DESIGN, SIMULATION AND MODELLING MICROMACHINED GRATING FILTER

Sanjeev Kumar and Prem Ranjan Kumar
Department of Electronics and Communication Engineering,
Ambedkar Institute of Technology, Delhi, India

ABSTRACT

This paper describes the Design and simulation of micromachined Dielectric waveguide bandpass filter in CST Microwave Studio. CST MWS enables the fast and accurate analysis of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures. HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows us to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time. Simulation is done using this software to determine no. of parameters. A WR-2.5 dielectric waveguide is designed for 67 GHz cut-off frequency. A micro machined dielectric grating waveguide band pass filter is designed for 67 GHz frequency with very sharp transition at both sides of the passband.

KEYWORDS: *Dielectric waveguide, Attenuation, cst microwave studio 9.0 and HFSS.*

I. INTRODUCTION

Dielectric integrated guides have been used in the design of a variety of passive and active components, thus facilitating the realization of complete receiver systems. The theory, design and simulation of dielectric waveguide and passive component grating waveguide filter made from this waveguide are discussed in this paper. In the dielectric waveguide design and simulation is done under CST MICROWAVE STUDIO to determine numbers of parameters. Whereas in dielectric waveguide filter is made Band pass by periodic cut in the structure. By controlling the length and depth of the cut waveguide filter pass band and stop band characteristics is changed.

II. DIELECTRIC WAVEGUIDE

The structure illustrated in Fig 1 is often called 'image line', since, in the absence of the horizontal conducting surface, it represents the upper half of a rectangular dielectric guide of twice the height. The field configuration of that guide is symmetrical and is not affected by a conducting surface in the symmetry plane. The fields inside the dielectric are those of a superposition of real waves travelling under oblique angles with respect to the axis and bouncing back and forth between the side walls. Outside, non radiative (evanescent) types travel along the guide with their amplitudes decreasing in direction away from the dielectric. The waves are attenuated in part due to the losses in the rod. Design of a practical dielectric guide involves a compromise. If the dielectric losses are to be small, the cross-section has to be small too, with the fields reaching far out into the surroundings. With increasing dimensions, on the other hand, the fields become better confined, but the dielectric losses are high and add to the considerable losses in the ground plane. Ceramic and ceramic-filled plastic are often used as dielectric. In DIW structures, most of the energy of the signal is confined inside the dielectric region.

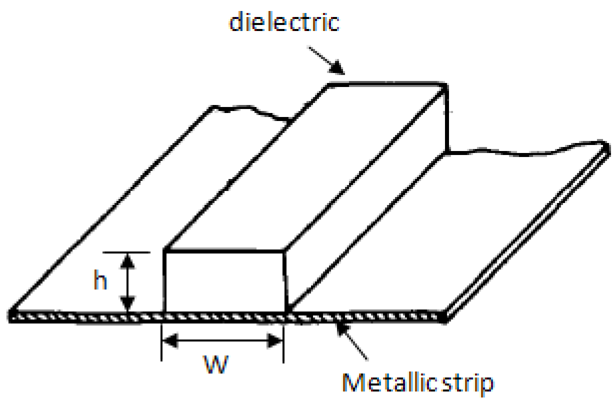


Figure 1: Typical micromachined Dielectric waveguide

In the mid-1970s considerable efforts were made to implement this guiding concept in designing millimetrewave integrated circuits. In some articles, imminent production of components and systems was indicated, but these plans did not materialize. Difficulties arose at production, and more basic problems were encountered with regard to confinement of the fields and losses, particularly in association with bends and discontinuities. At about the same time, modifications to improve the properties were proposed by having the dielectric composed of two or more parts with different permittivities.

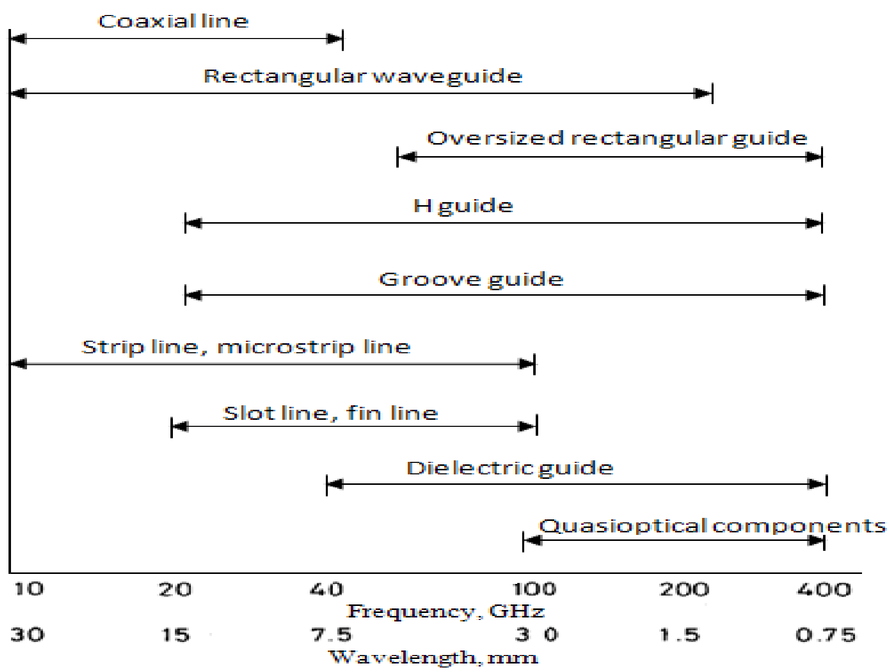


Figure 2: Useful ranges of millimeter waveguide

III. Characteristic of Image Waveguide

3.1. Attenuation characteristic

The attenuation in a dielectric integrated guide occurs due to:

- Conductor loss
- Dielectric loss

In open guide structures, the radiation loss forms a third contributing factor to attenuation. Radiation loss results primarily from bends and surface irregularities.

Conductor loss: conductor loss occurs due to the finite resistivity of the metallic plane of the dielectric integrated guide. The attenuation constant α_c due to the conductor loss is normally calculated using the following expression:

$$\alpha = \frac{\text{power loss per unit length}}{2 \times \text{power transmitted}} \tag{1}$$

$$\alpha_c = \frac{P_l}{2P_T} = \frac{0.5R_s \oint [\,|H_{tan}|^2 dl]}{\sum_n Z_n \iint |H_t|^2 ds} \tag{2}$$

Where
P_l =power loss/unit length of the guide
P_t =total power transmitted
R_s =surface resistance of the metal plane
H_{tan} =tangential magnetic field at the surface of the metal plane
H_t =magnetic field transverse to the direction of propagation
Z_n =wave impedance looking in the direction of propagation
Dielectric loss: the attenuation due to dielectric loss is derived by introducing a complex dielectric constant.

$$\frac{\alpha_d}{\alpha} = \frac{\lambda}{2\pi}\left[\left(\frac{k_0^2 \varepsilon_r}{a}\right)\tan\delta + \frac{\beta_x \alpha_x}{\alpha} + \frac{\beta_y \beta_y}{\alpha}\right] \tag{3}$$

Where

$\lambda = \frac{\beta_z}{2\pi}$ is the guided wavelength and

$$\alpha = \frac{\pi\sqrt{\varepsilon_r}\tan\delta}{\lambda_0}$$

is the attenuation constant of the infinite dielectric medium.

3.2. Dispersion characteristic

In the Dispersion characteristic plot show the variation of the normalized propagation constant β / k_0 as a function of the operating frequency. The fundamental dominant $E_{11}^{y}(TM11)$ mode of the image waveguide has no lower cut-off. That is the fundamental mode exists down to zero frequency and for any height of the guide.

3.3. Bandwidth characteristic

The image guide is normally excited in the E_{11}^{y} mode. The E_{11}^{x} mode which is orthogonal to the E_{11}^{y} mode is not excited. The waveguide bandwidth the lower frequency is chosen as that at which the power in the air region becomes equal to that in the dielectric strip. Below this frequency energy travelling in the air region would be greater than in the dielectric region. In image waveguide the bandwidth increases with an increase in ε_r and for a given dielectric maximum bandwidth is achieved when a/b approaches unity.
The other factor that may be considered for determining the frequency limit is the characteristic impedance of the guide. The formula used for determining the impedance Z is

$$Z = b^2E^2 / 2P_t \tag{4}$$

Where P_t =total power flow in the air and dielectric regions, E =max. Value of electric field.

For the larger dielectric constant the smaller the variation in impedance as a function of frequency. Increasing the dielectric constant offers better confinement of energy to the dielectric thereby reducing leakage radiation.

IV. APPLICATION

Wave guiding media are presently key elements in millimeter-wave circuitry. One of the reasons is the variety of functions in which they are potentially involved. Power transport, interconnection of components and operation as parts of circuits are the major possible uses. Another cause having evolved recently is that solid-state devices which were key elements before are now readily available and their costs are relatively low.

The most widely employed guide structures in component development so far have been the image guide. The various passive and active components constituting millimeter wave transmitter and receiver systems have been realized in one or the other of the dielectric guide configurations. The emphasis has been in the frequency range 30 to about 120 GHz. The best potential that this technology can offer appears to be at frequencies above 60 GHz the factors in favor of dielectric guides are low loss, convenient size, low cost, and ease of manufacture.

One of the most useful features of dielectric guide techniques is the convenience that it offers for realizing high performance antennas as an integral part of the circuits. The best potential of dielectric guide techniques can be utilized by using high resistivity semiconductor dielectric guides and adopting monolithic fabrication to integrated both active and passive devices. Another attractive property of semiconductor guides is that its conductive and dielectric properties can be controlled optically. This feature offers the possibility for realizing a class of dynamically controlled devices such as switches, phase shifters, and attenuators.

There are two distinctly different situations where these media are used. The first one is associated with point-to-point transport of energy, and the second with the use as a circuit element for interconnecting components or serving as an integral part of these components. The former application involves the energy transport over large or moderate distances. Examples are waveguides for the transmission of information-carrying signals between communication centers and between antennas and transmitters or receivers in communication links.

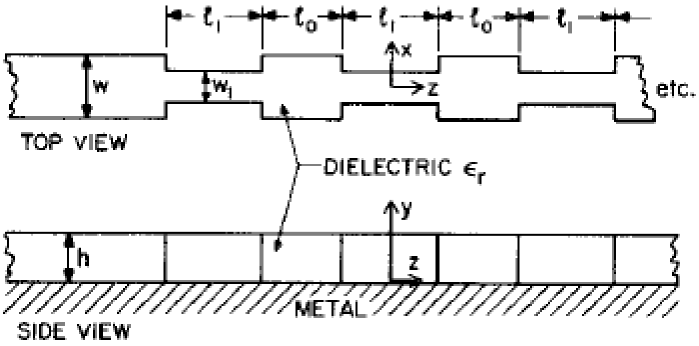
V. GRATING FILTER

Our work with gratings in dielectric image guide shows that it is distinctly advantageous to place the grating notches on the sides of the guide, or on the top of the guide, depending on the mode used. Means are discussed for modeling gratings using an equal-fine-length transmission-line equivalent circuit. Excellent agreement between computed and measured Band stop frequency responses of gratings is obtained. Design relations for gratings are presented.

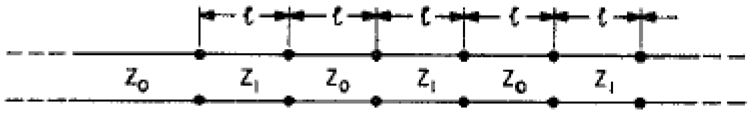
Open dielectric guides with grating notches are known to offer very good stop band attenuation. Grating type band stop filters have been realized for the commonly used E_{11}^{y} mode of excitation (dominant TM mode), which has its electric field vertically polarized the grating notches cut are cut on the two sides of the guide whereas for the E_{11}^{x} mode (dominant TE mode) which has its electric field horizontally polarized notches on the top are found to be most effective. For excitation in the E_{11}^{y} mode, cutting notches on the sides is known to yield a strong stopband with no nearby spurious response. Since the E_{11}^{y} mode and the grating structure are symmetrical with respect to the *x*-direction, any TM to TE mode conversion and higher order TM mode generation due to the discontinuities must also have even symmetry with respect to the *x*-direction. Thus the immediate higher order E_{21}^{y} and E_{11}^{x} modes, which have odd symmetry, are not generated. The nearest spurious TM mode that can be generated is the E_{31}^{y} or E_{12}^{y} mode and the nearest spurious TE mode is the E_{21}^{y} mode. These modes occur far away from the desired stop band for the E_{11}^{y} mode.

For the purpose of filter design, the dielectric grating can be modeled as a transmission line having line sections of equal length (which assumes the same phase velocity throughout). The equivalent circuit is shown in figure 3.

(a)



(b)



(c)

Figure 3 the dielectric-waveguide (DW) (a) with upper notches (b) with side notches (c) An equal-line-length equivalent circuit for gratings [3]

Where Z_0 and Z_1 are the wave impedances of the section of width w_0 and w_1, respectively. It can be seen that at a frequency f_0, where all the sections are one-quarter wavelength long, the grating structure offers maximum attenuation. If the grating is terminated in Z_0 at both ends, the mid-stop band attenuation L_{max} is given by:-

$$L_{max} = -10\log\left[\frac{4\gamma^{2n}}{(\gamma^{2n}+1)^2}\right]\text{dB} \tag{5}$$

Where

$$\gamma = {}^{Z_1}/_{Z_0} > 1$$

And n is the number of sections having the impedance Z_1. The ratio γ is given by the approximate expression

$$\gamma \approx \frac{v_{P1}}{v_{P0}} \tag{6}$$

Where v_{P1} is the phase velocity in the region having impedance Z_1 and v_{P0} is the phase velocity in the region having impedance Z_0.

VI. ASSIGNMENTS IN DIELECTRIC WAVEGUIDE

Assignment1. Design and simulation of micromachined Dielectric waveguide bandpass filter in CST Microwave Studio 9.0 and HFSS with following specification.

1 .Electrical Permittivity of substrate: 11.8(silicon).

2. Cut-off frequency: 67 GHz

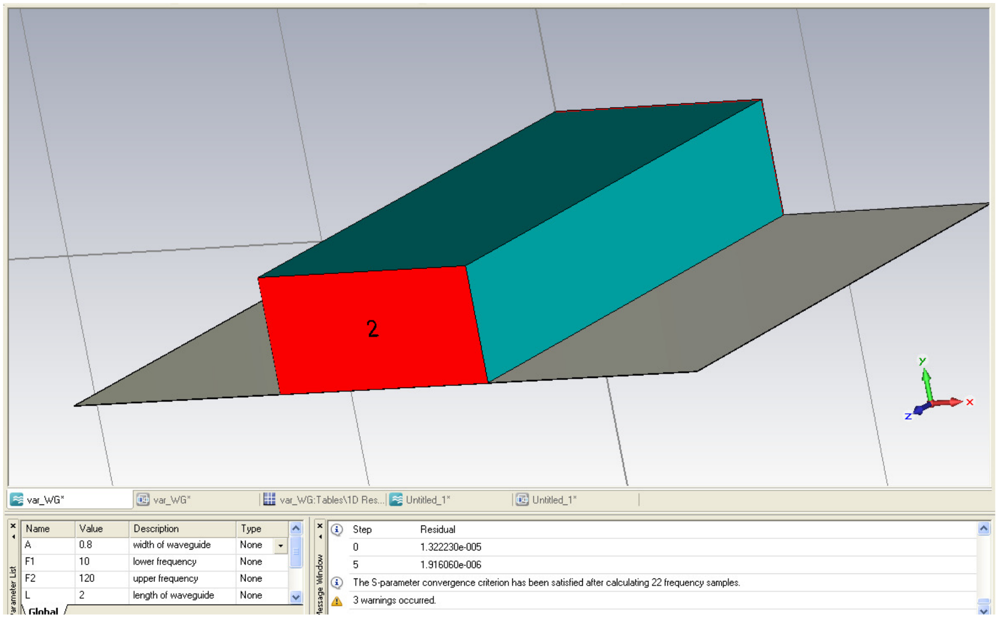


Figure 4: WR-2.5 Dielectric Image Waveguide

Structural Parameters of Dielectric Waveguide Filter:

Length of waveguide	*9608 ìm*
Waveguide	*WR-2.5(635 X 317.5) ìm*

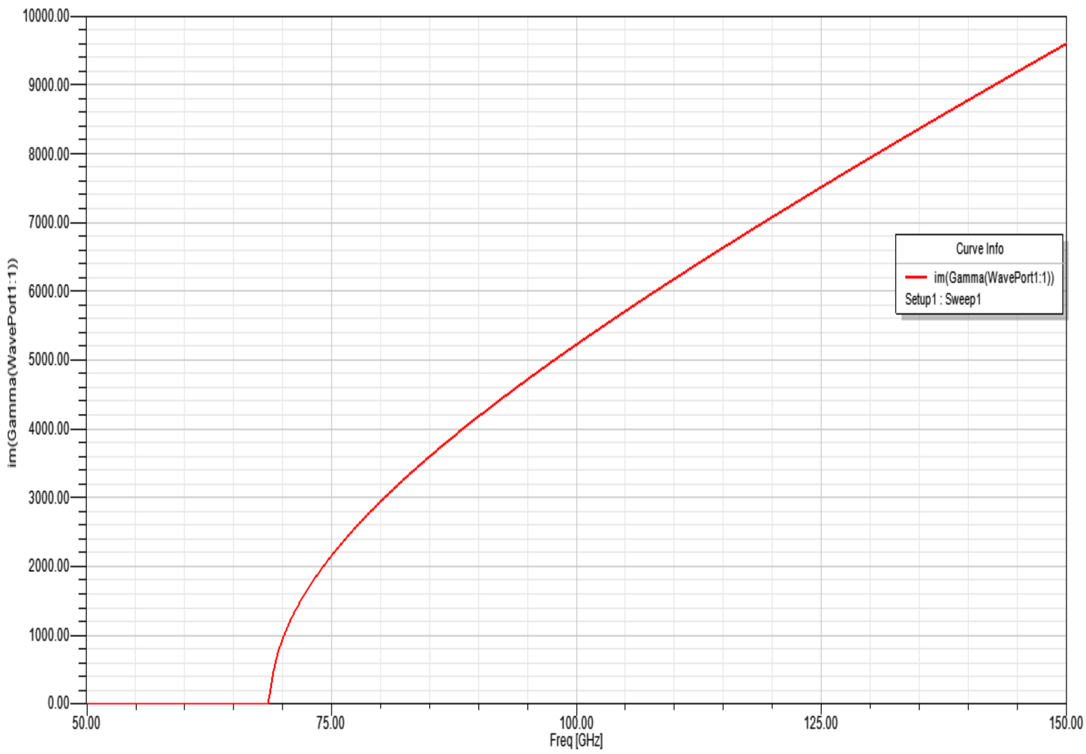


Figure 5: propagation constant of dielectric waveguide WR-2.5

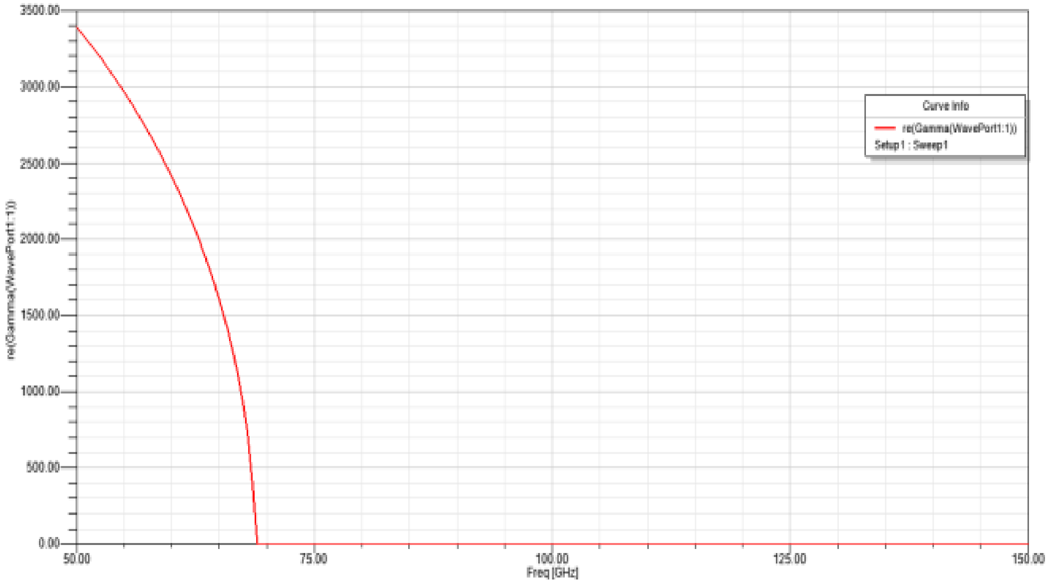


Figure 6: attenuation constant of dielectric waveguide WR-2.5

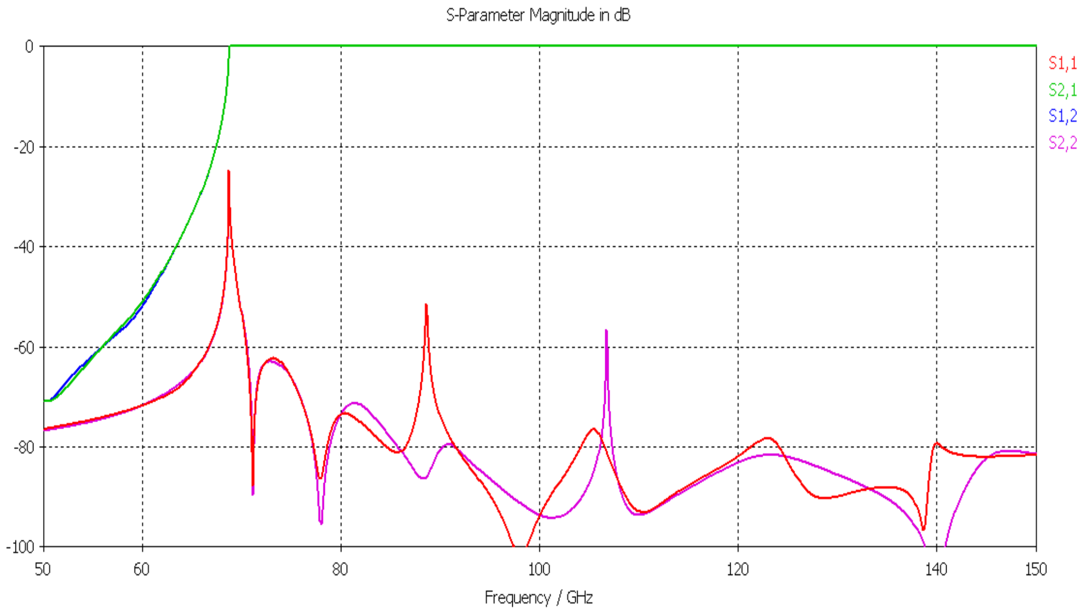


Figure 7: s-parameter of dielectric waveguide WR-2.5

Assignment2. Design and simulation of micromachined Dielectric waveguide bandpass filter in CST Microwave Studio 9.0 and HFSS with following specification.

1 .Electrical Permittivity of substrate = 11.8(silicon)

2. N (order of filter) = 16.

3. Bandpass Center frequency = 77.86 GHz

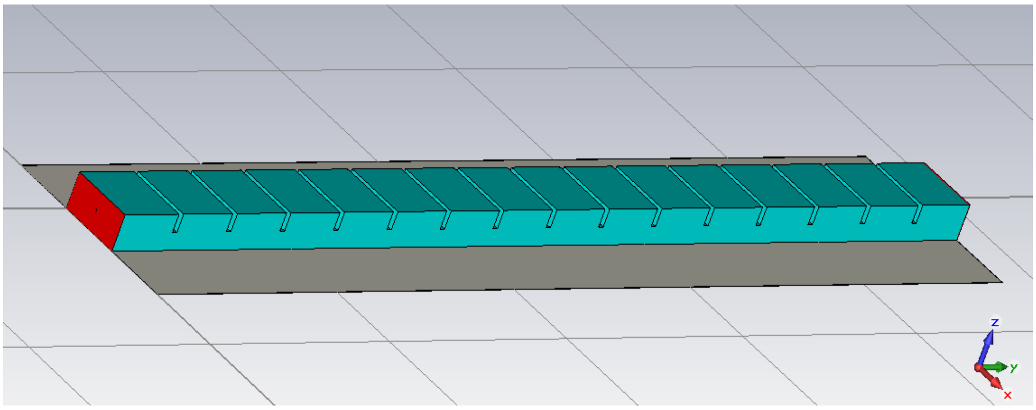


Figure 8: the dielectric-waveguide (DW) with upper notches filter with no. of gating = 16

Table 1.: Structural Parameters of Dielectric Waveguide Bandpass Filter

Length of waveguide	9608 ìm
Waveguide	WR-2.5(635 X 317.5) ìm
Width of each grating	50 ìm
Breadth of each grating	158.75 ìm

VII. Result and Discussion

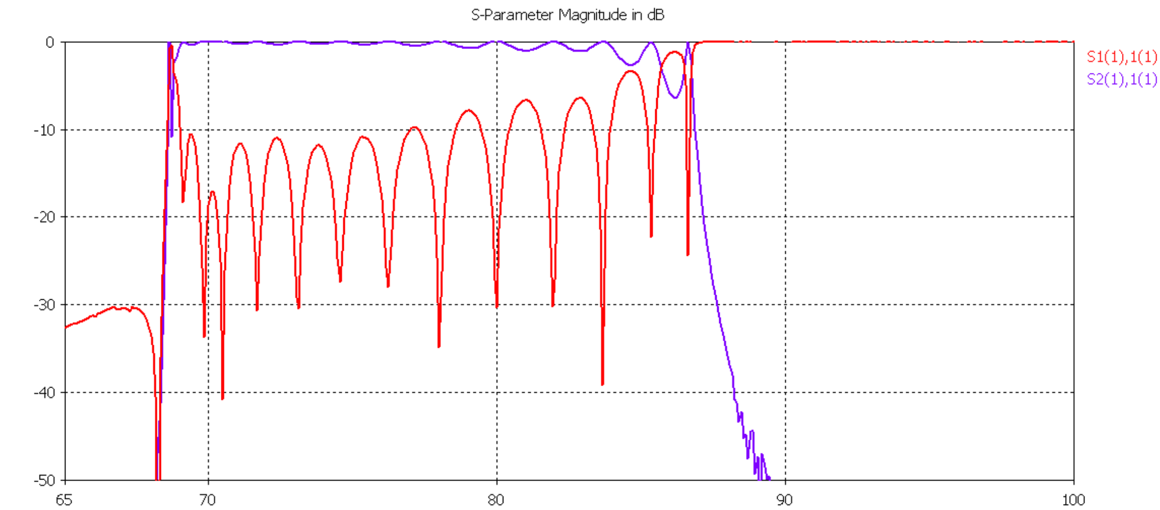


Figure 9: Dielectric-waveguide filter response with no. of gating = 16

In the Waveguide Grating Filter bandpass response is achieved by the periodic cut in the structure and this periodicity is done in after every $\lambda/4$ (i.e. βl=90^o). In each periodic structure there is a cut part of the waveguide and dielectric part of the waveguide due to this each section of air and dielectric wave travels through alternately in air and dielectric region. This part acts as a step impedance like in microstrip filter structure. In the above filter when each section of (dielectric and air waveguide) is cascaded one after the other for sharp cut-off of bandpass filter. When the above periodic structure is more in number than order of filter is increases and sharpness of cutoff is also increase.

VIII. Conclusion

A WR-2.5 dielectric waveguide is designed for 67 GHz cut-off frequency. A micro machined dielectric grating waveguide band pass filter is designed for 67 GHz frequency with very sharp transition at both sides of the passband. It has been found that sharpness of cutoff increases as no. of order of filter is increased.

REFERENCES

[1] P. L. Kirby, D. Pukala, H. Manohara, I. Mehdi, and J. Papapolymerou "Characterization of Micromachined Silicon Rectangular Waveguide at 400 GHz " in IEEE microwave and wireless components letters, vol. 16, no. 6, June 2006

[2] E. A. J MARCATILI "Dielectric Rectangular Waveguide and Directional Coupler for integrated optics" in The BELL system technical journal, September 1969.

[3] D. C. Park, George L. Matthaei, and M. S. Wei "Dielectric waveguide Grating Design for Bandstop and Bandpass Applications" in IEEE MTT-S DIGEST.

[4] William **R.** McGrath, Christopher Walker, Markus Yap, and Yu-Chong Tai "Silicon Micro machined Waveguides for Millimeter-Wave and Submillimeter-Wave frequency" IEEE microwave and guided wave letters, vol. 3, no. 3, march 1993

[5] KLAUS SOLBACH M INGO WOLFF "The Electromagnetic Fields and the Phase Constants of Dielectric Image Lines" in IEEE transactions on microwave theory and techniques, vol. mtr-26, no. 4, April 1978.

[6] Arun Kumar, K. Thyagarajan, and A. K. Ghatak "Analysis of rectangular-core dielectric waveguides: an accurate perturbation approach" Optics Letters, Vol. 8, Issue 1, pp. 63-65 (1983)

[7] H. Cory, Z. Altman, and Y. Leviatan "Determination of a dielectric waveguide propagation constant using a multifilament-current model" Optics Letters, Vol. 14, Issue 18, pp. 1026-1028 (1989)

[8] M.S.Aftanasar, P.R.Young, I.D.Robertson', S.Lucyszyn "Fabrication of Dielectric-Filled Rectangular Waveguide using Thick-Film Processing"

[9] Hinken, J.H.: "Band-pass Filters in integrating waveguide technology and adapters to standard waveguides", Conference Proceedings - European Microwave Conference 1984 , pp. 299-304

[10] **F.** J. Tischer, "Experimental attenuation of rectangular waveguides at millimeter wavelengths," *IEEE Trans. Microwave Theory Tech.,* vol. MlT-27, pp. 31-37, Jan. 1979.

[11] www.wekipedia.org

Authors

Sanjeev Kumar has done his M.Tech. in Electronics and Communication. He is pursuing Ph.D. in Electronics and Communication. He has an overall experience of 8 years including appox. 3 years in Industry. He is working as Assistant Professor in AIACTR (Ambedkar institute of technology, Govt. of NCT of Delhi).

Prem Ranjan Kumar has done his B.Tech in Electronics and Communication from Guru Jambheshwar University of Science and Technology, Hisar. He is pursuing M.Tech in RF and Microwave Engineering from AIT Delhi.