Study and Analysis of Power and Polarization Splitting techniques for mm waves using COMSOL Multiphysics 5.2a

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Abstract- To test different properties of plasma radiation, different ECE instruments like Michelson interferometer and Radiometer are placed at a distance from the front end optics. To guide the radiation source from the front end optics to the measuring instruments, power/beam splitter box or power switching techniques are used. In this paper, numerical simulation of different techniques for power and polarization splitting unit is analyzed using COMSOL Multiphysics 5.2a software. First technique is of rectangular waveguide power splitter unit, in which the power at the output ports are analyzed. Second technique discussed is based on wire grid polarizer having a unit cell structure. Transmission coefficient for parallel and perpendicular waves are simulated. Lastly, circular waveguide based power splitter unit is designed and analyzed for power distribution at output ports.

Keywords:*Waveguide, Millimeter waves, Power and Polarization Splitting, COMSOL Multiphysics (RF Module)*

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I. INTRODUCTION

Active free-space millimeter wave (mm-wave) systems have gained more and more attraction during the last few years due to their various applications. Front-end components are of an essence to any millimeter waves subsystem. Power dividers (equal division and unequal division) are important front-end components in many millimeter wave systems. Diagnostics systems are installed inside and outside the tokomak's vacuum chamber used to measure the plasma's temperature or density profiles. Objective of Electron Cyclotron Emission (ECE) diagnostic system is to obtain time evolution of electron temperature with high temporal (~ microsec) and spatial (~ cm) resolution from Plasma radiation. In ITER, the ECE radiation over a wide range of frequency (70 to 1000 GHz) is required to be carried over a distance 30-40 meters from the tokamak to the diagnostics area. The intensity of ECE radiation is low at high frequency. To test different temporal and spatial properties of plasma radiation, different ECE instruments like Michelson interferometer and Radiometer are placed at a distance from the front end optics. The ECE Diagnostic instruments are designed to receive the power in specific frequency bands and polarization. To guide the radiation source from the front end optics to the measuring instruments, power/beam splitter box or power switching techniques are used. [5] An oversized circular waveguide is used for transmitting the low power mm-wave radiation from the fusion plasma to millimeter wave diagnostics system.

P Buratti et.al [1] showed a 16 m long, square pipe which is used to links the power splitter system with the spectrometers. The power splitter system included H-plane wave front divider which splits the square section pipe into two rectangular ones connected to the Fourier transform spectrometer and to grating polychromator respectively. A. Simonetto et. al. [2] represented a confocal quasi optical system made of modular blocks using mirrors and wire grid polarizer to split the polarizing beam. The characteristic of the wire-grid polarizers in sub millimeter wave range was represented by Hairui Liu et.al. [3] A millimeter wave beam splitter was designed by S. Islam et.al [4]with slot FSS array where the slot length is the main design parameter used to optimize the phase properties of the array. D. A. Naylor et.al [5] shows Mylar beam splitters for far i.r. Michelson interferometers. The main concern of power splitter design analysis is to achieve low return loss, low insertion loss, high isolation loss, phase difference, gain, port matching, good amplitude, wide bandwidth, and compact size. We have analyzed two techniques for power and polarization splitter unit according to our design parameters and compared results which are discussed in this paper. Simulation is carried out in RF Module of COMSOL Multiphysics software.

II. COMSOL Multiphysics (RF Module)

COMSOL Multiphysics is Finite element method based simulation software. It solves electromagnetic Maxwell's equation using Finite element method. RF Module of COMSOL allows users to study and analysis of S-parameters and electromagnetic wave propagation. It solves equation for frequency domain based on three basic material properties: Electrical conductivity, Relative Permeability and Relative permittivity. The electrical conductivity quantifies how well a material conducts current. The relative permittivity quantifies how well a material is polarized in response to an applied electric field and the relative permeability quantifies how a material responds to a magnetic field.We have assumed that materials are isotropic and their properties are constant over frequency range.

Physics: Electromagnetic Wave, Frequency Domain

The Physics applied to the model is the Electromagnetic Wave, Frequency Domain. The Wave Equation, Electric is the main feature node of this physics interface. The governing equation is given below

$$\nabla \times ({\mu_r}^{-1} \nabla \times E) - {k_0}^2 \varepsilon_{rc} E = 0$$

The wave number of free space k_0 is defined as

$$k_0 = \omega\sqrt{\varepsilon_0 \mu_0} = \frac{\omega}{c_0}$$

where c_0 is the speed of light in vacuum. Relative Permittivity is selected as the Electric Field Displacement model, the default Relative Permittivity ε_r is taken from the material applied. Relative Permeability is selected as the Magnetic Field, the default Relative Permeability μ_r is taken from the material.

III. Analysis of power and polarization Splitter techniques using COMSOL Multiphysics

A. Rectangular Waveguide Power Splitting Unit

As per the design concept of the power splitting unit for mm waves in P. Buratti [1], a model is prepared in COMSOL Multiphysics software to analyze the splitting process of the incoming radiation with an arrangement of reflecting mirror. A model consisting a square waveguide as an input is designed in software which further divided into two rectangular waveguide using a reflecting mirror placed at the center of the waveguide with an angle of 45º rotation. The geometry consist of air as the inner material inside the waveguide and the outer surface is treated as Perfect Electric Conductor. Here, mesh is applied on the geometry is unstructured free triangular mesh.

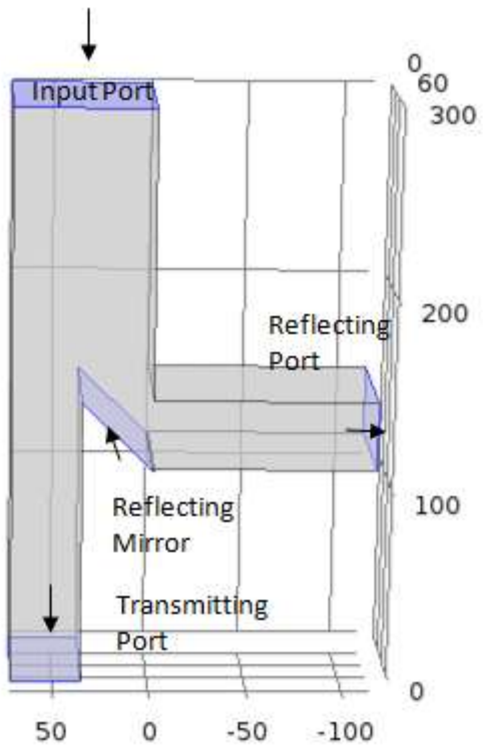

Figure 1:3D model of rectangular splitter unit

Simulation Results

S-Parameters

The transmission and reflection can be measured using the S-parameters. S-parameters are complex values, frequency dependent matrices describing the transmission and reflection of electromagnetic energy measured at different ports of waveguides. S-parameters in terms of power can be expressed by equation [28],

$$S_{31} = \sqrt{\frac{Power\ delivered\ at\ port-3}{Power\ incident\ on\ port-1}}$$

$$S_{21} = \sqrt{\frac{Power\ delivered\ at\ port-2}{Power\ incident\ on\ port-1}}$$

$$S_{11} = \sqrt{\frac{Power\ reflected\ from\ port-2\ and\ port-3}{Power\ incident\ on\ port-1}}$$

S-parameters for the geometry is computed using COMSOL Multiphysics software at the operating frequency of 3-12GHz with input power of 1W for TE_{01} mode. Power at the transmitting port and reflecting port is shown in the fig 5.7 below. Graph shows nearly equal power division at higher frequencies. Due to limitation of the computational resource, analysis upto 12 GHz is carried out in the software.

ISSN: 2321-8169
273 – 276

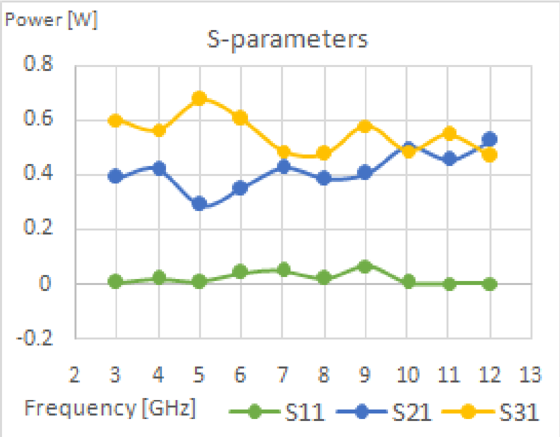

Figure 2: S-parameters plot for different frequencies

B. Wire Grid Polarizer

Closely wound grids of fine wire act as polarizing elements at millimeter, sub- millimeter, and far infrared wavelengths. A free-standing grid will cause less absorption than a grid fabricated through deposition of metal onto a substrate; however, precise free-standing grids become difficult to make as the wire dimension and spacing become small. Hairui Liu .et.al[4] presented the characteristic of the wire-grid polarizers in sub millimeter wave range. The transmittance of wire-grid polarizer was evaluated by using a novel quasi-optical system having free standing wire grid polarizer. A model in COMSOL Multiphysics is developed to analyze characteristics of the transmittance coefficient of wire grids with different wire spacing and incident angle.

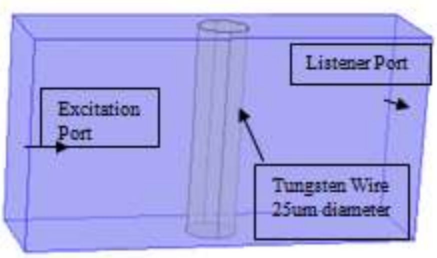

Figure 3: 3D model of the unit cell

A *unit cell* for wire grids shows the free standing wire grids which are separated by period ***h*** of 50µmand has diameter ***a*** of 25µm. RF module is used to simulate an electromagnetic wave incident upon periodic structures as wire grid polarizers. It uses Floquet periodic boundary conditions and periodic ports to compute the reflected and transmitted electromagnetic waves as a function of incident angles and wavelength.Mapped mesh is applied on the geometry which maps a regular grid defined on a surface of the domain.

Simulated results

(a) Parallel transmission

For millimeter wave's frequency range of 70-1000 GHz, transmittance for vertical polarization at 0 degree incident angle for $\frac{1}{2} \leq \frac{a}{h} \leq \frac{1}{5}$ is analyzed as shown in the figure. The transmittance is very low as the field parallel to the wire grids.

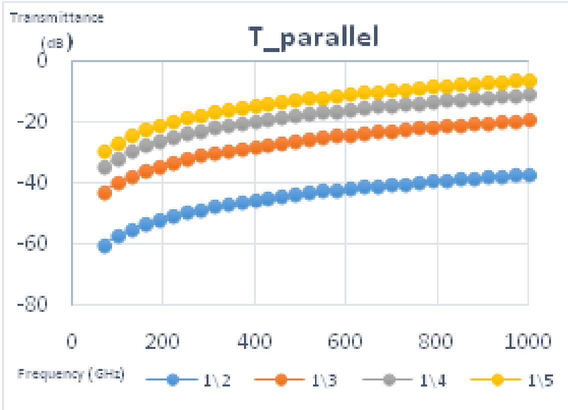

Figure 4: Transmittance for parallel transmission at 0 degree incident angle for $\frac{1}{2} \leq \frac{a}{h} \leq \frac{1}{5}$

(b) Perpendicular transmission

For millimeter waves frequency range of 70-1000 GHz, transmittance for horizontal polarization at 0 degree incident angle for $\frac{1}{2} \leq \frac{a}{h} \leq \frac{1}{5}$ is analyzed as shown in the figure. The transmittance is very high as the field perpendicular to the wire grids.

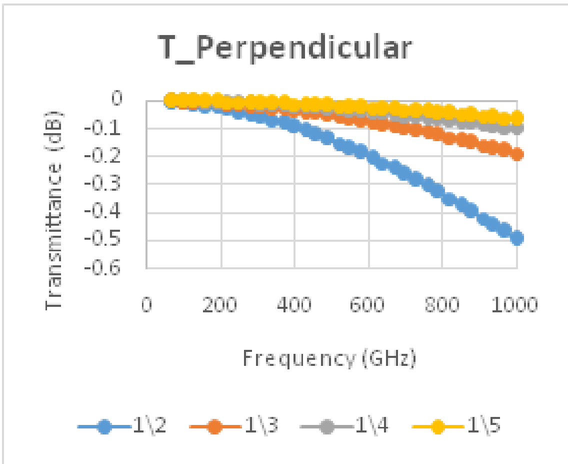

Figure 5: Transmittance for perpendicular transmission at 0 degree incident angle for $\frac{1}{2} \leq \frac{a}{h} \leq \frac{1}{5}$

C. Circular Waveguide Power Splitter

An oversized circular waveguide is used for transmitting the low power mm-wave radiation from the fusion plasma to millimeter wave diagnostics system. The ECE Diagnostic

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273 – 276

instruments are designed to receive the power in specific frequency bands or polarization. Therefore, a beam or polarization splitting unit is required to split the millimeter wave radiations. A splitter box consisting of circular waveguide is simulated at low frequencies due to limitation of computer memory of workstation.

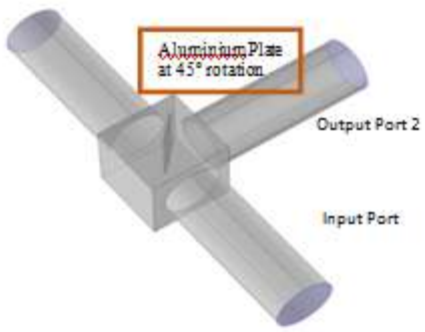

Figure 6: Design of circular waveguide splitter unit

Here, the above fig shows the design geometry of the circular splitter unit with diameter of 72mm and aluminium plate as splitting mirror placed with 45º angle of rotation.

Simulated Results

The fundamental mode of the circular waveguide, TE_{11} is excited through the input port with 1 W power. The resultant power ratio at the two output is analyzed. Due to limitation of computational resource, the 3D geometry is computed at low frequencies. Table 1 shows the S-parameters for different frequencies. Very preliminary results are presented.

Table 1: S-parameters

Frequency[GHz]	S-parameters		
	S11	**S21**	**S31**
3	0.0469	0.465	0.488
4	0.376	0.368	0.256
5	0.25	0.08	0.67
6	0.334	0.237	0.429
7	0.2423	0.3474	0.3994
8	0.633	0.23	0.135

IV. CONCLUSION

Based on literature study we concluded that various techniques are available for beam and polarization splitting in mm waves. We used the power splitter design concept described by P Buratti [1] and simulated the same for low frequency due to limitation of computation resources. The characteristics of free standing wire-grids in sub-millimeter wave range is analyzed according to conceptual design given by Hairui Liu [4]. A Circular waveguide based splitter unit is designed with 72 mm diameter and simulated at low frequency due to limitation of computational resources.

REFERENCES

[1] P. Buratti, 0. Tursco and M. Zerbini “A broadband light collection system for ECE diagnostics on the FTU tokamak” *Elsevier, Infrared Physics*. Vol. 34, No. 5, pp. 533-541, 1993.

[2] A. Simonetto, Ist. di Fisica del Plasma, CNR, Milan, Italy, C. Sozzi , S. Cirant , A. Bruschi, “Design of the quasi optical interface system for JET's new microwave access” *IEEE Infrared and Millimeter Waves, 2004 and 12th International Conference on Terahertz Electronics*, Vol.10, issue 3, 0-7803-8490-3, Oct 2004.

[3] S. Islam, J. Stiens, I. Jaeger and Roger Vounckx, “Grounded Frequency Selective Surface Array as Millimeter Wave Beam Splitter”, *Society of Photo Optical Instrumentation Engineers (SPIE) Digital Library*, Vol. 6994 69940A-1, 2008.

[4] Hairui Liu, Junsheng Yu and Xiaoming Liu “Characteristic of Free Stand Wire-Grid Polarizers in Sub-millimeter Wave Range”, *Applied Mechanics and Materials* Vol 290 pp 127-132, 2013.

[5] C. L. Mok, W. G. Chambers, T. J. Parker and A. E. Costley “The Far-Infrared Performance and Application Of Free-Standing Grids Wound From 5μm Diameter Tungsten Wire”, *Infrared Physics* Vol. 19. pp. 437 to 442, 1979.

[6] D. A. Naylor, R. T. Boreiko, and T. A. Clark “Mylar beam-splitter efficiency in far infrared interferometers: angle of incidence and absorption effects”, *Applied Optics*, Vol. 17, No. 7, 1 April 1978.

[7] G. Taylor, et al “Status of the design of the ITER ECE diagnostic” *European Physics Journal Web of Conferences*, 2015

[8] Lee, C. S.; Lee, S. W.; Chuang, S. L., “Plot of Modal Field Distribution in Rectangular and Circular Waveguides,” *IEEE Transactions onMicrowave Theory and Techniques*, vol.33, no.3, pp.271,274, Mar 1985.