Study of Fabry Perot Type Band Pass Notch Filter at 170 GHz

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Abstract— A Fabry Perot band pass Notch filter at 170 GHz has been studied for use in millimetre wave Fusion Plasma Diagnostics. Notch filters are needed to protect ECE Diagnostic from stray RF heating power. We have designed a notch filter which can transmit the Electron Cyclotron frequencies from 70-1000 GHz and reject 170 GHz. Good results have been obtained for transmission and reflection of the filter. In this paper we will present the study and theoretical analysis of Fabry Perot Notch filter. We inferred that there are multiple band pass notches at the multiple harmonics of the 170 GHz.

Key words: Wide band stop filter, Notch filter, Fabry Perot filter

I. INTRODUCTION

There will have high power Gyrotron system at 170 GHz for plasma heating and other applications on ITER. These RF sources give high levels of stray radiation. This stray radiation is potentially harmful to other RF systems, one of which is the ECE diagnostics system. Therefore, necessary arrangements need to be done to protect the systems from such stray radiation. One such protection mechanism is use of quasi-optical notch filters in the transmission line. Notch filters reflect back the unwanted stray radiation at band stop central frequency while allowing all other frequencies to pass through it. The ECE diagnostic frequency range extends from 70-1000 GHz. The filter needs to be designed such that it has low insertion loss for the ECE frequency range 70-1000 GHz and a high return loss of more than -30 dB at 170 GHz with notch bandwidth of less than 4 GHz. Also it should have good power handling capability so that it can withstand high stray RF power of ~20 KW. There are many techniques for design of notch filter such as ladder network of LC components, dielectric resonator filters, filter using stub etc. But they have low power handling capabilities. In this paper, we summarize the various types of notch filter configurations and their responses which are used in Fusion diagnostics worldwide. The different types of configurations include Fundamental waveguide using resonator cavities, molecular absorption gases, Corrugated waveguide structure and Fabry Perot filter [1-7,11-13]. Fabry Perot filter is proposed as a possible solution meeting our requirement. In order to use Fabry Perot filter as a notch filter, it has to be kept at an angle (<90 degree) so that transmitted frequency(170 GHz) is absorbed. We present the study of the Fabry Perot Band pass notch filter in this paper.

II. TYPES OF NOTCH FILTER

1) Fundamental waveguide using resonator cavities

In this method, Fundamental rectangular waveguide is used with side coupled resonator cavities. This method provides the good rejection up to the -100 dB [3] at band stop central frequency. However, it has limited pass band due to cutoff frequency of Fundamental waveguide and after cutoff frequency, transmission of waveguide will be distorted.

2) Corrugated waveguide

Corrugated waveguide is based on the principle of Bragg reflection. There is a corrugation inside the wall of oversized waveguide. The corrugation period and number of corrugations decide the response of filter. For the frequencies for which Bragg condition is satisfied, the corrugated waveguide works as a reflector at those frequencies. For the frequencies for which Bragg condition is not satisfied, then those frequencies can pass through the waveguide. This method provides very low insertion loss in pass band and provides very low notch band width of Megahertz. In the Corrugated waveguide notch filter configuration, there is fundamental waveguide at the input of the filter. But as per the ITER requirement, the notch filter needs to be placed in the oversized circular waveguide transmission line having inner diameter of 72 mm. Therefore the corrugated waveguide filter is not suitable for the ITER ECE diagnostic system .

3) Molecular absorption gases

This method is based on absorption mechanism. In a gas chamber, Carbon Sulphide (OCS) molecule and Hydrogen Sulphide (H2S) molecules are used at some specific pressure. According to pressure and path length the resonant frequency and pass band insertion loss will be defined. But in this method we get multiple notch frequencies and it also does not support wide band frequency range 70-1000 GHz [3].

4) Fabry Perot Filter

These are optical filters, made up of the two parallel plates placed at few distance apart depends on wavelength of the radiation. These plates and spacer medium are made up of different dielectric constants. Due to this; interference is created between two successive transmitted waves. Constructive interference passes the radiation at the particular wavelength and destructive interference blocks the radiation at the particular wavelength. Material selection, distance between two plates and phase difference between two successive transmitted wave are important parameters. By using multiple stacks of alternate high and low index, we can improve notch bandwidth. As number of layer increases, notch bandwidth decreases and transmittance decreases [10-13]. These optical filters can provide wide band transmission of up to 1THz and sharp notch.

5) Frequency Selective Surface filter

Frequency Selective Surface (FSS) is a wireless filter in microwave frequency range. FSS structures exhibit the filtering property of pass band and stop band using apertures and printed patches. For band stop filter metal patches of arbitrary shapes can be used. These metal patches are printed onto the dielectric substrate. FSS can be used as an antenna, filters etc. They are used for low frequency as well as high frequency applications [4-6, 9, 14, 15]. They provide the band stop notch filter with notch band width of 10-20 GHz in high frequency applications [5]. We can reduce the band width by increasing the metal thickness and by using multiple layers of FSS structures [16-17].

Thus, it can be understood that there are two techniques which are suitable for our application: Fabry Perot filter and FSS filter. Fabry Perot filter provides notch band width in MHz and wide band transmission of up to optical range, therefore we have carried out the study of the of the Fabry Perot band pass filter.

III. FABRY PEROT FILTER DESIGN

Fabry Perot Filter is used in optical range as a notch filter for passing or reflecting particular frequency. Fabry Perot filter consists of two flat mirrors separated by spacer which is half wavelength thick. It is based on the principle of multiple beam interference. Its fringes are very sharp. So it is called narrow band filter or notch filter. When any plane wave or light incident on the boundary between two media; reflection and refraction occurs. Some of the light is reflected and some of the light is propagated into the second medium. Phase and amplitude of reflected and refracted waves depend on the physical laws. Phase difference between two waves is $\delta=m\pi$. For m=0, ±1, ±2… Transmittance T is maximum, there is constructive interference and for m=±1/2, ±3/2… there is destructive interference. Successive peaks of T are called fringes and m is called order of fringes. The ratio of adjacent fringes to the FWHM (Full Width Half Maximum) is called finesse. It gives the sharpness of filter [13]. We define the transmittance T as the ratio of transmitted and incident intensities, and reflectance R as the ratio of reflected and incident intensities. These parameters are given by equations 3.1 and 3.2 [13].

Here n0,n1 is the refractive index of incidence medium and transmitted medium respectively.

$$T=\frac{I_t}{I_i}=\frac{4n0n1}{(n0+n1)^2} \quad (3.1)$$

$$R=\frac{I_r}{I_i}=\frac{(n0-n1)^2}{(n0+n1)^2} \quad (3.2)$$

$$\text{Transmittance } T=\frac{1}{1+F\sin^2(\delta)} \quad (3.3)$$

Where, $\delta=(2\pi nd\cos\theta)/\lambda$; n and d are refractive index of spacer material and distance between two plates.

Finesse $f=(\pi\sqrt{F})/2$ = FSR/FWHM

Where F is the coefficient of finesse and it is given by,

$$F=\frac{4R_S}{(1-R_S)^2} \quad (3.4)$$

For multiple layers the reflectance is calculated as,

$$R=\left[\frac{1-\left(n_H/n_L\right)^{2P}\left(n_H^2/n_S\right)}{1+\left(n_H/n_L\right)^{2P}\left(n_H^2/n_S\right)}\right]^2$$

where, n_H and n_L is the refractive index of high and low index material respectively. n_S is index of the spacer material and there are 2P+1 number of layers in whole stack [13].

IV. SIMULATION RESULTS FOR 170 GHZ NOTCH FILTER

The design calculation of Fabry Perot notch filter has been done using the mathematical tool MATLAB. Different parameters considered for the design are given in Table 1.2

Parameters	Value
Resonant Frequency or wavelength	170 GHz
High index material and refractive index	Mica, n=1.53
Low index material and refractive index	Air, n=1
Loss Tangent of Mica	0.0001
Value of m	3
Incident angle	20°
No. of layers	8

Table 1.2: List of parameters for designing 170 GHz Notch filter

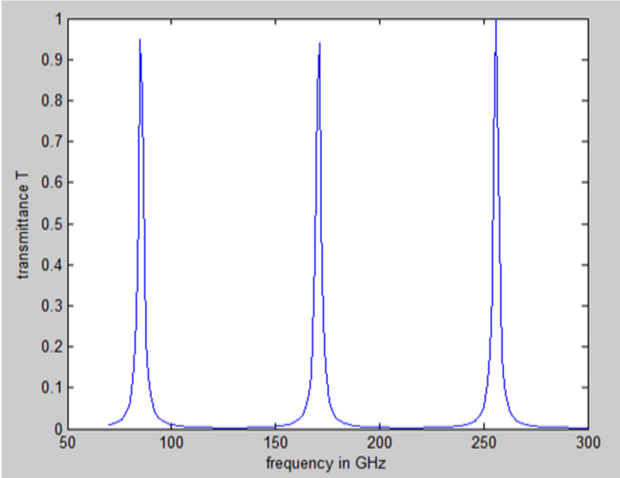

Fig. 1: Transmittance vs. frequency graph for 170 GHz

Here from the above figure we can see that it gives notch at 170 GHz. Pass band is from 70-300 GHz. We get notch frequencies at the multiples of distance between two plates. In pass band of 70-300 GHz, we get three notch frequency components.

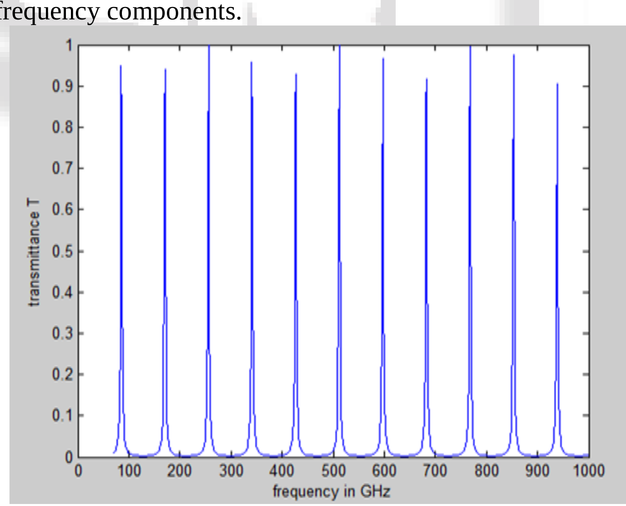

Fig. 2: Transmittance vs. frequency graph for 170 GHz in Full Band 70-1000 GHz

Above figure shows full band simulation from 70-1000 GHz. We have got 11 notch frequency components of same amplitude. This is not acceptable due to multiple notch frequency components present in the response which leads to higher losses.

V. CONCLUSION

There are two types of notch filters, Fabry Perot filter and Frequency Selective Surface Filter which can meet our requirement. From the calculation results for Fabry Perot filter, we can see that multiple notch frequencies are obtained in pass band from 70-1000 GHz which is not acceptable for our application. So further analysis of second type, (i.e., Frequency Selective Surface) notch filter will be done to assess its suitability for ITER ECE diagnostic system.

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