E_{z} = 0, i.e., z-segment of magnetic field Hz ≠0, must exist in order to transmit energy through the waveguide. The TM_{mn} mode in a rectangular waveguide are characterised by Hz = 0. Implies that z-component of
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The wave equations for waves propagating along \( z \) direction are given by

\[
\nabla^2 H_z = -\omega^2 \mu E_z \quad \text{for TE wave} \quad (E_z = 0) \ldots \ldots 1
\]

\[
\nabla^2 E_z = -\omega^2 \varepsilon H_z \quad \text{for TM wave} \quad (H_z = 0) \ldots \ldots 2
\]

Where \( E_z \) and \( H_z \) are the components of the electric and magnetic field along the \( z \)-direction for TE and TM waves respectively. The mode which has the lowest cutoff frequency in a specific waveguide is called dominant mode. The dominant mode in a rectangular waveguide with dimension \( a > b \) is the \( \text{TE}_{10} \) mode. It is a mode which is utilized for practically all electromagnetic transmission in the rectangular waveguide. Dominant mode is almost always a low loss, distortionless transmission and higher modes result in a significant loss of power and also undesirable harmonic distortion.

The cutoff frequency for \( \text{TE}_{mn} \) mode is given by

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

\[
m = n = 0, 1, 2, \ldots \text{but } m = n \neq 0
\]

The propagation constant is given by

\[
\gamma = \alpha + j\beta
\]

Here

\[
\gamma = \text{Propagation constant}
\]

\[
\alpha = \text{Attenuation Constant}
\]

\[
\beta = \text{Phase Constant}
\]

\[
\gamma_{mn} = j\beta_{mn}
\]

\[
\beta = \omega \sqrt{\mu \varepsilon (1 - \left( \frac{L}{f} \right)^2)} \quad \text{for } f > f_c
\]

The wave propagate in the waveguide if operating frequency is greater than the cutoff frequency \( f > f_c \), i.e., the frequency at which the value of the propagation constant changes from real to imaginary is called cutoff frequency.

The characteristic impedance is given by

\[
Z = \frac{\eta}{\sqrt{1 - (f_c/f)^2}} \quad \text{for TE wave}
\]

\[
Z_{TM} = \eta \sqrt{1 - \left( \frac{f_c}{f} \right)^2} \quad \text{for TM wave}
\]

II. NUMERICAL ANALYSIS

a) ELECTRIC FIELD STRENGTH

The strength of an electric field as created by source charge \( Q \) is inversely related to square of the distance from the source. This is known as an inverse square law. ... If the separation distance increases by a factor of 4, the electric field strength decreases by a factor of 16 (4^2). And finally, if separation distance decreases by a factor of 2, the electric field strength increases by a factor of 4 (2^2). The equation is given by

\[
E = \frac{K \cdot Q}{d^2}
\]

Here \( Q = \text{Source Charge} \)

\( d = \text{distance} \)

b) MAGNETIC FIELD STRENGTH

Magnetic field can be defined as that which can exert a magnetic force and can produce magnetic induction in the matter placed in it. The equation is give as

\[
B = \frac{\mu_0 m}{4\pi d^2}
\]

Where \( B = \text{magnetic field} \)

\( \mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1} \)

c) PROPAGATION CONSTANT

In the Figure-4 Propagation constant is observed that where the frequency increases the propagation constant also increases. As propagation constant is proportional to frequency,

\[
\gamma_{mn} = \alpha_{mn} + j\beta_{mn}
\]

\[
\gamma_{mn} = \beta_{mn}
\]

\[
\beta = \omega \sqrt{\mu \varepsilon (1 - \left( \frac{L}{f} \right)^2)}
\]
**CONCLUSION**

In this paper we studied the two rectangular waveguides of different sizes. The comparison of both waveguides is as follows:

(a) Rectangular waveguide of size $a \times b = 22.86 \times 10.16 \text{ mm}$ has more electric field and magnetic field strengths than the rectangular waveguide of size $a \times b = 32.86 \times 20.16 \text{ mm}$. This high electromagnetic radiation may result in thermal effects on human while transmitting the information.

(b) As the size of the waveguide increased, the cutoff wavelength increased or cutoff frequency decreased. This results in good propagation constant and allows lower frequencies to propagate.

(c) Characteristic impedance also decreased significantly as the size increases. Which results in transmission of information without any loss.

Thus the different characteristics of waveguide are studied. We can choose a waveguide of better performance to propagate the waves.

**REFERENCES**