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Mode Patterns in Rectangular Waveguide

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***Abstract*—** The rectangular waveguide field distribution for various modes in an open-ended rectangular waveguide when the waveguide is in the free space is computed using HFSS software. The analysis is made for dissimilar parameters. The electric and magnetic fields strengths are analyzed inside a rectangular waveguide along with fundamental modal distributions. Usually refer to the modes as TE_{mn} or TM_{mn} , where 'm' indicates the number of half-wave variations of the electric field (or magnetic field in TM) across the wider dimension 'a' (in the X direction) of the waveguide and 'n' indicates the number across the narrow dimension 'b' (in the Y direction). The WR-102 waveguide components are assemblies for monitoring electromagnetic waves and are sometimes called a waveguide transmission line. The WR-102 waveguides are low damage RF transmission lines capable of handling high power with high isolation. These WR102 waveguides are often used for RF and microwave waveguide communications requiring low loss capabilities. The WR 102 waveguides can be used in system designs for their high-power handling capabilities, antenna feed networks for low damage and phase accuracy and test labs. An HFSS simulation platform for the analysis of the opening radiation from a dielectric filled rectangular waveguide is described.

***IndexTerms*—**Waveguide,WR-102,HFSS, mode patterns, TE_{mn} and TM_{mn}

I. INTRODUCTION

The radiating rectangular waveguide is an important electromagnetic structure and one about which a great deal was known. An open-ended rectangular waveguide is normally taking the form of an enclosed conducting waveguide. The EM waves propagating inside the waveguide may be categorized by reflections from the conducting walls. It is a radiating structure finds many applications in a communication system, radar, biomedical, and both as the single radiator and as coupled radiators. etc. It is possible to propagate several modes of electromagnetic waves within a rectangular waveguide. EM wave consists of electric fields and magnetic fields which are always perpendicular to each other. At the surface of a conductor, the electric field cannot have a component parallel to the surface. This indicates that the electric field must always be perpendicular to the surface of a conductor. On the other hand, the magnetic field is always parallel to the surface of the conductor and cannot have a component perpendicular to it at the surface. The rectangular waveguide is a transmission medium supports TE_{mn} and TM_{mn} modes. Because of the lack of a center conductor, the electromagnetic field supported by a waveguide can only be TE or TM modes. The modes are usually refer to TE_{mn} or TM_{mn} , where 'm' indicates the number of half-wave variations of the electric field (or magnetic field in TM) across the wider dimension 'a' (in the X direction) of the waveguide and 'n' indicates the number across the narrow dimension 'b' (in the Y direction). The TM_{11} and TE_{10} is the dominant mode in a rectangular waveguide, which has the lowest cut-off frequency. The dominant mode is almost always a low loss, distortionless transmission and higher modes result in a significant loss of power. The analysis of rectangular waveguide field distribution is carried out by several investigators.

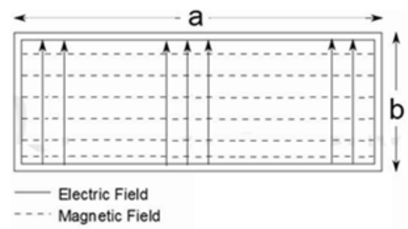

Fig 1: Radiation pattern of TE_{10} mode

The WR 102 waveguide components have one of the main selections of waveguide components in the RF/microwave engineering. The term 'WR' means for 'Waveguide Rectangular' and the number with it indicates the waveguide dimensions' inner width in hundredths of an inch. WR102 waveguide sizes are available in a rectangular waveguide design and are manufactured with square cover waveguide flange type that are all in-stock. The component, as well as the waveguide square cover flange, are made of quality aluminum to be precise, and lightweight, but sturdy construction. WR-102 waveguides are available in frequency ranges between 7 GHz and 11 GHz. These WR-102 waveguides include K Band waveguide components that can be found in the navigation.

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. Thus, waveguide structures characterization is very important. Waveguides depend on the geometrical method of the waveguide and property of the medium. The HFSS is a software package analysis showing and analysis of 3-dimensional structures. HFSS utilizes a 3D full-wave finite element method to compute the electrical behaviors of high frequency and high-speed components. The HFSS is extra accurately characterized the electrical performance of components and effectively evaluates various parameters. It helps the user to observe and analyze the various performance of electromagnetic properties of structures such as propagation constant, characteristic port impedance, generalized S-parameters, and Y- Parameter etc. are normalized to exact port impedances, the Eigen modes or resonances of the of the buildings. The HFSS software is designed for extracting modal parameters by simulating passive devices. It is necessary for designing high frequency and high-speed components used in modern electronic devices. The HFSS simulated results are more accurate and helpful before design and constructing of real world components. In this paper modes of the rectangular waveguide are simulated using HFSS. This analysis much helps in the fundamental of the waveguide. Most near field antenna measurements are made using an open-ended rectangular waveguide.

II. MATHEMATICAL MODELING

Consider a rectangular waveguide placed in the Cartesian coordinate system with its breadth along X-axis, the width along Y-axis and the wave is assumed to be circulating along Z-axis direction. The rectangular waveguide is filled with air, which is used as the dielectric medium. The electromagnetic waves travel in the z-direction which suggests that the H component of the magnetic field Hz must exist for the energy transmission in the waveguide. The electromagnetic waves inside the waveguide have several field patterns which can propagate independently and are called modes. It is suitable to categorize two-dimensional fields as transverse magnetic (TM) waves or transverse electric (TE) waves according to whether E or H was transverse to the direction of spread (or decay). The TEmn mode is characterized by Ez =0, i.e. the Hz component must exist for the transmission in the waveguide. In TMmn modes, Hz =0, and the Ez component must exist for the transmission in the waveguide (Ez≠0).

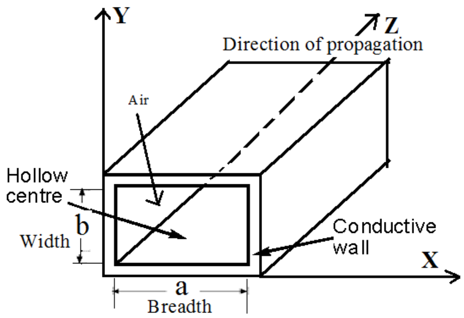

Fig 2: Rectangular Waveguide

Choose a rectangular waveguide with 0 < x < a, 0 < y < b and a > b. There are two types of waves in a hollow waveguide with only one conductor;

• Transverse electric waves (TE-waves). E = (Ex, Ey, 0) and H = (Hx, Hy, Hz).

• Transverse magnetic waves (TM-waves). E = (Ex, Ey, Ez) and H = (Hx, Hy, 0).

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 rectangular waveguide is as shown below. A material with permittivity and permeability fills the inside of the conductor. The wave equation for TE and TM waves are given by: $\nabla^2 \overline{E} = \gamma^2 \overline{E}$ for TM wave and $\nabla^2 \overline{H} = \gamma^2 \overline{H}$ for TE wave, where γ is the propagation constant and it is given by $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$.

For free space $\sigma = 0$, $\gamma = \sqrt{j\omega\mu_0 \times j\omega\varepsilon_0}$ $\Longrightarrow \gamma = \pm j\omega\sqrt{\mu_0\varepsilon_0}$ $\Longrightarrow \gamma^2 = -\omega^2\mu_0\varepsilon_0$

For TE wave $E_z = 0$; $\nabla^2 H_z = -\omega^2\mu_0\varepsilon_0 H_z$

For TM wave $H_z = 0$; $\nabla^2 E_z = -\omega^2\mu_0\varepsilon_0 E_z$

The propagation vector components for the modes in a rectangular waveguide.

$$h^2 = \gamma^2 + \omega^2\mu\varepsilon \; ; \quad A = \frac{n\pi}{b} \text{ And } B = \frac{m\pi}{a}$$

$$h^2 = A^2 + B^2 \Longrightarrow \gamma^2 + \omega^2\mu\varepsilon = A^2 + B^2$$

$$\Longrightarrow \gamma^2 + \omega^2\mu\varepsilon = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 \Longrightarrow$$

$$\gamma^2 = \left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 - \omega^2\mu\varepsilon \Longrightarrow \gamma = \sqrt{\left(\frac{n\pi}{b}\right)^2 + \left(\frac{m\pi}{a}\right)^2 - \omega^2\mu\varepsilon}$$

But, $\gamma = \alpha + j\beta$

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

At lower frequencies, the propagation constant γ becomes real and positive and equal to the attenuation constant α. i.e., the wave is completely attenuated and there is no phase change. Hence, the wave cannot propagate. It concludes that the propagation is of the form $e^{-\alpha z}$ i.e. the wave is attenuating or is evanescent as it propagates in the +z direction. This is happening for frequencies below the cut-off frequency. At higher frequencies, there is no attenuation constant (α=0), the propagation constant becomes imaginary, there will be phase constant β and hence the wave propagates. At transition, propagation constant γ becomes zero and the propagation just starts. The frequency at which γ just becomes zero is defined as the cut-off frequency or threshold frequency. It is denoted by fc. The cut-off frequency or threshold frequency is

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

The cut-off wavelength λ_c is $\lambda_c = \frac{c}{f_c} \Longrightarrow \lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$

Or $$\lambda_{c_{m,n}} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} \; or \; \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$$

All wavelengths greater than λ_c are attenuated and wavelength less than λ_c are allowed to propagate inside the waveguide.

III. NUMERICAL ANALYSIS

Numerical analyses are carried out for modes of a rectangular waveguide structure. The field patterns for the dominant TE10 modes are shown. The electric field exists only at right angles to the direction of propagation whereas the magnetic field has a component along the z-direction. Since n = 0, there is no variation of the electric field along the y-direction but varies only along x-direction The electric field is maximum at the center of the waveguide and decreasing sinusoidal towards the side walls and finally becomes zero all along the left and right two sides of the walls. Circulation of electric and magnetic field is important while considering a waveguide.

The WR-102 rectangular waveguide has been designing with recommended frequency 7-11 GHz, the cutoff frequency is 5.7GHz and dimensions 25.908x12.954 mm. Using HFSS software in rectangular waveguide field variation for TE_{10}, TE_{20}, TE_{01} and TE_{02} modes are shown in below fig 3 to fig6.

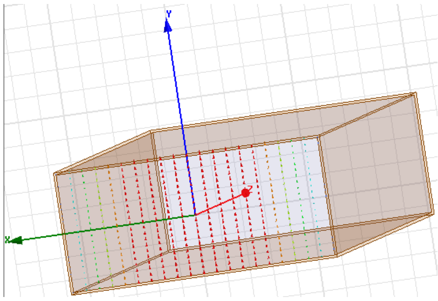

Fig 3: Field variation for TE_{10} modes

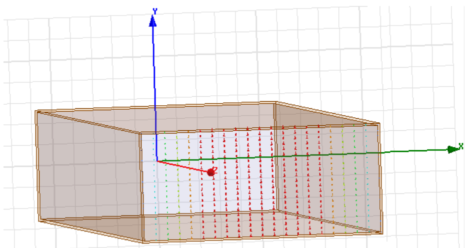

Fig 4: Field variation for TE_{20} modes

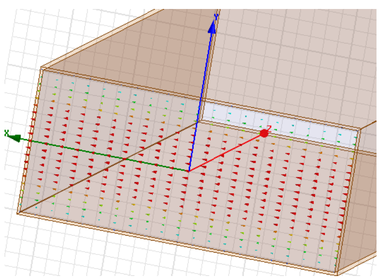

Fig 5: Field variation for TE_{01} modes

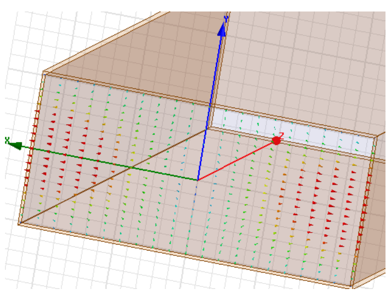

Fig 6: Field variation for TE_{02} modes

Using HFSS software in rectangular waveguide side view and top view field variation shown in below fig 7 to fig12.

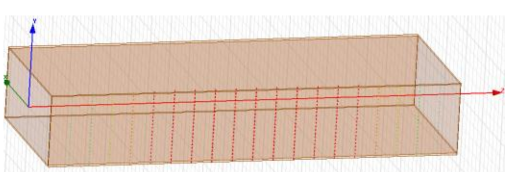

Fig 7: Side View Field variation for TE_{10} modes

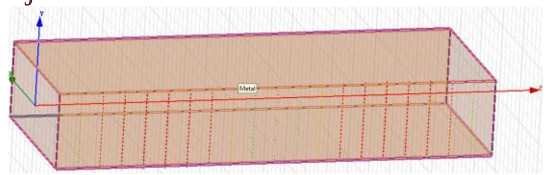

Fig 8: Side View Field variation for TE_{20} modes

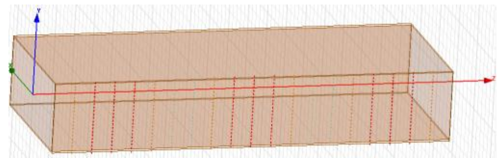

Fig 9: Side View Field variation for TE_{30} modes

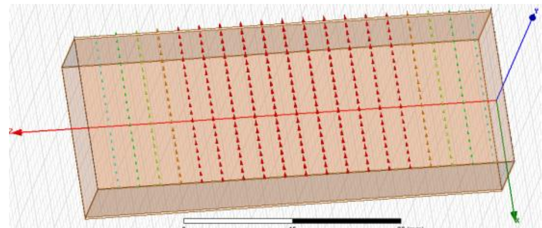

Fig 10: Top View Field variation for TE_{10} modes

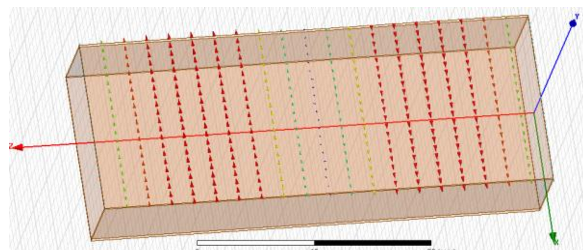

Fig 11: Top View Field variation for TE_{20} modes

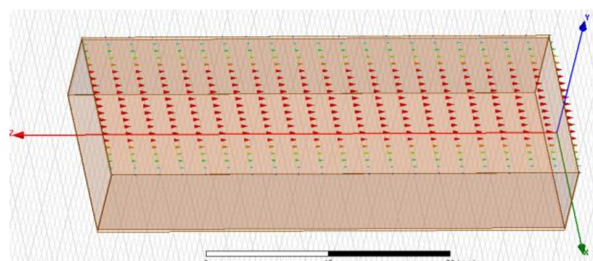

Fig 12: Top View Field variation for TE_{01} modes

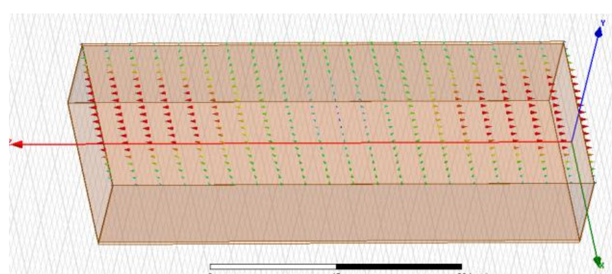

Fig 12: Top View Field variation for TE_{02} modes

Electric field variations inside the rectangular waveguide, magnetic field variation inside the rectangular waveguide, EF &MF inside the rectangular waveguide and J field variation inside the rectangular waveguide are simulated using HFSS software and simulation results are shown from fig 13 to fig 16.

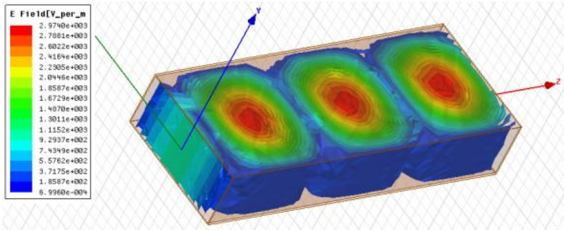

Fig 13: Electric Field Variation inside the rectangular waveguide

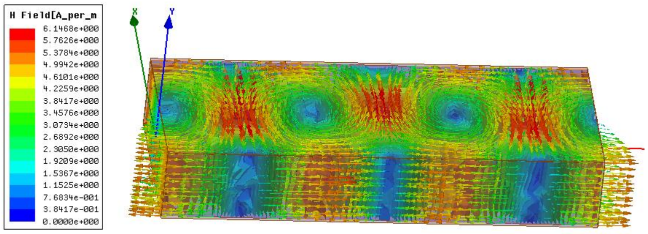

Fig 14: Magnetic Field Variation inside the rectangular waveguide

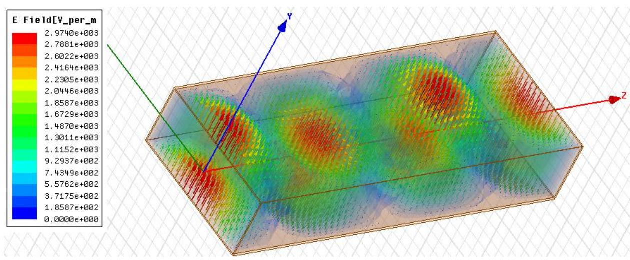

Fig 15: Electric and Magnetic Field Variation inside the rectangular waveguide

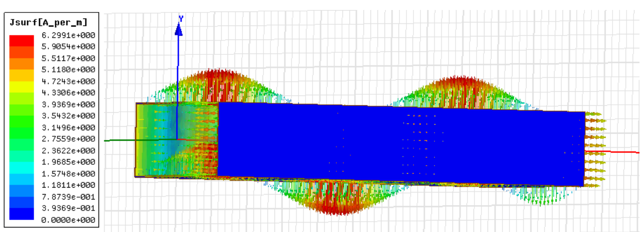

Fig 16: J Field Variation inside the rectangular waveguide

CONCLUSION

The properties of the waveguides are used to determine the modes of the waveguide. The simulations are carried out for lower microwave frequencies for X band. For analysis purpose different modes are considered to understand the properties of electric and magnetic field distributions, simulations are carried out. Numerical results are compared with existing theoretical results. This simulation is useful for experimental analysis and results are more accurate and helpful before design and fabricating of real-world components.

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