Electrical Engineering Department

ENEE5302

ELECTROMAGNATIC II

Project 1

Rectangular waveguide design and analysis using HFSS

Prepared by :

Taghreed Mustafa 1110149

Refaa Budair 1111456

Marah Safi 1101600

Instructor :

DR-Atheer Barghouthi

Date :

1/1/2015

Abstract:

Aim of the project:

To improve our skills in using HFSS program to analyze rectangular waveguide also to ensure our theoretical information about rectangular waveguide

Introduction:

The HFSS is a software package analysis modeling 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 more accurately characterizes the electrical performance of components and effectively evaluates various parameters.

It helps the user to observe and analyze various performance of electromagnetic properties of structures such as propagation constant, characteristic port impedance, generalized S-parameters and Y Parameter etc are normalized to specific port impedances, the Eigen modes or resonances of the of the structures.

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 fabricating of real world components

The rectangular waveguide characteristics and field distribution for different 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 different

Parameters. The electric and magnetic fields strengths are analyzed inside a rectangular waveguide along with fundamental modal distributions. Simulation analysis is carried out for X-band. Characteristic profiles are analyzed and the performance of rectangular waveguide is studied. Theoretical analysis and simulation are carried out for waveguide and both results are compared. A HFSS simulation platform for the analysis of the aperture radiation from a dielectric filled rectangular waveguide is described.

The electromagnetic waves propagating inside the waveguide may be characterized by reflections from the conducting walls. It is a radiating structure finds many applications in communication system, radar, biomedical, and both as single radiator and as coupled radiators .It is possible to propagate several modes of electromagnetic waves within a rectangular waveguide. The rectangular waveguide is a transmission medium supports TE and TM modes. Because of the lack of a center conductor, the electromagnetic field supported by a waveguide can only be TE or TM modes. For rectangular waveguide the dominant mode is TE10, which has the lowest cut-off frequency.

Theory:

$$\nabla^2 H_z = \mu\varepsilon \frac{\partial^2 Hz}{\partial t^2} \text{ and } E_z = 0 \text{ for TE waves}$$

$$\nabla^2 E_z = \mu\varepsilon \frac{\partial^2 Ez}{\partial t^2} \text{ and } H_z = 0 \text{ for TM waves}$$

Where Ez and Hz are the components of the electric and magnetic field along the z- direction for TE and TM waves respectively. The mode which having lowest cutoff frequency in a particular waveguide is called dominant mode. The dominant mode in a rectangular waveguide with dimension a > b is the TE10 mode. It is a mode which is used for practically

All electromagnetic transmission in the rectangular waveguide. Dominant mode is almost always a low loss, distortion less transmission and higher modes result in a significant loss of power and also undesirable harmonic distortion.

The cutoff frequency for the TE_{mn}

$$f_c = \frac{1}{2\sqrt{\mu\varepsilon}} \sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2}}$$

m,n = 0,1……..

$m = n \neq 0$

The guided wavelength λg given by

$$\lambda g = \frac{\lambda}{\sqrt{1-(fc/f)^2}} \quad \text{for } f > f_c$$

The propagation constant gamma

$$\Upsilon = \sqrt{((R + j\omega L)(R + j\omega C))}$$

$$\Upsilon = \alpha + j\beta$$

Where

α is the attenuation constant

β is the phase constant

The wave will propagate in the waveguide if operating frequency must be greater than cutoff frequency f > fc i.e. the frequency at which the value

Of the propagation constant changes from real to imaginary is called cut-off frequency.

The propagation constant/phase (
expressed as

$$\beta = \omega\sqrt{\mu\varepsilon}\sqrt{1-(fc/f)^2} \quad \text{for } f > f_c$$

Where

f_c *is* the cutoff frequency

Characteristic wave impedance z is

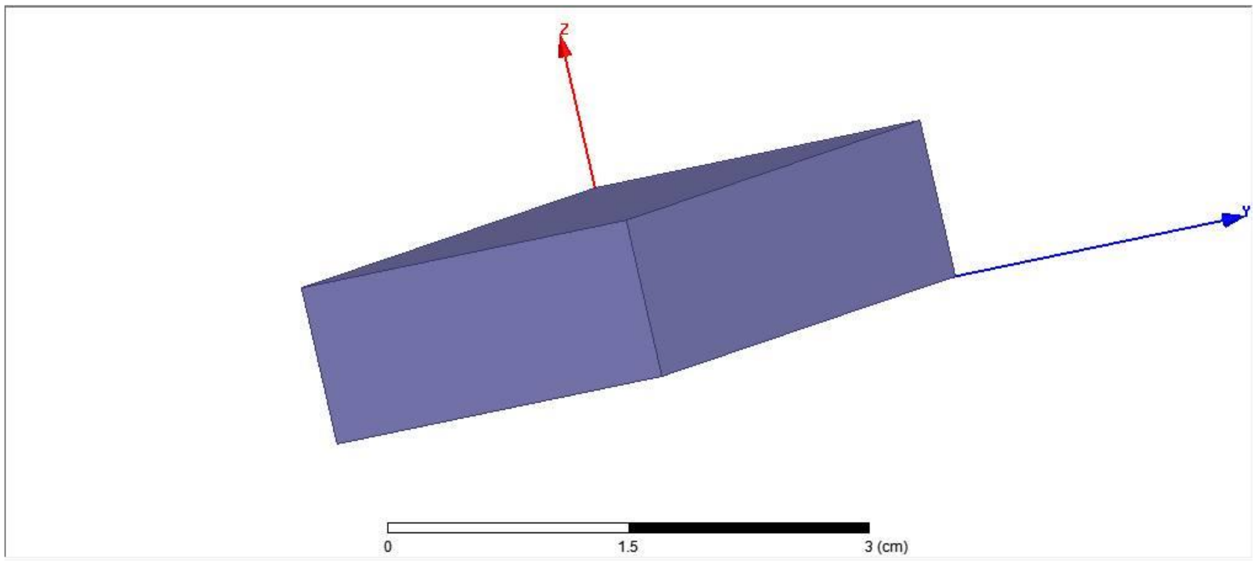
$$z = \frac{\eta}{\sqrt{1-(fc/f)^2}} \quad \text{for } f > f_c$$

Where

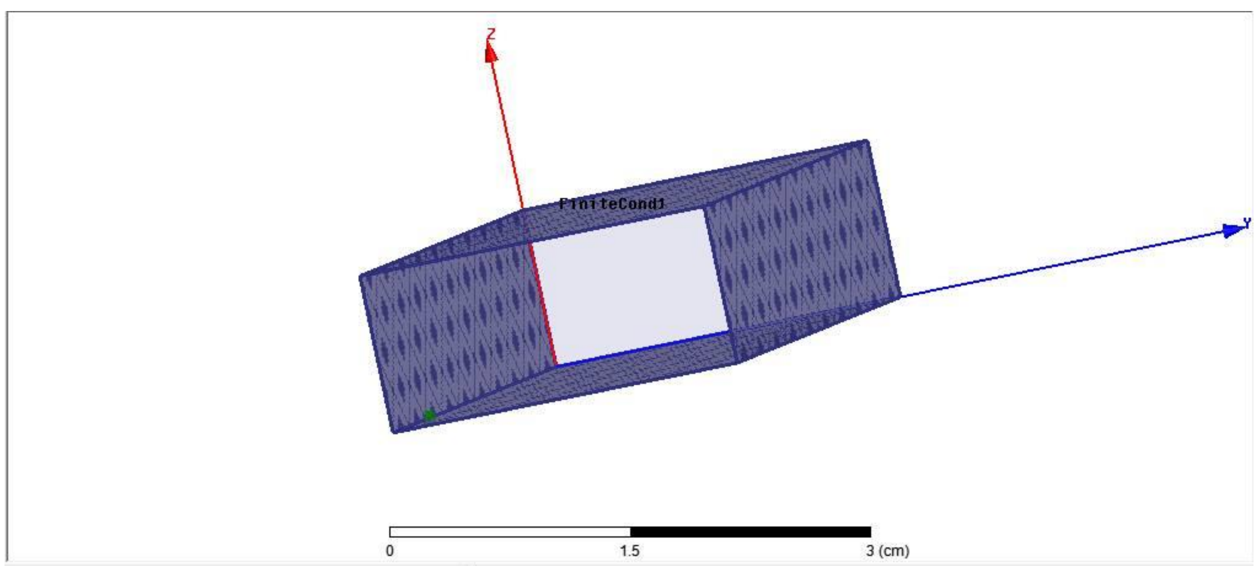
$\eta = 1/\sqrt{\mu\varepsilon}$ is the intrinsic impedance

Analysis using HFSS program:

The rectangular wave guide model:

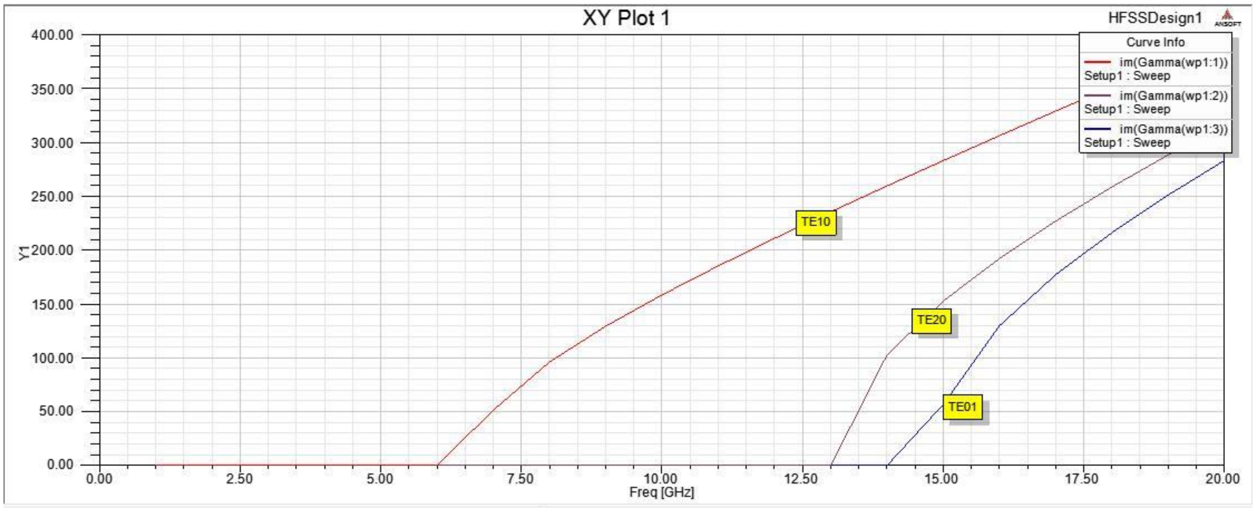


FIG(1):rectangular wave guide



FIG(2): infint conductor surface

the plot of BETA for three mode :



FIG(3):BETA for TE 10,01 ,20

Data Table 1

HFSSDesign1

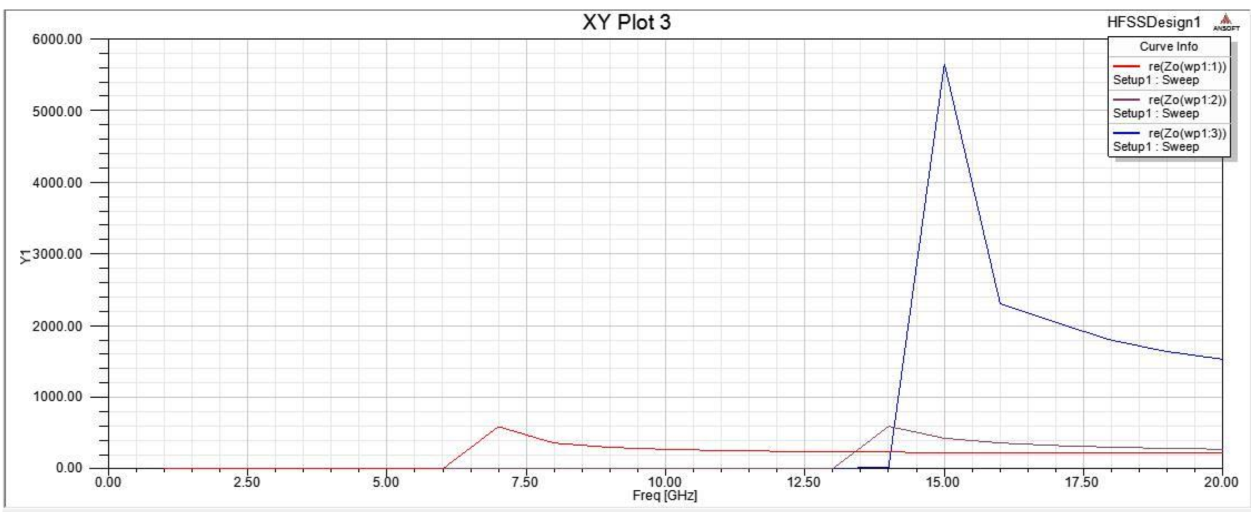
	Freq [GHz]	im(Gamma(wp1:1)) Setup1 : Sweep	im(Gamma(wp1:2)) Setup1 : Sweep	im(Gamma(wp1:3)) Setup1 : Sweep
1	1.000000	0.013037	0.025343	0.063773
2	2.000000	0.010301	0.018436	0.045557
3	3.000000	0.010076	0.015771	0.037835
4	4.000000	0.011245	0.014566	0.033568
5	5.000000	0.014365	0.014137	0.030996
6	6.000000	0.024699	0.014248	0.029459
7	7.000000	51.382101	0.014827	0.028669
8	8.000000	96.069017	0.015902	0.028506
9	9.000000	129.216655	0.017615	0.028964
10	10.000000	158.250367	0.020315	0.030144
11	11.000000	185.116062	0.024929	0.032328
12	12.000000	210.644901	0.034927	0.036198
13	13.000000	235.272459	0.111642	0.043743
14	14.000000	259.255708	102.738960	0.064671
15	15.000000	282.758642	152.624135	56.802426
16	16.000000	305.891992	192.123665	129.782033
17	17.000000	328.733789	226.732042	177.027668
18	18.000000	351.340902	258.421892	216.131350
19	19.000000	373.755918	288.157710	250.928810
20	20.000000	396.011456	316.490747	283.012922

TABLE (1): value of BETA at different frequencies

The plot of LAMBDA for three mode :

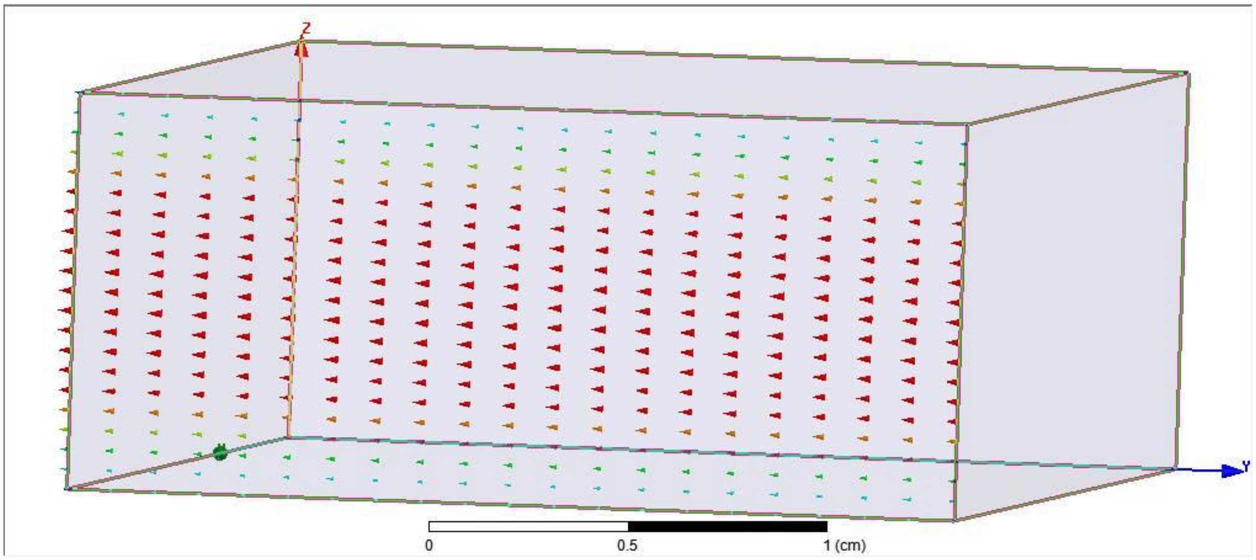
FIG (4): the wavelength for different mode

The plot of Zo for three mode :

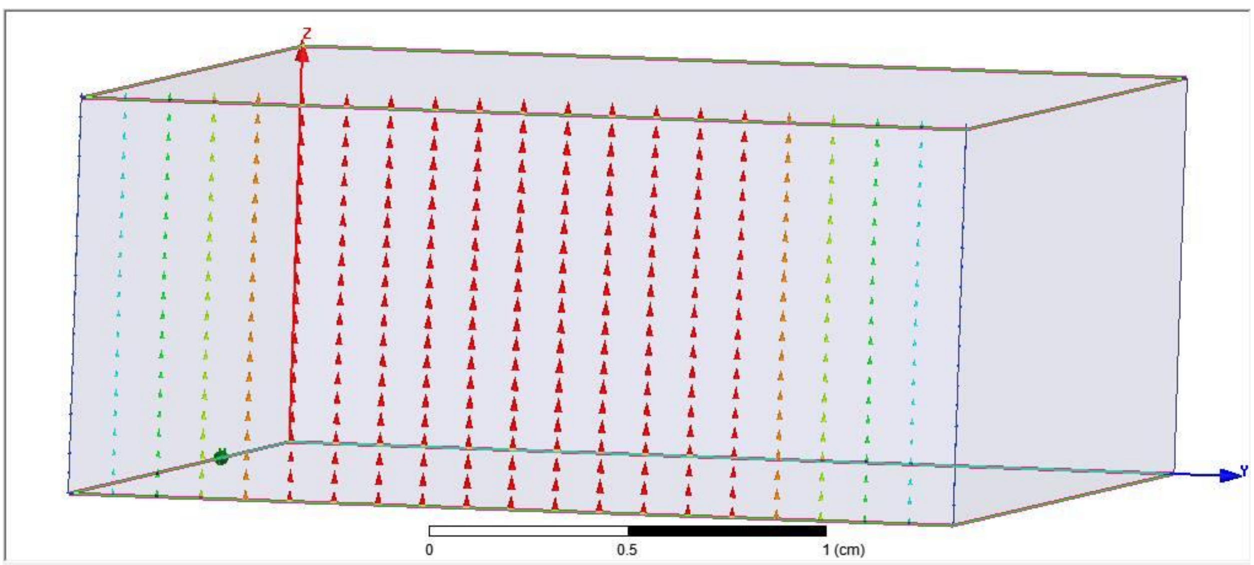


FIG(5): the intrinsic impedance for different mode

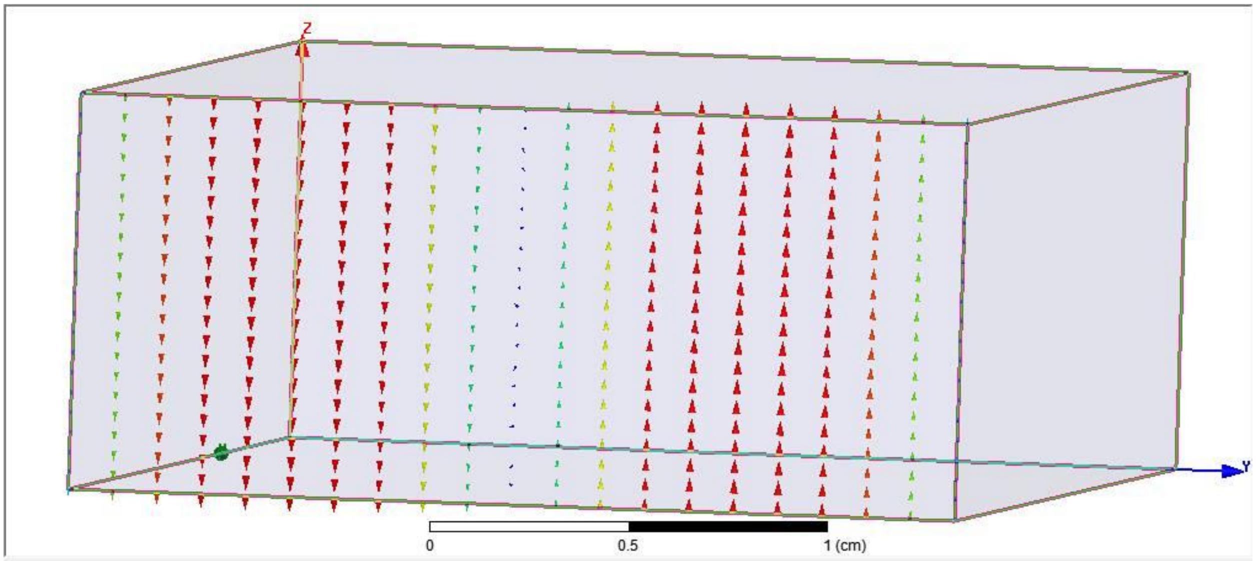
TE MODES :



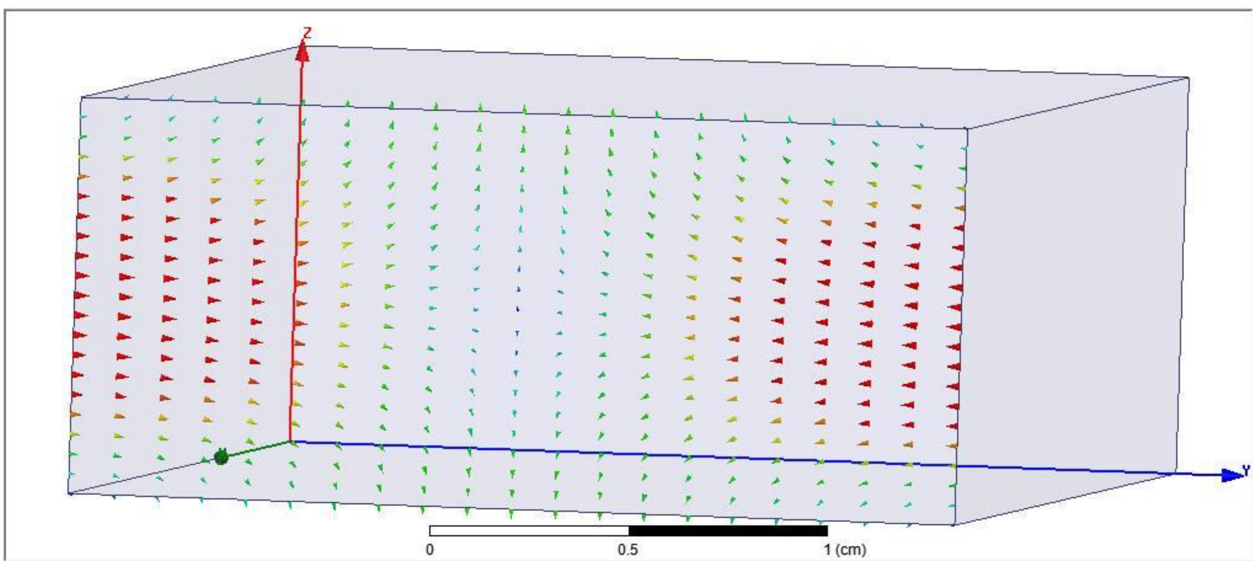
FIG(6):TE01



FIG(7):TE10

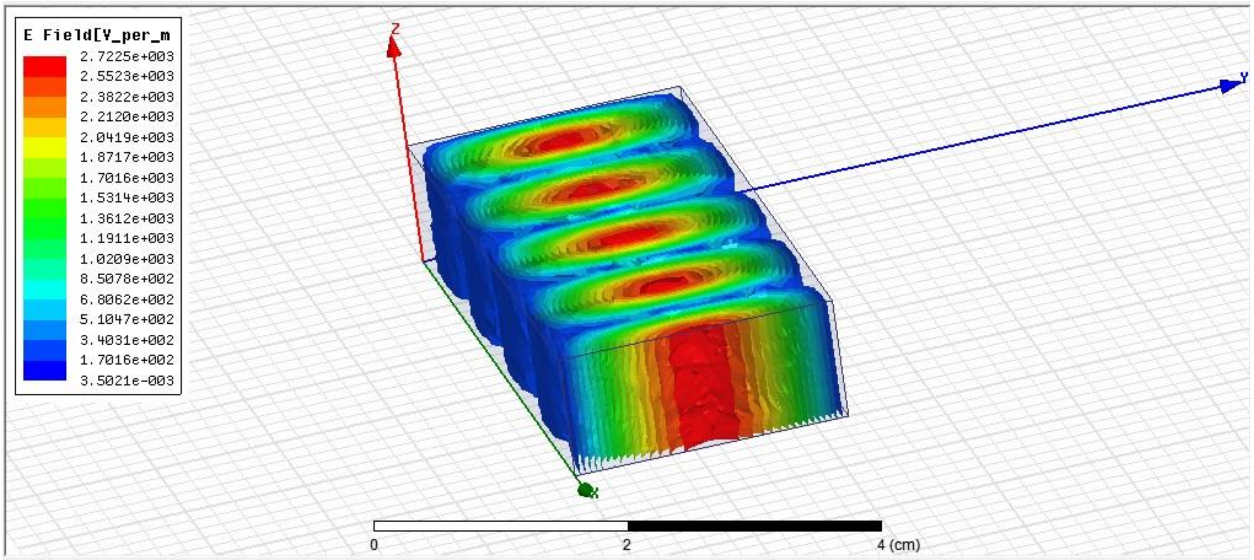


FIG(8):TE20

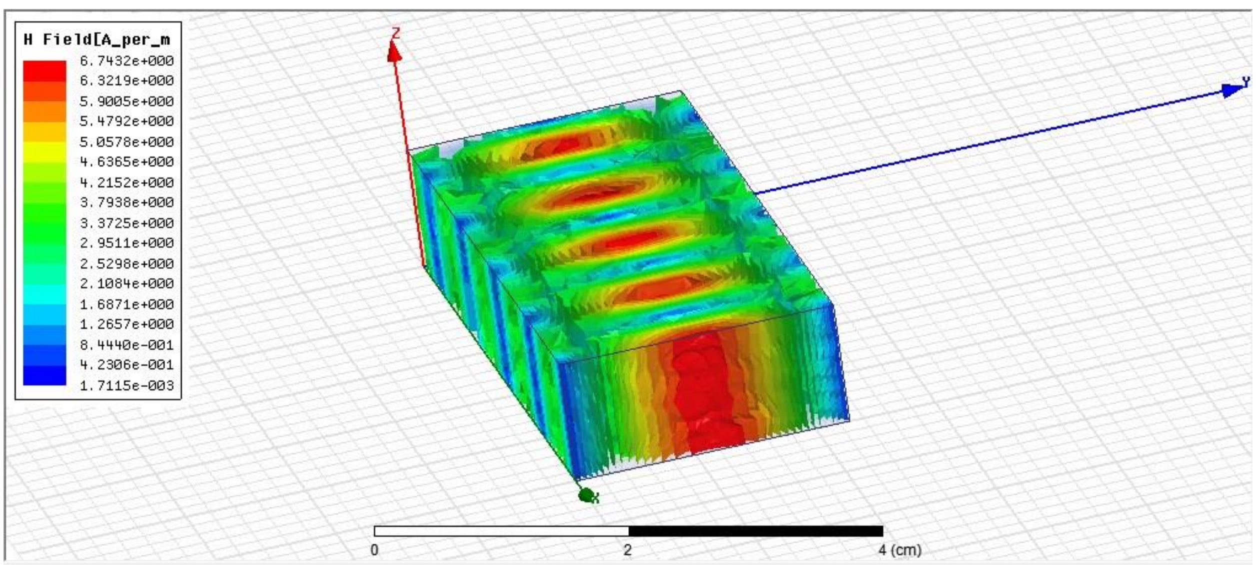


FIG(9):TE11,TM11

E (v/m) and H(A/M) PLOTS:



FIG(10):E(V/m)



FIG(11):H(A/m)

Analysis using matlab :

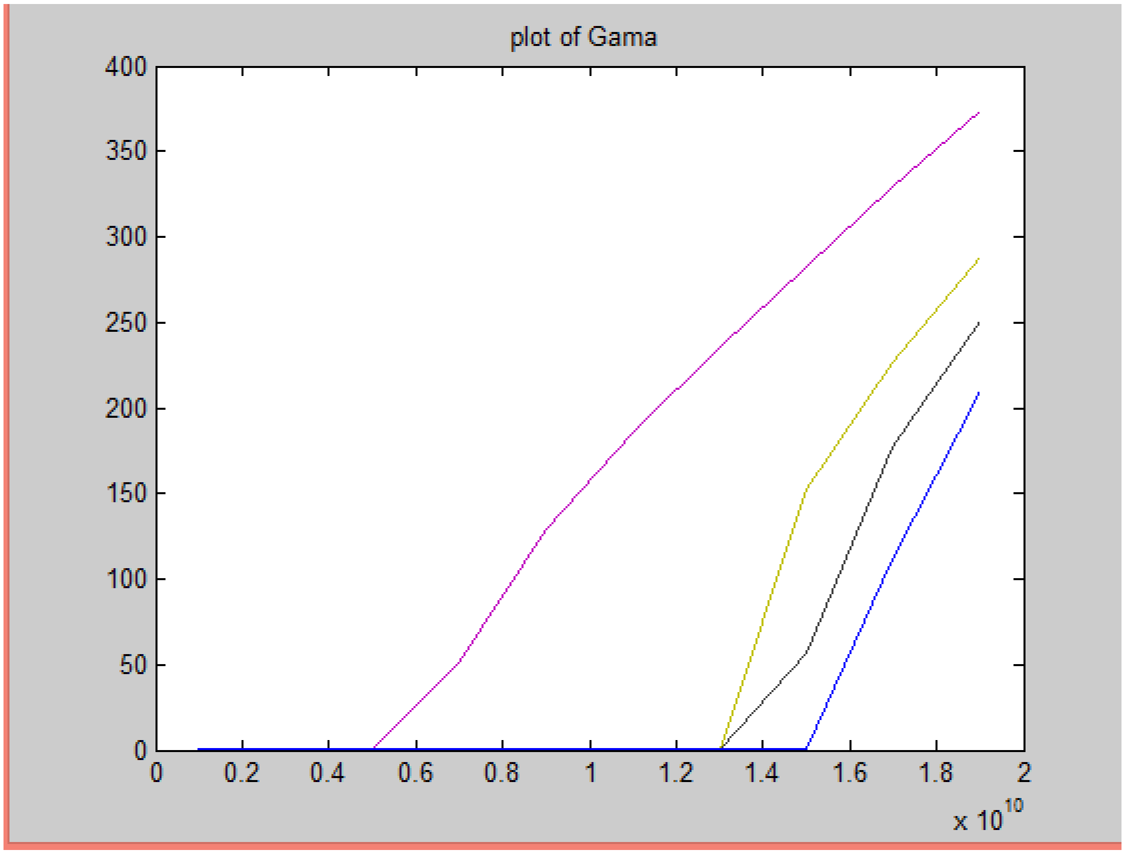
The matrix of Gama solution using matlab export :

```
 % Matlab m-File exported from HFSS13.0.0
% Note: In three-dimensional arrays, like S(i,j,k), the first index corresponds to the frequency.
%       So, S(N,j,k) is an S(j,k) matrix for frequency N.

f = zeros(10,1);
Gamma = zeros(10,8);

f = [1000000000 3000000000 5000000000 7000000000 9000000000 11000000000 13000000000 15000000000 17000000000 19000000000 ];
Gamma(1,:) = [
   1.358071E+002 +    1.303700E-002i,    2.740336E+002 +    2.534681E-002i,    3.084456E+002 +    6.376879E-002i,    3.376926E+002 +    6.341766E-002i,    1.35
Gamma(2,:) = [
   1.221909E+002 +    1.007568E-002i,    2.675552E+002 +    1.577258E-002i,    3.027228E+002 +    3.783186E-002i,    3.324755E+002 +    3.782515E-002i,    1.22
Gamma(3,:) = [
   8.889549E+001 +    1.436490E-002i,    2.540845E+002 +    1.413855E-002i,    2.908915E+002 +    3.099322E-002i,    3.217405E+002 +    3.129027E-002i,    8.88
Gamma(4,:) = [
   2.898024E-002 +    5.138265E+001i,    2.324158E+002 +    1.482728E-002i,    2.721730E+002 +    2.866608E-002i,    3.049215E+002 +    2.928791E-002i,    2.89
Gamma(5,:) = [
   1.389266E-002 +    1.292169E+002i,    1.999018E+002 +    1.761457E-002i,    2.449966E+002 +    2.896039E-002i,    2.809307E+002 +    2.985681E-002i,    1.38
Gamma(6,:) = [
   1.171526E-002 +    1.851162E+002i,    1.496330E+002 +    2.492772E-002i,    2.060436E+002 +    3.232386E-002i,    2.476940E+002 +    3.304916E-002i,    1.17
Gamma(7,:) = [
   1.103566E-002 +    2.352726E+002i,    3.612663E+001 +    1.116262E-001i,    1.461854E+002 +    4.373768E-002i,    2.006675E+002 +    1.915472E-002i,    1.10
Gamma(8,:) = [
   1.085874E-002 +    2.827587E+002i,    2.887882E-002 +    1.526237E+002i,    1.098785E-001 +    5.681467E+001i,    1.251695E+002 +    3.792849E-002i,    1.08
Gamma(9,:) = [
   1.090698E-002 +    3.287339E+002i,    2.135406E-002 +    2.267318E+002i,    3.488501E-002 +    1.770316E+002i,    5.199919E-002 +    1.115643E+002i,    1.09
Gamma(10,:) = [
   1.107113E-002 +    3.737560E+002i,    1.848357E-002 +    2.881575E+002i,    2.460202E-002 +    2.509316E+002i,    3.419885E-002 +    2.099395E+002i,    1.10
plot(f,imag(Gamma))
title('plot of Gama ')
```

The plot of BETA using matlab :



FIG(12): BETA VS. FREQ Theoretically

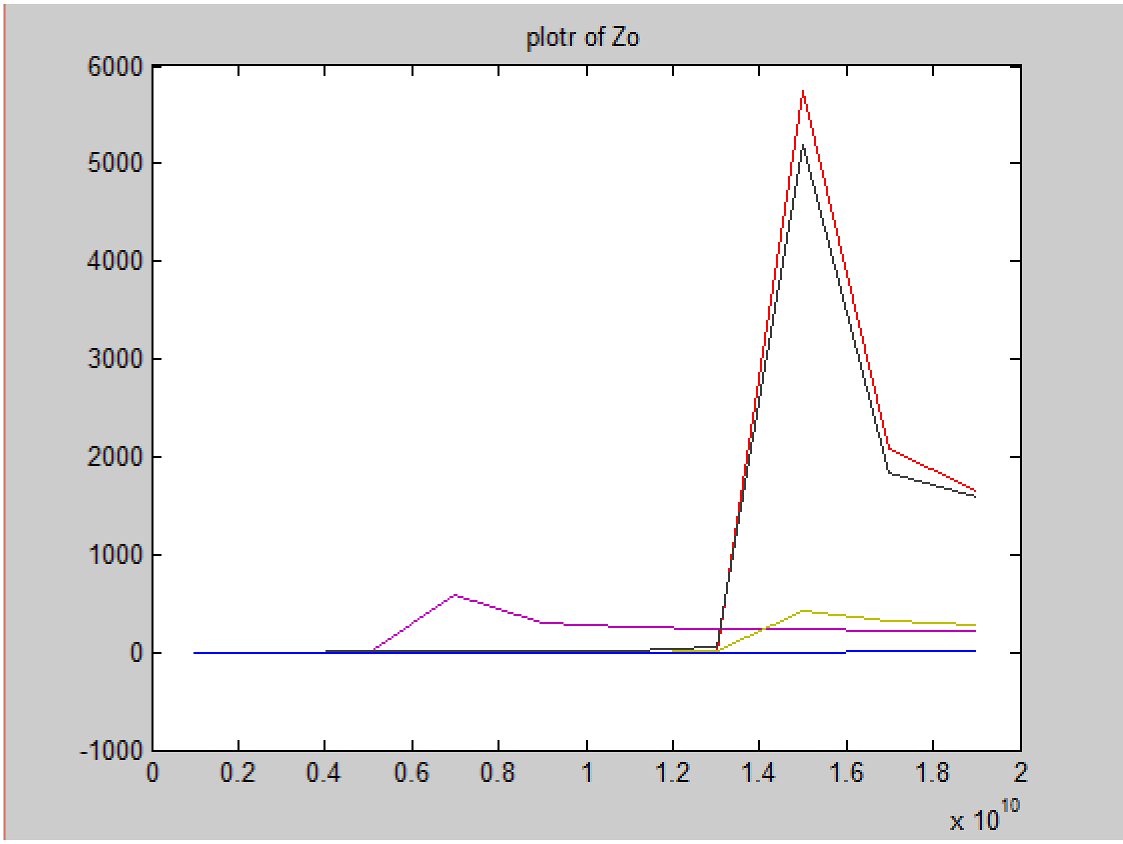
The matrix of Zo solution using matlab export :

```
% Matlab m-File exported from HFSS13.0.0
% Note: In three-dimensional arrays, like S(i,j,k), the first index corresponds to the frequency.
%       So, S(N,j,k) is an S(j,k) matrix for frequency N.

f = zeros(10,1);
Zo = zeros(10,8);

f = [1000000000 3000000000 5000000000 7000000000 9000000000 11000000000 13000000000 15000000000 17000000000 19000000000 ];
Zo(1,:) = [
   6.668453E-003 +   3.187688E+001i,   3.278435E-003 +   1.587892E+001i,   7.492802E-003 +   7.043816E+001i,   1.186233E-002 +   9.667633E+000i,   6.712
Zo(2,:) = [
   1.492238E-002 +   1.062814E+002i,   5.442611E-003 +   4.878773E+001i,   3.678583E-001 +   2.152411E+002i,  -3.909631E-001 -   1.140698E+002i,   1.506
Zo(3,:) = [
   4.757256E-002 +   2.434752E+002i,   7.478275E-003 +   8.562174E+001i,   4.115388E-001 +   3.731641E+002i,  -3.489026E-001 -   6.658269E+001i,   4.789
Zo(4,:) = [
   5.897044E+002 +   3.240437E-001i,   1.030867E-002 +   1.310436E+002i,   3.922709E-001 +   5.581999E+002i,  -1.192803E-001 -   4.529264E+001i,   5.893
Zo(5,:) = [
   3.014882E+002 +   3.354116E-002i,   1.710992E-002 +   1.958843E+002i,   2.800429E-001 +   7.970780E+002i,   4.994872E-002 -   3.249905E+001i,   3.013
Zo(6,:) = [
   2.572098E+002 +   2.194763E-002i,   4.833862E-002 +   3.198348E+002i,  -4.525781E-002 +   1.157971E+003i,   1.068267E-001 -   2.339955E+001i,   2.570
Zo(7,:) = [
   2.391679E+002 +   2.105903E-002i,   4.764039E+000 +   1.564672E+003i,   3.016714E-001 +   1.931281E+003i,   8.213139E-002 -   1.597904E+001i,   2.390
Zo(8,:) = [
   2.296136E+002 +   2.278098E-002i,   4.275954E+002 +   1.074216E-001i,   5.744939E+003 +   1.204267E+001i,   2.568177E-002 -   8.599143E+000i,   2.294
Zo(9,:) = [
   2.238298E+002 +   2.562147E-002i,   3.261999E+002 +   5.789411E-002i,   2.086214E+003 +   7.188446E-001i,   6.742911E+000 -   1.929778E-002i,   2.237
Zo(10,:) = [
   2.200238E+002 +   2.909507E-002i,   2.868526E+002 +   4.870561E-002i,   1.644832E+003 +   3.494398E-001i,   1.132459E+001 -   1.107921E-001i,   2.198
plot(f,real(Zo))
title('plotr of Zo')
```

The plot of Zo :



FIG(13):Zo VS. FREQ theoritcally

Conclusion:

The properties of the waveguides are used to determine the

Characteristics 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.