Analysis of Ohmic Loss in Oversized Smooth Walled Circular Waveguide using FEM

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***Abstract*—In this paper we discuss the attenuation occur due to ohmic losses in oversized smooth walled circular waveguide. Ohmic losses depend on the radius of the waveguide and material used for the wall of the waveguide. It also depends on the mode propagating in the waveguide. We calculate the ohmic loss for W-band frequency that ranges from 70-110 GHz and have verified the results using COMSOL v2.a software.**

Keywords—oversized waveguide; smooth walled waveguide; ohmic loss; attenuation constant

I. INTRODUCTION

Delivery of electromagnetic waves in dielectric and conducting media is difficult because of radiation at high frequencies. Circular waveguides are one type of transmission line in which air is used as dielectric because it has low loss than other insulation material. Circular waveguides offer implementation advantage over rectangular waveguide as its installation is much simpler.The circular waveguide supports Transverse Electric (TE) & Transverse Magnetic (TM) modes. The cut off frequency of circular waveguide depends on the waveguide dimensions and shape. The electromagnetic wave at frequency greater than the cut-off frequency can propagate in the waveguide. The TE_{0n} modes of circular waveguide have very low attenuation in the case of oversized waveguide. More than one mode propagates in the oversized waveguide so it is called overmoded. The reason it is used is that the resistive losses are reduced as the waveguide becomes oversized. [1][4]

II. MODES IN SMOOTH WALL CIRCULAR WAVEGUIDE

We consider the parameters of smooth wall circular waveguide for mode calculations as shown in figure 1.

Fig. 1 smooth walled cylindrical waveguide with radius ‘a’[2]

A. TM Mode

We know that the wave made up of Transverse Electric (TE) and Transverse Magnetic (TM) components. First we see the TM modes. In these modes Z component of magnetic field must be zero ($H_z = 0$).[2] Therefore

$$E_z = E_0 J_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix} e^{-jk_z z} \tag{1}$$

Where, E_0 is arbitrary amplitude of the mode.

Rest of the field equations can be derived using Maxwell equations and dispersion relation for cylindrical waveguide.

$$E_r = \frac{j k_z k_r E_0}{k^2 - k_z^2} J'_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix} e^{-jk_z z} \tag{2}$$

$$E_\phi = \frac{j k_z E_0}{k^2 - k_z^2}\frac{m}{r} J_m(k_r r)\begin{Bmatrix}\cos(m\phi)\\ -\sin(m\phi)\end{Bmatrix} e^{-jk_z z} \tag{3}$$

$$H_r = \frac{-j\omega\varepsilon E_0}{k^2 - k_z^2}\frac{m}{r} J_m(k_r r)\begin{Bmatrix}\cos(m\phi)\\ -\sin(m\phi)\end{Bmatrix} e^{-jk_z z} \tag{4}$$

$$H_\phi = \frac{j\omega\varepsilon k_r E_0}{k^2 - k_z^2} J'_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix} e^{-jk_z z} \tag{5}$$

Where,

$$k_r = \frac{X_{mn}}{a} \tag{6}$$

And X_{mn} is the nth root of the mth Bessel function of the first kind, so that $J_m(X_{mn})=0$.

$$k_z = \sqrt{\omega^2 \mu\varepsilon - k_r^2} \tag{7}$$

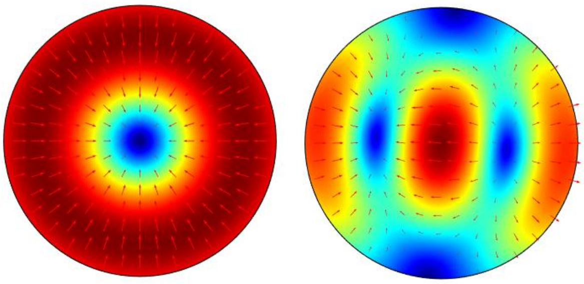

Fig. 2 TM_{01} & TM_{11} mode pattern respectively

As a result of mode analysis with radius of 36 mm we get the mode patterns of TM mode as shown in figure 2.

B. *TE Mode*

We can perform the same for the TE modes. In these modes Z component of electric field must be zero ($E_z = 0$).[2] Therefore

$$H_z = J_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix}e^{-jk_z z} \tag{8}$$

Using Maxwell equations solution for other transvers electric (TE) field is given by,

$$H_r = \frac{j k_z k_r}{k^2 - k_z^2} J'_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix}e^{-jk_z z} \tag{9}$$

$$H_\phi = \frac{j k_z}{k^2 - k_z^2}\frac{m}{r} J_m(k_r r)\begin{Bmatrix}\cos(m\phi)\\ -\sin(m\phi)\end{Bmatrix}e^{-jk_z z} \tag{10}$$

$$E_r = \frac{j\omega\mu}{k^2 - k_z^2}\frac{m}{r} J_m(k_r r)\begin{Bmatrix}\cos(m\phi)\\ -\sin(m\phi)\end{Bmatrix}e^{-jk_z z} \tag{11}$$

$$E_\phi = \frac{-j\omega\mu k_r}{k^2 - k_z^2} J'_m(k_r r)\begin{Bmatrix}\sin(m\phi)\\ \cos(m\phi)\end{Bmatrix}e^{-jk_z z} \tag{12}$$

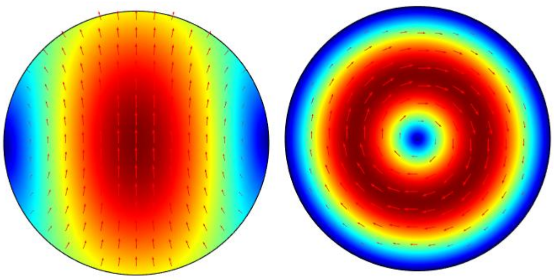

Fig. 3 TE_{11}& TE_{01} mode pattern respectively

As shown in figure 3 we can observe that the field intensity is low in theTE_{01} mode at the boundary compare to the TE_{11} mode. Sothe ohmic attenuation of the TE_{01} is low for the oversized waveguide.

III. OHMIC LOSS

The loss occurs in waveguide known as ohmic loss as a result of finite conductivity of waveguide wall. Ohmic losses arise due to small field penetration into the conductor walls of the waveguide.The attenuation coefficient for the TE_{mn} modes inside circular waveguide are given by, [3]

$$(\alpha_c)^{TE}_{mn} = \frac{R_s}{a\eta\sqrt{1-(\frac{f_c}{f})^2}} \times \left[(\frac{f_c}{f})^2 + \frac{m^2}{(\chi'^{2}_{mn}) - m^2}\right] Np/m \tag{13}$$

And for the TM modes α_c is given by,

$$(\alpha_c)^{TM}_{mn} = \frac{R_s}{a\eta\sqrt{1-(\frac{f_c}{f})^2}} Np/m \tag{14}$$

Where a, f, fc, χ'_{mn}, η, n, and m are the radius of waveguide, propagating frequency, cut-off frequency, nth zero of the derivative of the Bessel function, impedance of the material, no of circumferential variations, no of radial variations respectively and surface resistance given by

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}} \tag{15}$$

Where σ = electrical conductivity of material.

The ohmic loss in circular waveguide depends on the mode propagate in it and radius of the waveguide.

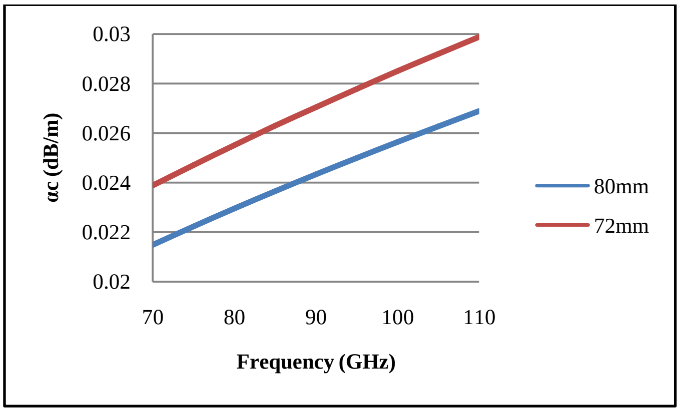

Fig. 4 Comparison of ohmic attenuation of TE_{11} mode

We calculate the ohmic attenuation of the TE_{11} mode into entire W-band for the diameter 72mm and 80 mm for the same conducting material aluminum. And we observe that for higher diameter ohmic loss is low.

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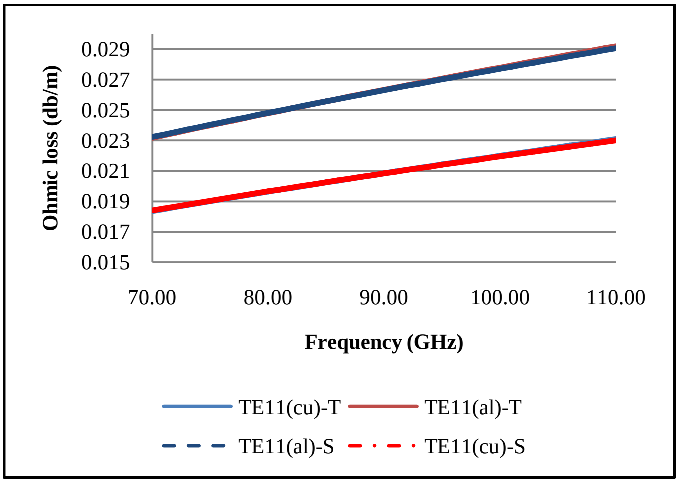

Fig. 5. Comparison between analytical and simulationvalues of ohmic attenuation for TE_{11} mode using aluminum and copper as wall material.

As shown in Fig. 5 we calculate the ohmic loss for the TE_{11} mode using two different material copper and aluminum for the 72 mm diameter of the waveguide. Continuous and dotted lines represent the theoretical and simulated values respectively. Result shows that there is a good agreement between theoretical and simulation values.

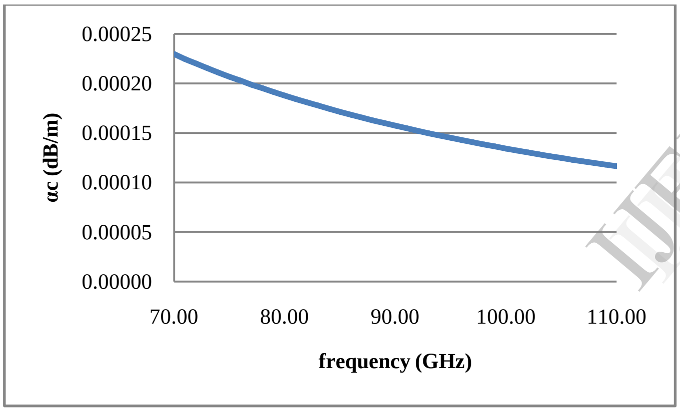

Fig. 6 Ohmic attenuation of TE_{01} mode

Up till now we have studied the impact of radius or the material used for wall for the TE_{11} mode. We observe the same for the TE_{01} mode as shown in the figure 6.

TABLE 1. Attenuation constants of TE_{11}& TE_{01} mode

Frequency (GHz)	$\propto_c$ of TE_{11} (dB/m)	$\propto_c$of TE_{01} (dB/m)
70	0.02318	0.00029
75	0.02400	0.00026
80	0.02480	0.00024
85	0.02557	0.00022
90	0.02633	0.00020
95	0.02707	0.00018
100	0.02779	0.00017
105	0.02850	0.00016
110	0.02919	0.00015

By observing the above values, we can say that the ohmic attenuation of the TE_{01} mode is much lesser than The TE_{11}.

CONCLUSION

We have seen that the ohmic attenuation of the waveguide mainly depends on the radius and conductivity of material used by waveguide wall. Ohmic loss can be decreases by increasing the diameter of the waveguide andusing highly conductive material. By observing the characteristics of TE_{11} and TE_{01} mode in smooth wall circular waveguide we can conclude that the TE_{01} is the lowest attenuated mode in oversized smooth walled circular waveguide.

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