Microwave filter Using Photonic Crystal Structure

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Abstract: *Photonic crystal structures have a certain photonic band gap that prevents propagating of wave (light) in certain frequencies with certain polarizations or incident angles. The properties of this band gap (attenuation and bandwidth) depend on parameters of the dielectric periodic structure, such as relative permittivity constant (*ε_r*), Fill Factor (f), etc, that would be discussed. In this paper, we will consider the properties of a scaled measurement of two-dimensional square lattice of dielectric columns. It has a band gap in microwave frequencies (instead of light wave frequencies) due to its big scale. Also, we simulate other structures for approaching our desired parameters of band gap and observe effects of changing the parameters of the structure on the properties of the band gap (using S-parameters).*

Keywords: Photonic Crystals, Microwave Filter Band Gap, Fill Factor, HFSS

1 Introduction

Wave propagation in periodic structures of materials was first studied by Lord Rayleigh in 1887, in connection with the peculiar reflective properties of a crystalline mineral with Periodic Twinning Planes. He identified that one-dimensional photonic crystals is angle-dependent in addition to have a narrow band gap prohibiting light propagation through the planes [2].
Yablonovitch and John in 1987 joined the tools of classical electromagnetism and solid-state physics, and the concepts of omni directional photonic band gaps in two and three dimensions were introduced [2].
In 20th century, controlling properties of materials advanced to electrical properties of materials specially semiconductors and transistors.
In 80s, a new frontier has emerged to control the optical properties of materials: prohibiting the propagation of waves in certain directions at certain frequencies, "*Photonic Crystals*".
Crystal lattice is a small, basic building block of atoms or molecules to be repeated in space.In particular, the lattice might introduce gaps into the energy band structure of the crystal, so that electrons are forbidden to propagate with certain energies in certain directions. If the lattice potential is strong enough, the gap might extend to all possible directions, resulting in a *complete band gap*. For example, a semiconductor has a complete band gap between the valence and conduction energy band. [1]
The optical analogy is the photonic crystal, in which the periodic potential is due to a lattice of macroscopic dielectric media instead of atoms. If the dielectric constants of the materials in the crystal are different enough, and the absorption of light by the material is minimal, then scattering at the interfaces can produce many of the same phenomena for photons as the atomic potential does for electrons. One solution to the problem of optical controlling of light is thus a photonic crystal, a low-loss periodic dielectric medium. In particular, we can design and construct photonic crystals with photonic band gaps, preventing light

from propagating in certain directions with specified energies [1].
If, for some frequency range, a photonic crystal reflects light of any polarization incident at any angle, we say that the crystal has a *complete photonic band gap* [1].
In such a crystal, no light modes can propagate if they have a frequency within the range. A simple one-dimensional crystal cannot have a complete photonic band gap because scattering occurs only along one axis. In order to create a material with a complete photonic band gap, we must arrange the dielectrics in a lattice that is periodic along three axes [1].
Nowadays various types of photonic crystals are designed,
In this paper, we simulate some Scaled two-Dimensional Rectangular (*2DR*) Structures by HFSS (High Frequency Structure Simulator) 9.1. Our goal is to design and fabricate a proper one that has a band gap in our desired frequency range (Microwave).
A two-dimensional photonic crystal is periodic along two of its axes and homogeneous along the third [1].

2 Simulation

2.1 Simulation Setup

The setup is an ideal rectangular waveguide - *PEC* boundaries- and *TE* wave ports for excitation.
S_{21} Parameter that would be measured in each experiment is the basis for comparison.

2.2 Design

Parameters below were determined.
D_l: Distance between canters of cylinders in length.
D_w: Distance between canters of cylinders in width
R : Cylinder's radius.
N_l **:** Number of cylinders in length.
N_w: Number of cylinders in width.
h: Structure's height

2.1.1. Material
Simulation was done for different materials with same structures. Figure2 illustrates an experiment with these parameters: $D_l = D_w = 20mm$, $R = 3mm$ and $N_l = N_w = 5$. Plexiglas seems to be more proper for our goal. In addition, it has very low dielectric loss in desired frequencies (Microwave Frequencies).

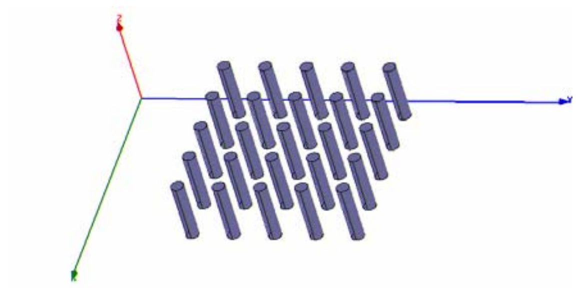


Figure1. 2-dimentional Rectangular

2.1.2. Structure
Below definitions is our basis for approaching band gap concept:
Bragg diffraction equation:
$\lambda = 2d\sin(\theta \pm \delta)$ [3]
Fill Factor:
Fill factor is an appropriate measure of the degree of concentration of the displacement fields in the high-ε regions (Dielectric regions) and defined as

$$f = \frac{\int_{\forall\varepsilon=3.4} E^*(r).D(r)dr}{\int E^*(r).D(r)dr}$$

The Fill factor measures the fraction of electrical energy located inside the high-ε regions (Dielectric) [1]. In other words, Fill factor is a function of the ratio of $\frac{R}{D}$.

D_l And D_w
Due to predictable difference between simulation and experimental testing results, we need to have as much as possible loss in the band gap. Because our goal is designing at 12GHz, upon Bragg equation for one-dimensional structures D_l and D_w considered about 12.5mm.
Simulations show that D_l and D_w parameters are closely in relation with the band gap frequency (Figure3).
R
Due to Fill Factor parameter, mentioned above, the loss takes its most value on a special radius. In addition, radius influences Band Gap frequency. (To have TE mode Band Gap in *2DR* it is better to use a square lattice of dielectric columns (Rods), and it is necessary to choose low fill factor, therefore the ratio of $\frac{R}{D}$ must be small enough [1], Figure4.)

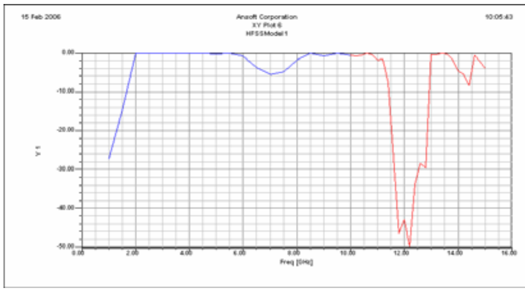


Figure 2.a

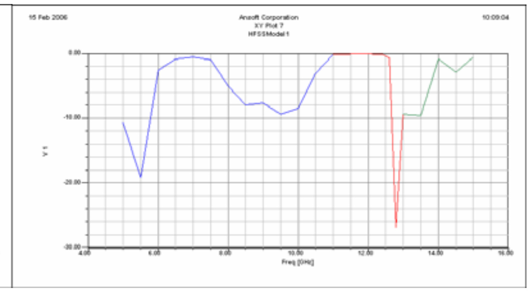


Figure2.b

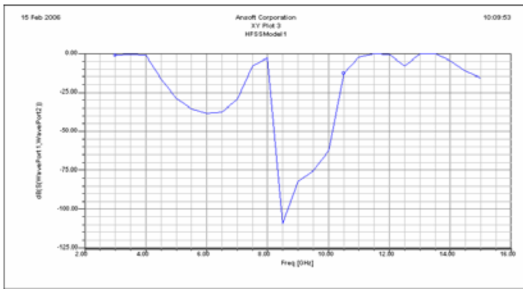


Figure 2.c

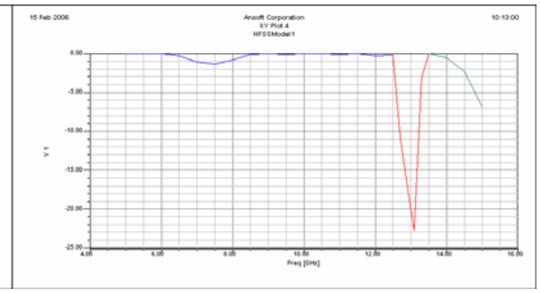


Figure2.d

Figure2.

a)Plexiglas($\varepsilon_r = 3.4, \tan\delta = .001$)Loss=50,Bandgap frequency=12.25GHz

b)Polyamide($\varepsilon_r = 2.1, \tan\delta = .004$)Loss=25, Band gap frequency=12.5GHz

c) Silicon ($\varepsilon_r = 4.3, \tan\delta = 0.0008$) Loss=120, Band gap frequency=8.5GHz, but it has so much loss in a wide range of frequencies

d) Teflon ($\varepsilon_r = 11.9, \tan\delta = .001$) Loss=20, Band gap frequency=13GHz

N_l And N_w

Since in the band gaps most of the waves mirrors from first rows of cylinders, N_l and N_W do not influence S-parameter's whole shape but they play an important role in band gap's details. (Figure5)

2.3. Simulation Result

Results in simulation had been Parameters $D_l = 20, D_w = 20$, $R = 3mm$, $N_l = N_w = 8$, in addition h must be more than antenna's height .

Its band gap frequency center is 12.5GHz.In this frequency loss is about 100dB.In a proper frequency range (11.7-13.1GHz) its loss is more than 20dB, also more than 40dB for 11.8-13GHz

The loss in other frequencies (8-10GHZ) is so low. In addition, sharp changes from pass band and stop band (20dB per 0.1GHz)

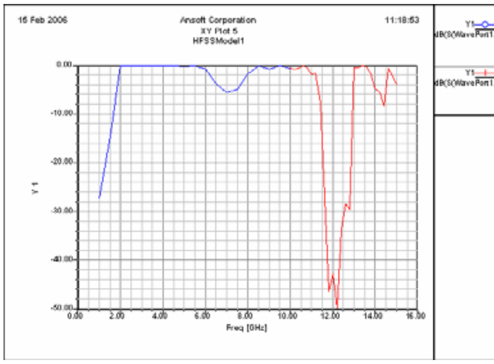


Figure 5.a

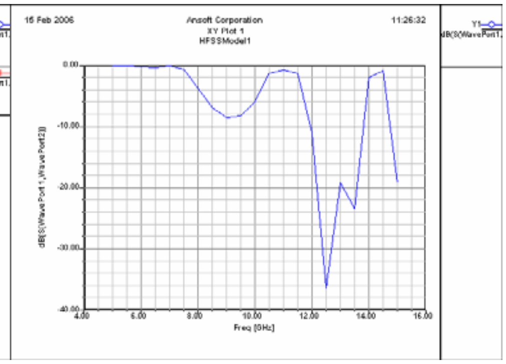


Figure5.b

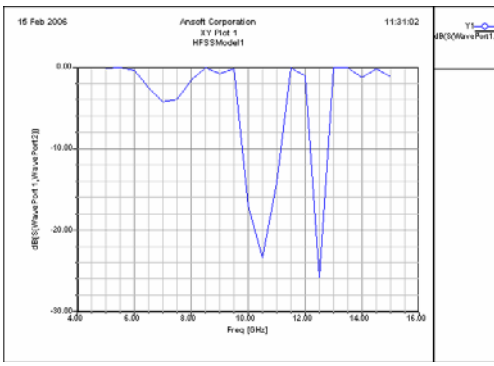


Figure 5.e

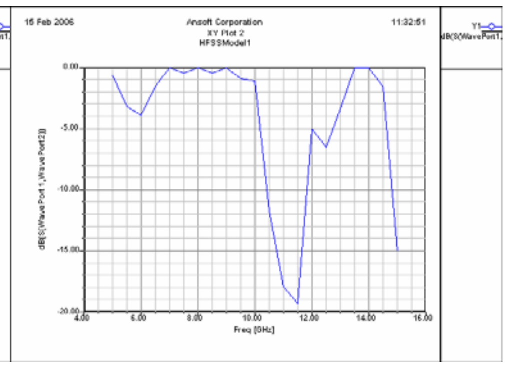


Figure5.d

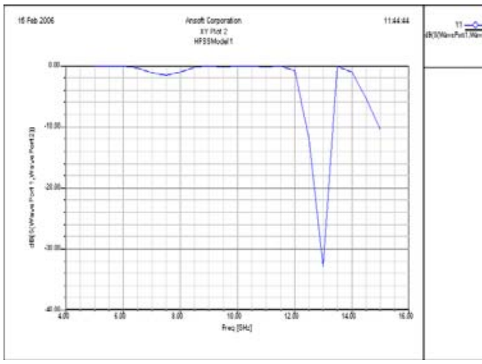
Figure5. $N_l = N_w = 5$

a) $D_l = 20, D_w = 20$ Loss= -50dB at 12.25GHz

b) $D_l = 15, D_w = 20$ Loss= -36dB at 12.5GHz

c) $D_l = 20, D_w = 25$ Loss= -26dB at 12.5GHz

d) $D_l = 25, D_w = 20$ Loss= -19dB at 11.5GHz



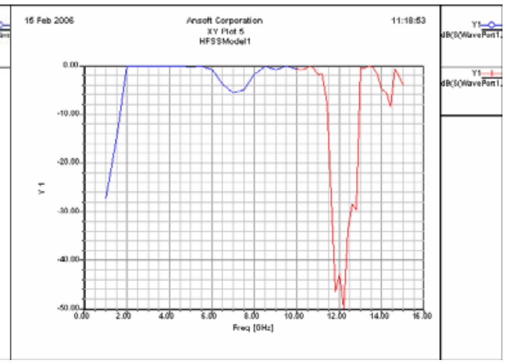
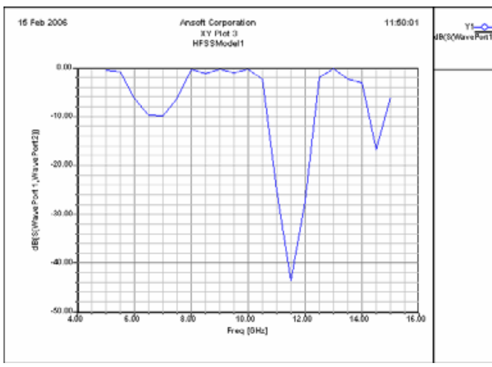


Figure 4.a **Figure 4.b**



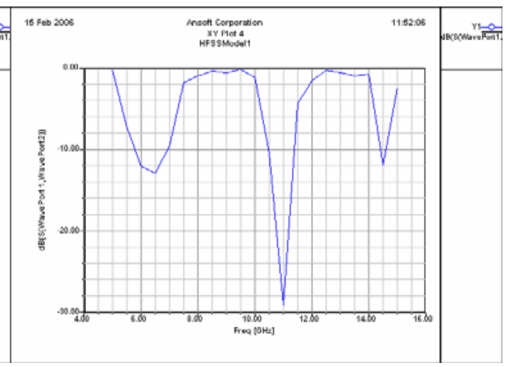


Figure 4.c **Figure 4.d**

Figure 4. $D_l = 20, D_w = 20 \; N_l = N_w = 5$

a) $R = 2mm$ Loss=32dB at 13GHz

b) $R = 3mm$ Loss=50dB at 12.25GHz

c) $R = 4mm$ Loss=44dB at 11.5GHz

d) $R = 5mm$ Loss=30dB at 11GHz

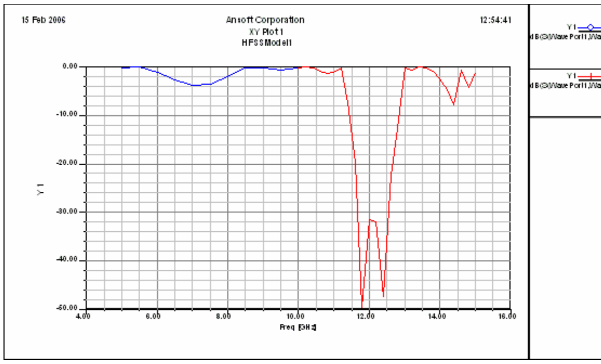


Figure 5.a

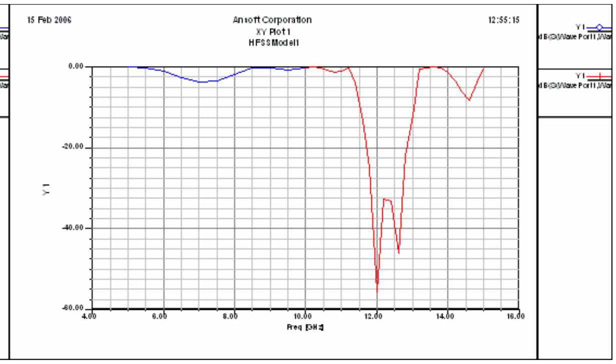


Figure 5.b

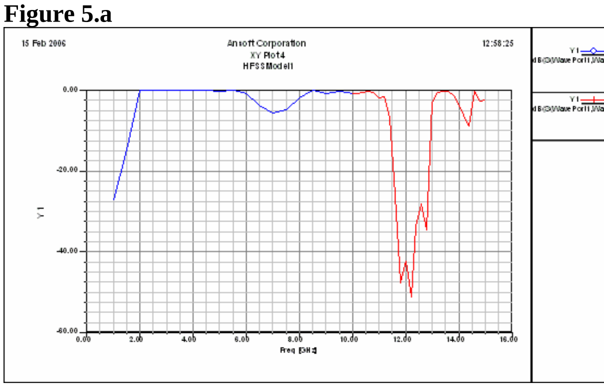


Figure 5.c

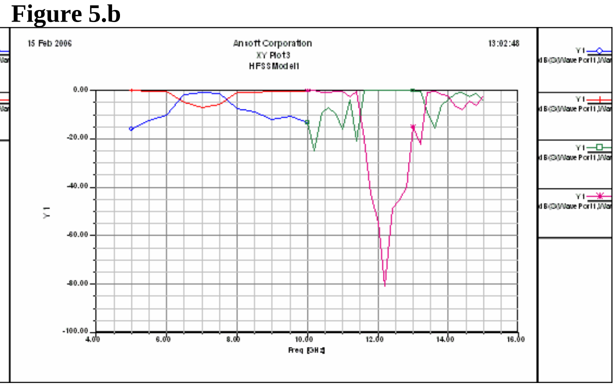


Figure 5.d

Figure7. $D_l = 20, D_w = 20\ R = 3mm$ a) $N_l = 4, N_w = 6$ Loss=60dB at 12GHz

b) $N_l = 4, N_w = 5$ Loss=60dB at 12GHz

c) $N_l = N_w = 5$ Loss=50dB at 12.25GHz

d) $N_l = N_w = 6$ Loss=80dB at 12.5GHz

Because of having band gap they are not so different in whole shape.

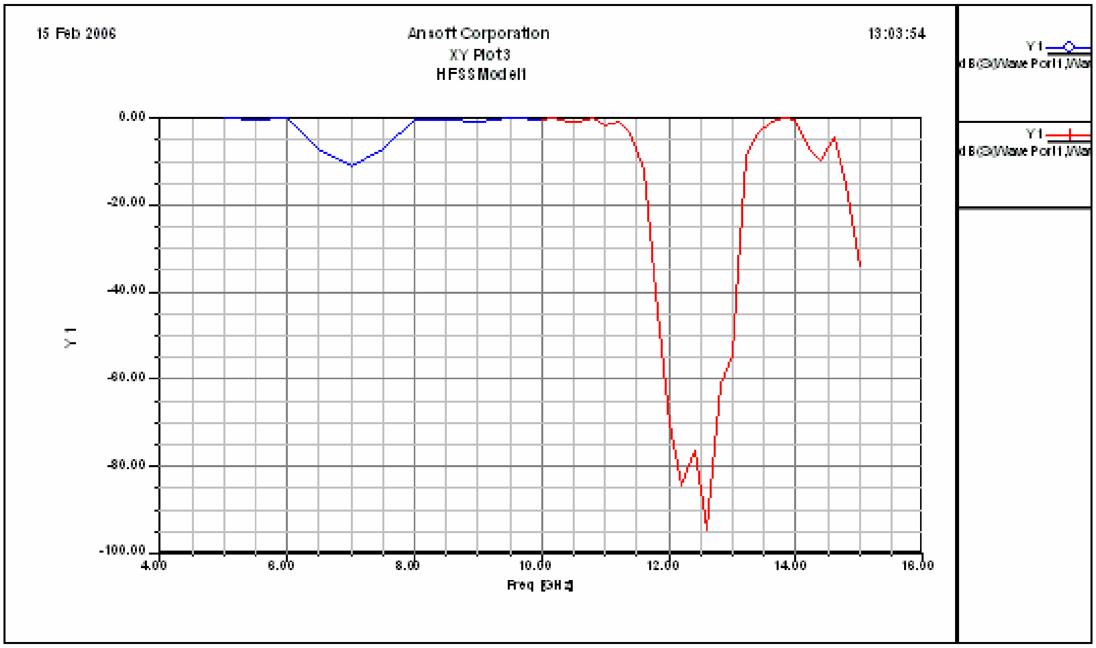


Figure6. Simulation resulted Structure, $D_l = 20, D_w = 20, R = 3mm, N_l = N_w = 8$,.

Its band gap frequency center is 12.5GHz.In this frequency loss is about 100dB.In a proper frequency range (11.7-13.1GHz) its loss is more than 20dB, also more than 40dB for 11.8-13GHz

3 Fabrication and Test

3.1 Fabrication

Fabricating resulted parameters, Plexiglas rods are shaped with two 16cm*16cm*3mm Plexiglas plans (Spacers)

3.2. Testing

Network Analyzer: Agilent HP8510C Network Analyzer
Antennas: 2 Horn antennas 10cm*8cm*6cm
Distance between antennas was 19cm .

3.3. Results

Result of testing is illustrated in figure7
It follows simulation results in band gap frequency and ripples.

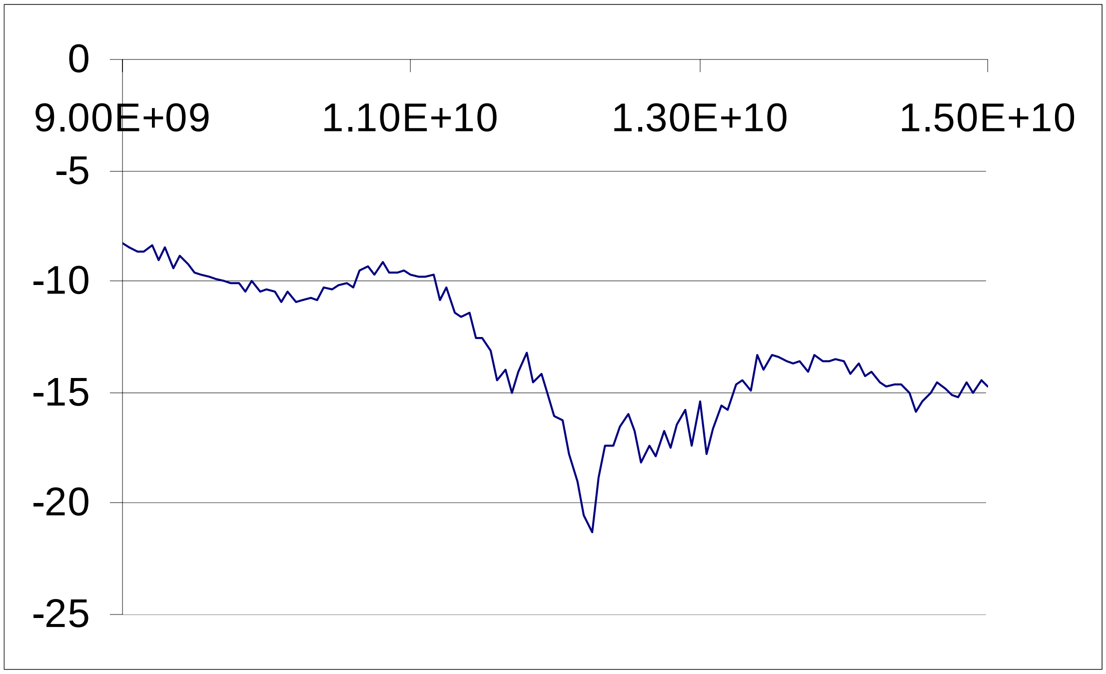


Figure7. Testing result: It follows simulation results in band gap frequency and ripples but not in attenuation, it is because of difference conditions in simulation and fabricating in addition to non-ideal situation of experimental testing.

Acknowledgements

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