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Study of Circular Waveguide Window for Millimeter Wave Transmission line

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Outline

- **Background**
- **Introduction**
- **Multiple Reflection Model**
- **Waveguide Window 2D Axial Symmetrical Modeling**
- **COMSOL Simulation Results**
- **Comparison with Theory**
- **Conclusions**

Background

- Vacuum window is required in the millimeter wave transmission line in ITER*
- Microwaves are guided between the vacuum vessel and the emission/detection equipment, located in a different building using oversized waveguides.
- They are critical in term of safety but also for the good performance of the diagnostic: they have to be designed to minimize transmission attenuation due to window material

*ITER is an international fusion reactor which is being constructed under the collaborative efforts of seven participating parties (termed as domestic agencies) namely China, European Union, India, Japan, South Korea, Russia and the United States of America. It is being constructed at Cadarache, France. The main objective of ITER is to demonstrate the scientific and technical feasibility of a controlled fusion reaction and thus producing about 500 MW of fusion power by Deuterium - Tritium Plasma

Introduction

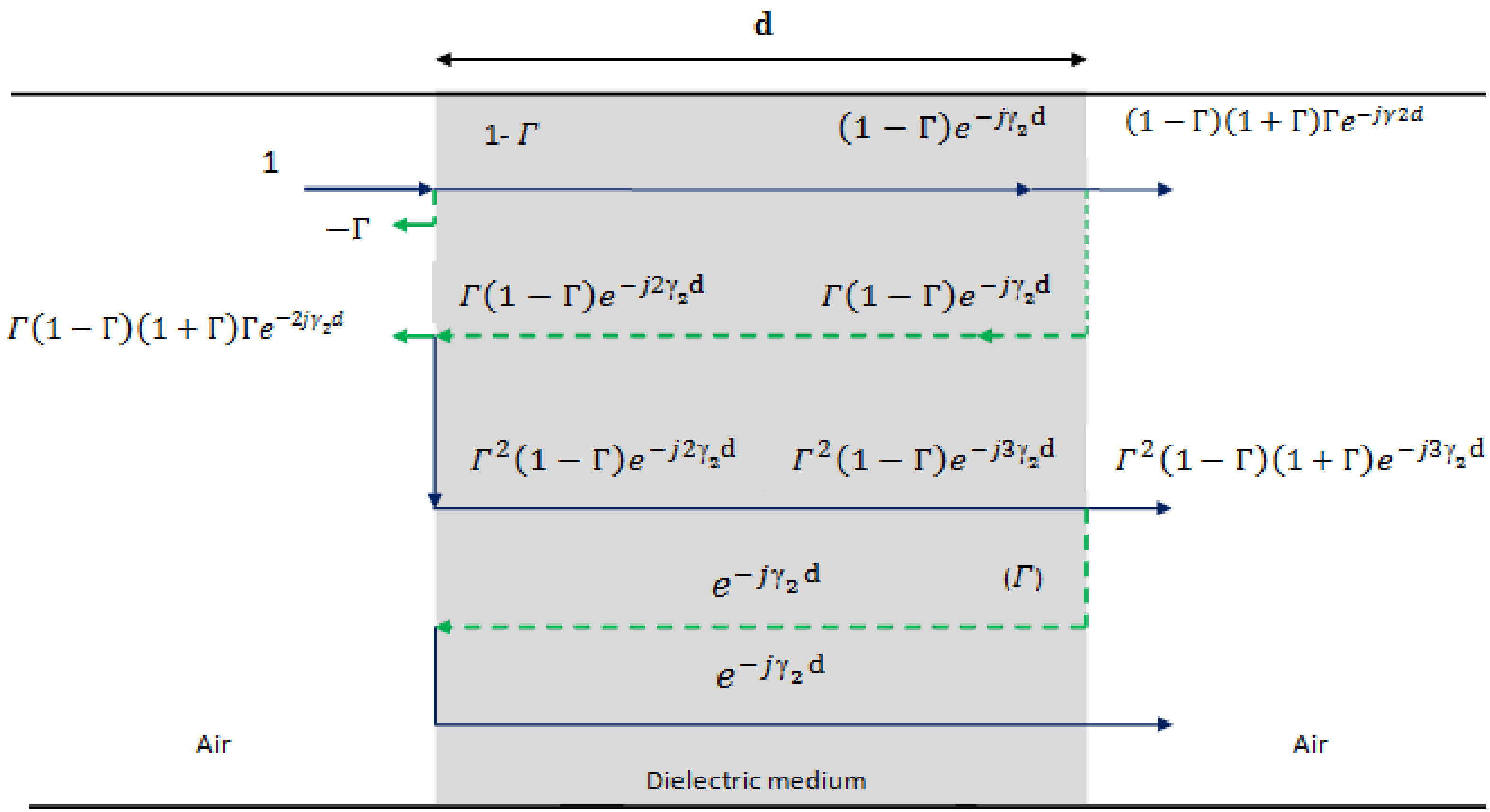
- Waveguide windows are integral component of a transmission line used in microwave plasma diagnostics. It provides vacuum isolation of the source side from the plasma chamber while transmitting microwaves with minimum attenuation [1]

- Dielectric materials are used as window material. The advantage of using dielectric material is that it gives low attenuation of mm wave signals

We have studied transmission characteristics of various dielectric materials over D-band frequency range (110-170 GHz) using RF Module of COMSOL Multiphysics v5.1. Purpose is to choose dielectric material with minimum transmission attenuation for designing of Circular Waveguide Window

Theoretical Approach

Multiple Reflection Model



Multiple reflection model of the electromagnetic scattering of a dielectric slab in a waveguide

Contd.

Assuming that, $|\Gamma| < 1$

Transmission $T = \frac{(1-\Gamma)(1+\Gamma)\, e^{-2dj\gamma 2}}{1-\Gamma^2\, e^{-2dj\gamma 2}}$

Reflection $\rho = -\Gamma + \frac{\Gamma(1-\Gamma)(1+\Gamma)e^{-j2\gamma 2d}}{1-\Gamma^2 e^{-j2\gamma 2d}}$

Where,
d = Thickness of Window
γ_2 = Wave Propagation factor
Γ = Fresnel coefficient

Fresnel coefficient $\Gamma = \frac{Z_1 - Z_2}{Z_1 + Z_2}$

Impedance $Z = \frac{\omega\mu}{\gamma}$

Wave propagation factor $\gamma = \beta - j\alpha$

Propagation factor

$\beta = k_0\sqrt{\Lambda}$ Air

$= k_0 A \cos P \approx k_0\sqrt{\Lambda\varepsilon_r}$ Dielectric

Attenuation constant

$\alpha = 0$ Air

$= k_0 A \sin P \approx k_0\sqrt{\Lambda\varepsilon_r}\ \tan\frac{\delta}{2\Lambda}$ Dielectric

Parameters

f= 110-170 GHz
d=5mm
Launching mode = TE01
Diameter = 19mm

Numerical Study using RF Module of COMSOL v5.1

Waveguide Window 2D Axial Symmetrical Model

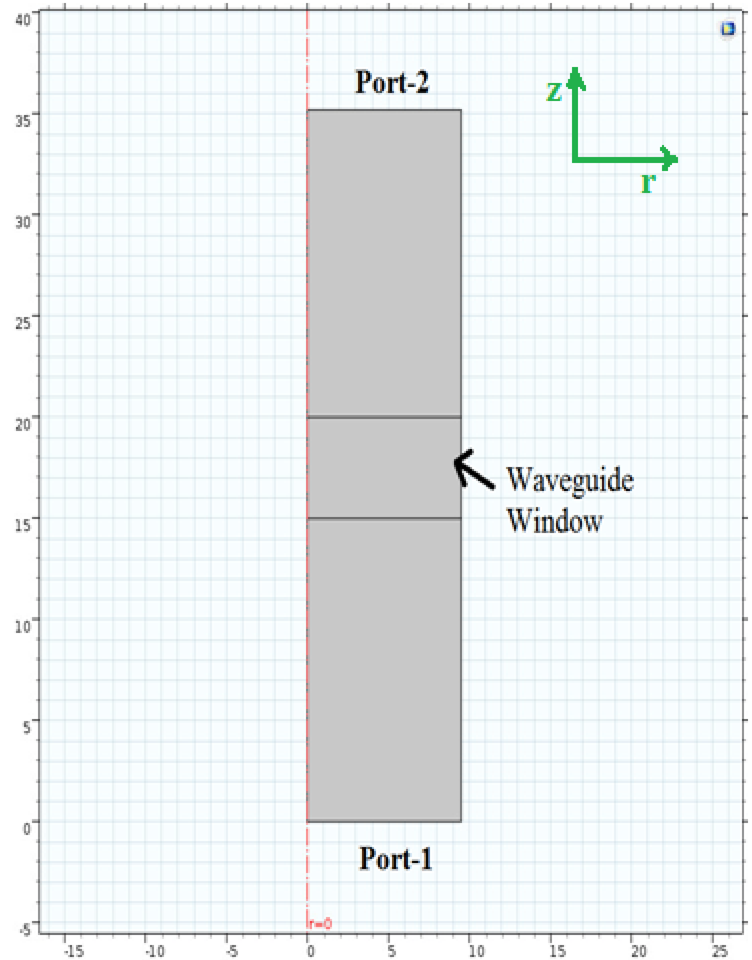
Geometry :

- Diameter of Circular Waveguide = 19mm
- Waveguide Window Length = 5mm
- Launching of Mode = TE01
- Frequency Range = 110-170 GHz
- Free space wavelength = 1.76 mm
- Impedance Boundary Condition

Frequency Domain Study

Meshing :

- Unstructured free triangular mesh
- The structure is meshed at 170GHz with mesh size λ/10



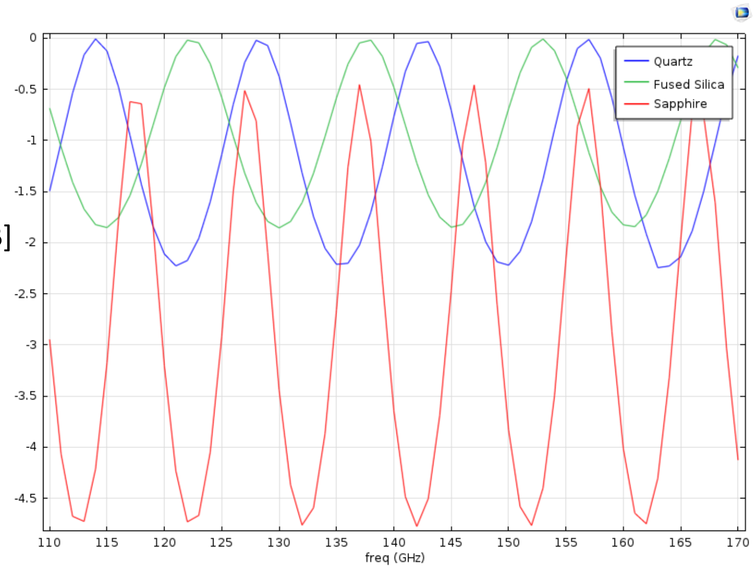
Results

Maxwell's equations in the frequency domain is given by,

$$\nabla\times(\mu_r^{-1}\nabla\times E)-\frac{\omega^2}{c_0^2}\left(\epsilon_r-\frac{j\sigma}{\omega\epsilon_0}\right)E=0$$

ε_r=Dielectric constant
σ= Electric conductivity
μ_r= Relative permeability

S21[dB]

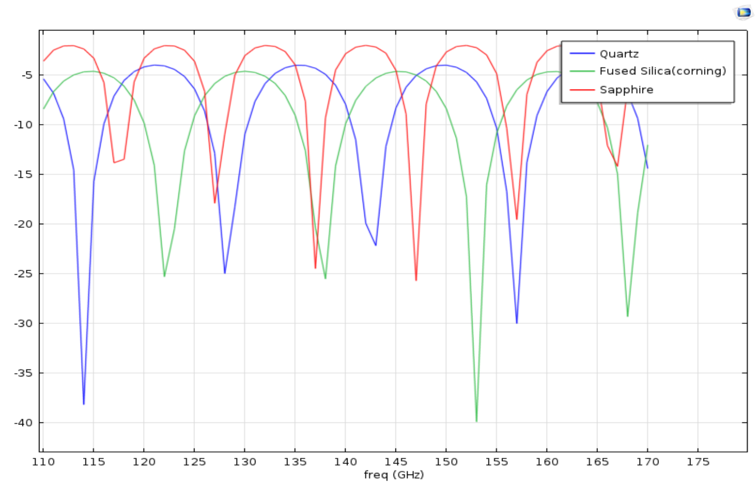


Dielectric Constants

Window Materials	Dielectric Constants
Quartz	4.43 [3]
Fused Silica	3.84 [4]
Sapphire	9.38 [5]

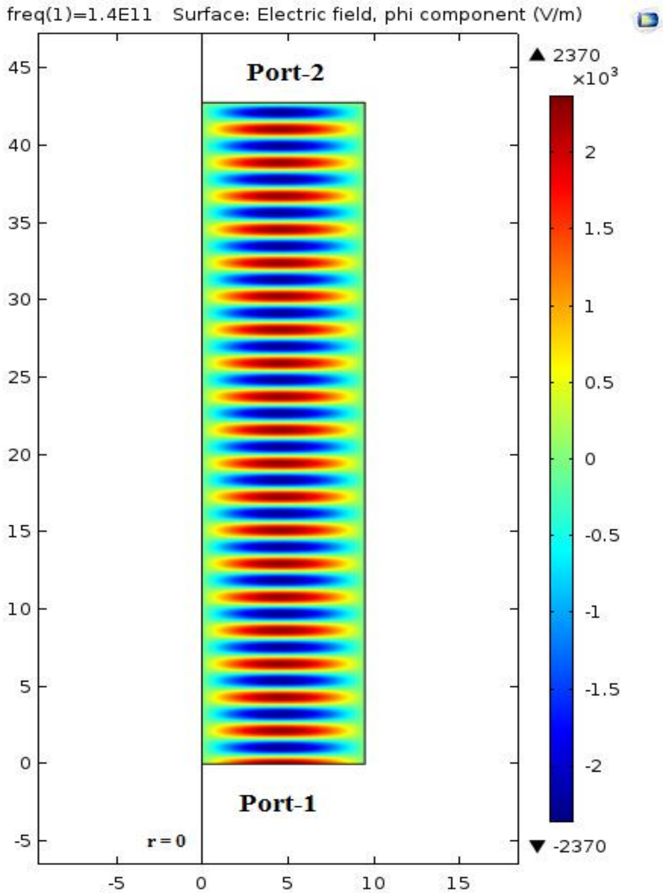
It is assumed that Materials are Isotropic and their properties are constant over frequency range

S11[dB]

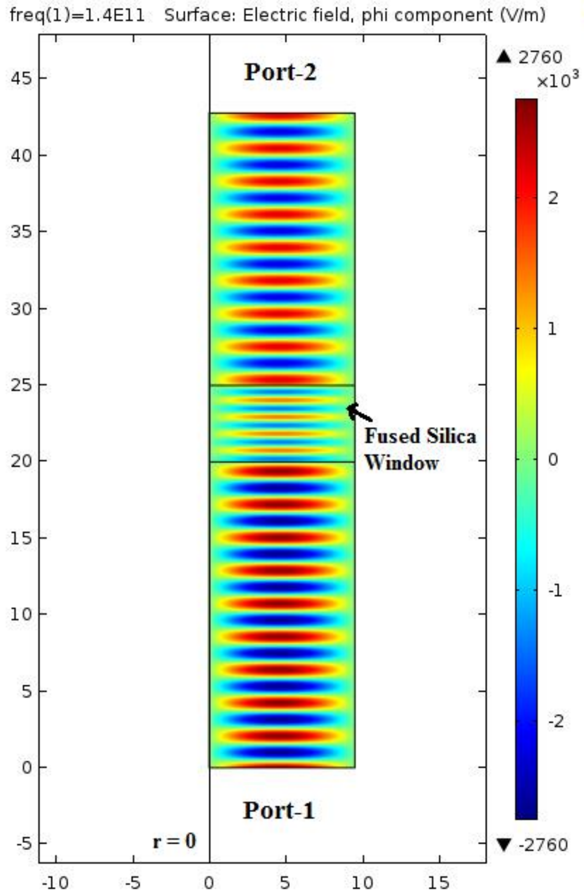


Results

Without Window

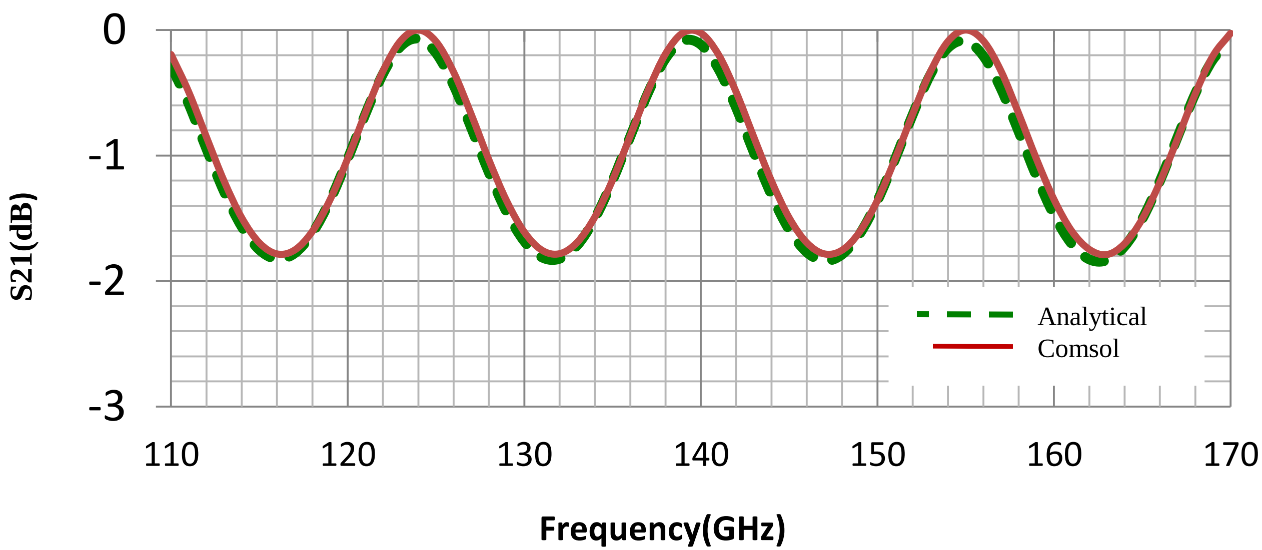


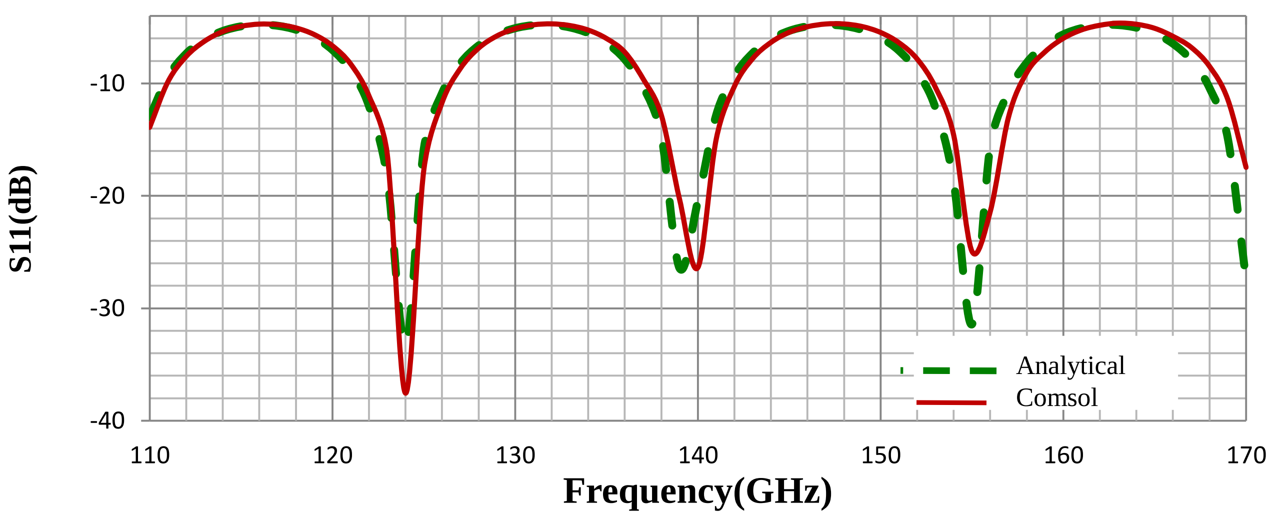
With Window



Propagation of Ephi component of TE01 mode

Comparison with Theory





Conclusions

- Multiple reflections of EM wave are occurred inside waveguide window which is reason behind generation of standing wave pattern

- Fused Silica offers better transmission than other dielectric materials for millimeter waves

- Simulation results are matching excellent with theory. Simulation results show 0.17% variation with respect to analytical result

References

[1] S. Bashaiah, P. Sharma, “Fabrication of High Dielectric Constant and Low Loss X Band Ceramic Waveguide Window for High Power Applications”, IEEE, 5th International conference on Computers and Devices for Communication, 2012

[2] R.Nesti, V. Natale, “Notes on Dielectric Characterization in Waveguide”, IRA-INAF Arcetri Astrophysical Observatory

[3] B. Klaus, J. Rivas, “Temperature Dependence of the Permittivity and Loss Tangent of High-Permittivity Materials at Terahertz Frequencies”, IEEE transactions on microwave theory and techniques, vol. 53, no. 4, 2005

[4] R. Bhaskaran, “Double window configuration as a low cost microwave waveguide window for plasma applications”, Rev. Sci. Instrument.68 (12), p.4424, Dec 1997

[5] C. Donaldson, W. He et’ al’, “Microwave windows for W-band gyro-devices”, IEEE microwave and wireless components letters, vol. 23, no. 5, 2013

Thank You…