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Analysis and Design of A Waveguide Notch Filter for Ka Band Applications

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ABSTRACT

Filters have played a very important part in electronic circuits to pass or block a certain band of frequencies that are required for specific tasks and applications; hence they become an important block into building such circuits. Waveguides are metal conduits used to confine and direct radio signals which are most commonly rectangular or circular at the cross section. A waveguide filter is an electronic filter that is made up of waveguide components. It has the same range of applications as other filter technologies in electronics and radio engineering but is different mechanically and in its principle of operation. Waveguide filters can be used in the frequency range of 2 GHz to 40 GHz. In this paper we talk about simulating a notch filter operating in the K_a band of microwave frequency, to filter out the desired frequency between 36.5 -37 GHz in the EHF band as defined under ITU regulations.

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1. INTRODUCTION

The need to filter or select a single frequency or a set of frequencies has been seen since the early war-time ages where the radio communication could efficiently happen at a specific VHF/UHF band for short distance communication and HF for long distance communication. Hence, a system or circuit that could do the same was necessary and essential to make communication effectively possible. Similarly, to tune on to different frequencies or a different spectra of light, we must be able to filter out or select a certain frequency at which the object or source that we want to see must be tuned or be vibrating upon. So to carry out the same for detecting cosmic radiations that consume the entire spectra of light we must be able concentrate on a specific frequency to observe the celestial bodies, since some cosmological objects are found to be operating in the Meter to sub millimeter ranges, we use transmission lines and filters designed especially for them in the radio telemetry instead of the lumped element filters that are used in smaller circuits for household requirements.

Transmission lines are capable of transmitting electromagnetic energy at which all light systems and celestial bodies radiate or absorb. These transmission lines exhibit various losses such as copper loss, dielectric loss, radiation loss and skin effect[1]. They are non planer devices so their integration with planer circuit and its components is difficult. As compared to traditional transmission lines metallic waveguides are a better wave guiding or electromagnetic transmission preference. Metallic waveguides are made of integration of active and passive components usually require transition from planar to non planar circuits. But, metallic waveguides are bulky and expensive to manufacture which make planar/non planar integration costly and voluminous[2].

Waveguide filters have less in common with lumped element filters; they do not contain any discrete capacitors or inductors. The design of a waveguide filter frequently starts from a lumped element design and converts the elements of that design into waveguide components. Waveguide filters operate in the frequency range of 2 GHz to 40 GHz. The normal transmission mode followed is the dominant TE_{10} for the rectangular waveguides. These are microwave filters that have very a low loss and high Q factors[3,4,5]. The only limits in their applications arise due to the relatively large size of the system as compared to that of a standard transmission line and the construction and setup costs.

A notch filter is used to remove a narrow band of frequencies from the signal path of a receiver or transmitter. For a conventional, “single-transmission-zero” notch filter, the maximum attenuation, or notch depth, occurs at a single frequency midway between the specified edges of the lower and upper passbands, and the selectivity can be described as the ratio of the notch depth to the bandwidth between the edges of the passbands[6,7,8].

This paper focuses on the simulation and building up of a Waveguide Notch filter with air as a substrate and 2 pure copper metals to support the necessary boundary conditions. The same has been simulated on the software CST Microwave studio – CST STUDIO SUITE [Student Edition] v. 2017. The Filters that have been simulated are Notch Filters, which are Band Stop Filters for a very small (<1GHz) Bandwidth (Filter a specific frequency) and a very high Q Factor, filtering the frequencies in the narrow frequency band between **36.5 – 37 GHz** in the ELF range of the microwave region which lies within the K_a band and can hence be used for further applications in cosmology etc.

2. WAVEGUIDE EQUATIONS:

The Cut-off frequency or f_c is defined as the minimum frequency below which the Electromagnetic Wave propagation is not possible. It is defines in the equation[9]

$$f_c = \frac{kc}{2\pi\sqrt{\mu\epsilon}} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (2)$$

The corresponding Cut-off Wavelength is determined by λ_c as defined in equation[10]

$$\lambda_c = \frac{2}{\sqrt{\left[\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2\right]}} \quad (3)$$

For the Dominant TE_{10} mode,

m = 1 ; n = 0

thus, f_c and the corresponding λ_c becomes;

$$f_c = \frac{1}{2\pi\sqrt{\mu\epsilon}} \quad (4)$$

$$\lambda_c = 2a \quad (5)$$

$$\beta = \sqrt{(2\pi f)^2\mu\epsilon - \left(\frac{\pi}{a}\right)^2} \quad (6)$$

3. OPTIMIZATION TECHNIQUES

The waveguide filter has been simulated on the CST Microwave Studio Suite [Student Edition] 2017 along with the Observed Plots and calculations as performed by relating to the results obtained. Reconfigurable antennas can also be designed using CST studio suite[11].

The Basic Units observed throughout the analysis are as follows:-

Dimensions – Millimeter or mm

Frequency – Gigahertz or GHz

3.1 Waveguide Filter 1

Dimensions considered for this waveguide filter are defined under the following variables:

- **slength** = Length of substrate along X Direction = **50mm**
- **swidth** = Width of substrate along Y Direction = **10mm**
- **sthick** = Thickness of substrate along Z Direction = **20mm**
- **metal_thick** = Thickness of metal used as boundary plates = **0.1mm**

Material of Substrate → Air

Material of Metal → Pure Copper

Table 2 Properties of metal

PROPERTY	VALUE
Material	Copper (pure)
Type	Lossy metal
Mu	1
Electric conductivity	5.96e+007 [S/m]
Rho	8930 [kg/m^3]
Thermal conductivity	401 [W/K/m]
Heat capacity	0.39 [kJ/K/kg]
Diffusivity	0.000115141 [m^2/s]
Young's modulus	120 [kN/mm^2]
Poisson's ratio	0.33
Thermal expansion	17 [1e-6/K]

3.2 3-D MODEL

The construction of the 3-D Model followed the following steps:

1. Building a substrate of dimensions – 20*10*50 mm^3
2. Attaching a Metal Plate of thickness 0.1mm to the top and bottom of the substrate
3. Establish Port 1 as Input for EM propagation in X Direction
4. Establish Port 2 as Output for EM propagation in X Direction
5. Simulate the time domain solver for obtaining the results with a (-40dB) accuracy

Following are the model clippings from the CST MWS Studio Suit [Student Edition] 2017:

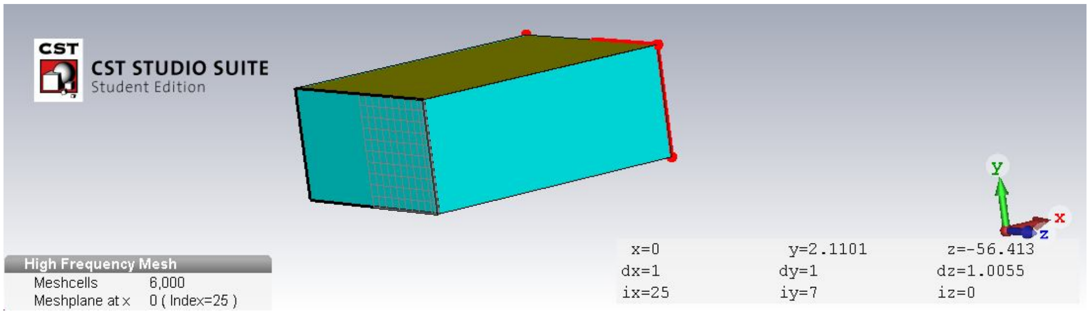

Fig. 1 Mesh of the Waveguide in the orientation along the axes on the bottom right corner

4. OBSERVATIONS AND PLOTS

Following are the Plots as obtained during the Time Domain simulations:

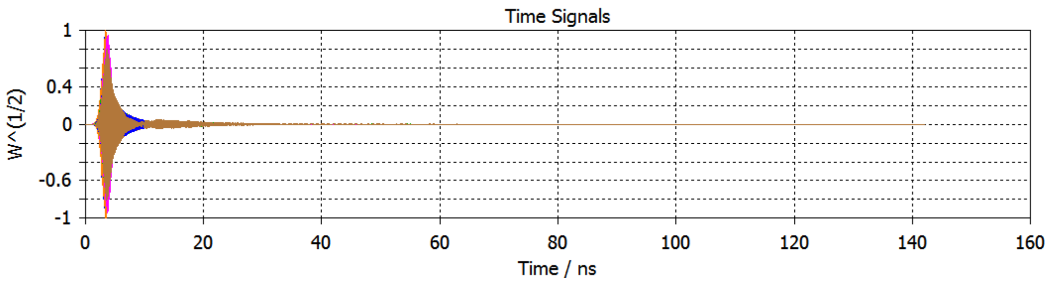

Fig. 2 Port signals from input port to output port

4.1 S- Parameter Plots

The S-parameter plots will ultimately determine the type of filter simulated.

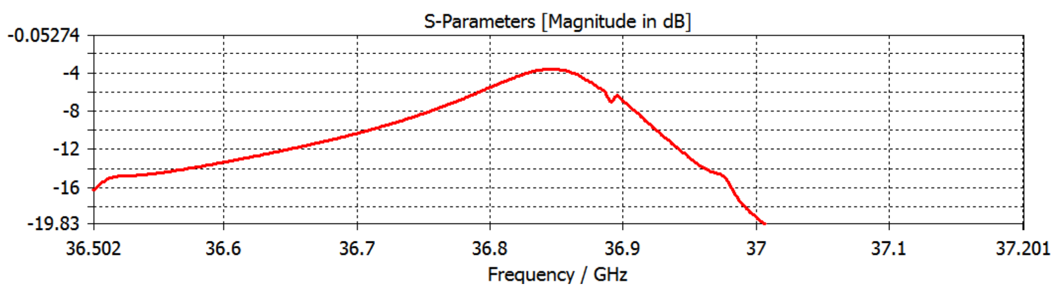

Fig. 3 S_{11} Plot

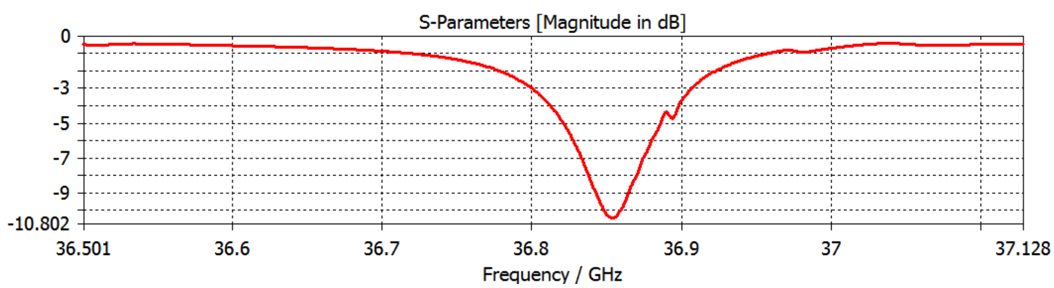

Fig. 4 S21 Plot

NOTE: We Observe that the S21 Plot is the EXACT Opposite of the S11plot, hence at the specific frequency of 36.854 GHz, we STOP the Band

Hence Notch Filter for Frequency 36.854 GHz at Peak and the narrow stop-band is:

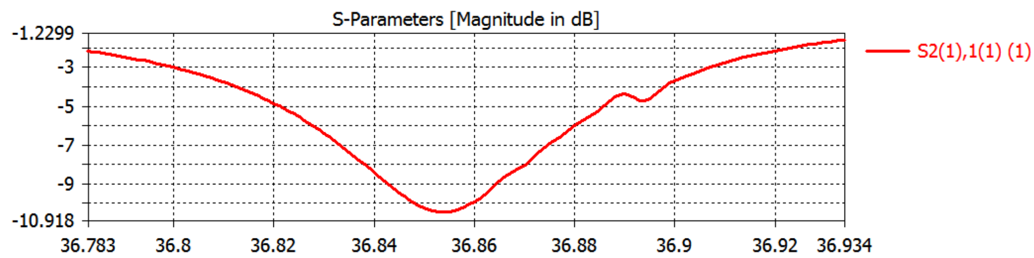

Fig 5 Frequency Stop-Band 36.783 – 36.934 GHz

4.2. Power And Energy Analysis Of Waveguide Notch (Narrow Stop-Band) Filter

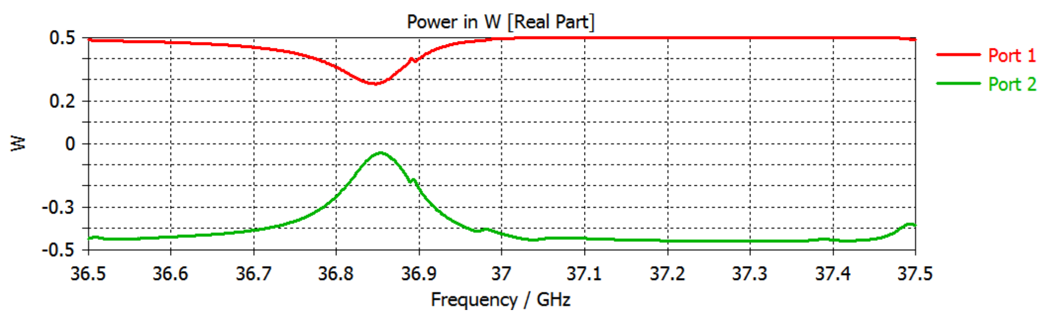

Fig 6 Power Accepted per Port

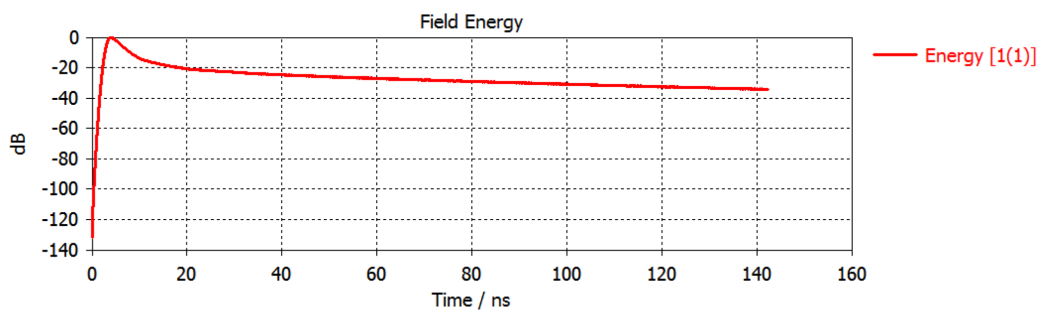

Fig 7 Field Energy

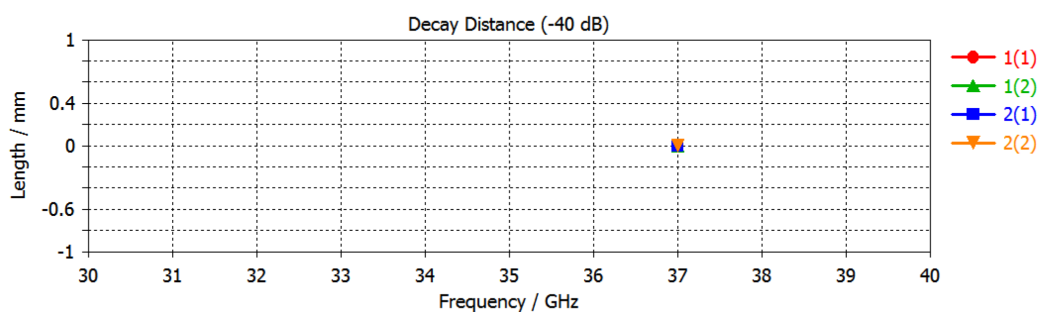

Fig 8 Decay Distance at 37 GHz

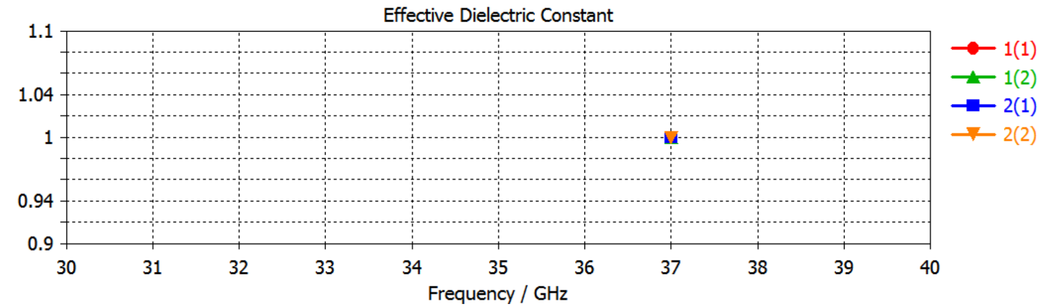

Fig 9 Effective Di-Electric Constant

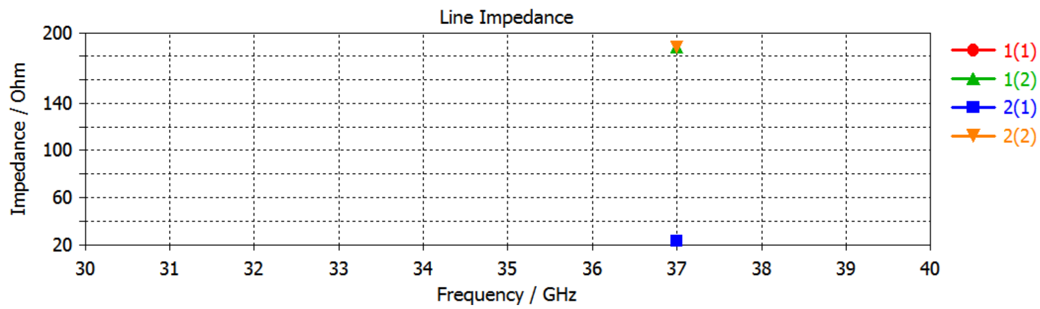

Fig 10 Line Impedance

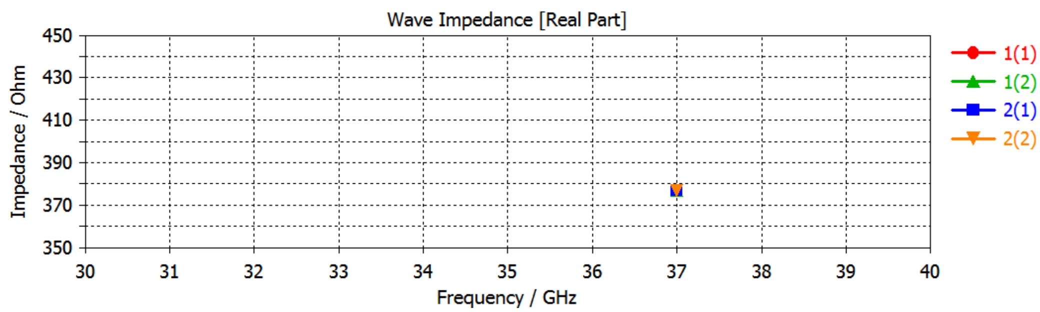

Fig 11 Wave Impedance

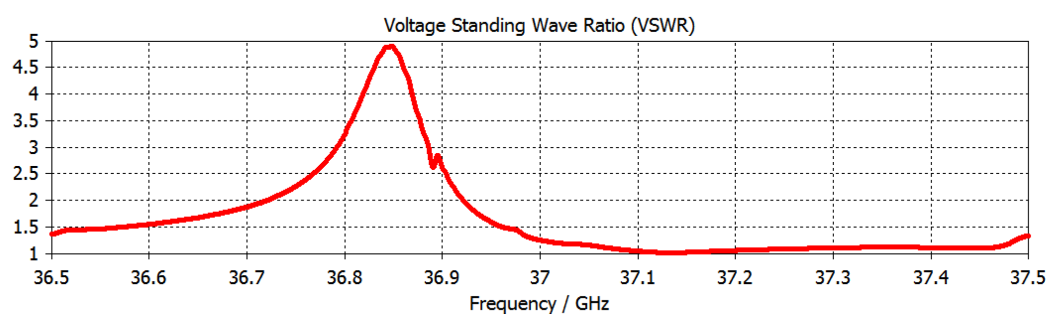

Fig 12 Voltage Standing Wave Ratio(VSWR) max value at 5

5. CONCLUSION

Starting with the building up, two Waveguide Notch Filters operating in the Ka Band of Microwave frequencies have been simulated at the narrow band width of **36.74-36.98 GHz, filtering waves of 8.14 mm** with peaks falling at **36.854 GHz and 36.849 GHz**. This has been established for a waveguide filter with air as a substrate and copper plates as boundary metals for the top and bottom. The waveguide filters built in this project can further be enhanced to form Substrate Integrated Waveguide filters or SIW's in which a different substrate other than air can be used inside the waveguide to give specific results for targeted frequencies and be used in applications for RADAR, satellite links etc. These waveguide filters can hence also be manufactured after simulations (for calculating real-time losses etc.) to be used in hardware applications to implement the above stated applications of these filters.

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