CHAPTER -4

Tunable Wide Ka-Band Stop Honeycomb EBG Filters with Hexagonal Basis

4.1 Introduction

Filters play an important role in many RF/microwave applications. Promising applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirements—high performance, small size, light weight, and low cost. For example, ultra wideband (UWB) technology requires wide radio spectrum. On the other hand, the frequency spectrum as a resource is valuable and limited, so the spectrum is always being used for several purposes.

Tunable microwave filters are attracting more attention for research and development because they are very important in improving the capability of current and future wireless systems. Tunable filter are also important component for many other microwave devices.

Tunable filters are often used in multiband telecommunication systems, radiometers and wideband radar systems. These filters can overcome the minor divergence in performance, due to that the manufacturing errors arises, and can also reconfigure the operating performance and characteristics of the system. They also reduce the cost and complexity of a system by reducing the number of circuits for
Separate operating systems. The purpose of miniaturization of wireless devices is to reduce size and weight which is a constraint in certain applications where portability and high device density are required. To achieve these prospective tunable filters and tunable matching networks are needed. Tunable filters are often used in multiband telecommunication systems, radio meters, and wideband radar systems [1].

Wideband communication and radar systems require high speed tunable wideband microwave bandstop and bandpass filters. Due to which the demand for high bandwidth is continuously increasing, in the latest development of internet and wireless technology. More applications such as remote sensing and broad band low earth satellite systems, tunable filters are also required [2].

The frequency range of 10 GHz to 100 GHz is particularly motivating for communications, military, and security applications. For example, there are clear needs to see through fog, clouds, and smoke, but this cannot be possible in visible light or infrared radiation. On the other hand, these obstacles are transparent, for electromagnetic waves at particular frequencies that is in the gigahertz range. Thus, signal processing in this range is of considerable importance.

There are few devices that operate at high frequencies however, they are large and bulky. Therefore, researchers are more interested in designing tunable planar filters.
4.2 **Planar Tunable Band Stop Filters using Electromagnetic Bandgap Microstrip Structure:**

Bandstop filters have important application in microwave circuits and systems. A planar bandstop filter with a deep rejection at a specified frequency is an important component for communication systems to reduce interference from the crowded adjacent channels.

Planar filters are radio frequency (RF) filtering device having all of its circuitry residing within or relatively thin plane. To achieve these planar filters, generally flat transmission lines are used. In same structures such as microstripline and stripline, transmission line normally includes a relatively thin flat centred conductor separated from the ground plane by a dielectric layer [2].

To design these planar tunable filters there are number of important considerations, such as:

1) Tunable planar filters should display very low insertion loss.

2) It should minimize noise and other unwanted resonances when the RF signal passes through it.

3) Tunable filters should have high degree of tuning selectivity and sensitivity.

4) It should have compact size for the components where space is a concern.

Due to band rejection properties of the Electromagnetic, band gap (EBG) structures at microwave frequencies, these structures are widely used to design wideband band stop filters. One of the major advantages in the development of these
structures in microwave has been their implementation in microstrip line technology [4] [5] [6].

This EBG Microstrip technology has some advantages which make it very popular in the scientific society:

(i) Simple to fabricate
(ii) Compact size
(iii) Easily integratable: compatible with monolithic technology
(iv) Offers good depth and width in rejected frequency bands.
(v) Cost effective [4]

Potential of EBG structure with microstrip line has been reported in several papers [7] [8] [9]. Min Hyunk Kim and researchers have proposed a new type of compact photonic band gap (PBG) structures employing T-type microstrip line for filters. A miniature band rejection filter with four cells was simulated, fabricated, and characterized. A filter with four proposed PBG structure exhibits band rejection characteristics [10]. Tae Yeoul and Kai Chang also designed a uniplanar one-dimensional Photonic Bandgap structures. In this the PBG structures consists of 1-D periodically etched slots along a transmission line or alternating characteristics of impedance series with wide band stop filter characteristics. A stop band width of 2.8 GHz with a stopband of 36.5 dB was obtained [11].

Similarly, X.H. Lee et. Al. were designed a dual plane compact electromagnetic bandgap (C-EBG) microstrip structure, where patches were etched periodically in
the ground plane to prohibit the propagation of electromagnetic waves in certain frequency bands, so as to provide band rejection filtering property [12]. S.Y Huang et. al. also presented the design and implementation of a novel tapered small size EBG (S-EBG) microstrip bandstop filter. This proposed structure consists of EBG structure with rectangular patches periodically inserted in the microstrip line and two auxiliary EBG structures in order to enhance the reactance contrast in an EBG cell. These three EBG structures in a unique configuration make a novel structure which has an ultra wide stopband with high attenuation and small size [13]. Sreedevi . K. Menon & researchers designed EBG structures that exhibited wide stop band with- out increasing the size of the unit cell. Slots of six different geometrical shapes having the same area and period are studied in detail [14].

Txema Lopetegi & researchers have proposed 2D photonic bandgap structures for microstrip lines by using tapering techniques. By increasing the radius of the circuit the rejection amplitude and bandwidth increases [15]. Ian Rumsay et.al. discussed the applications of photonic bandgap structures as substrates in microstrip circuits. The effects of substrate thickness, microstrip transmission line location, and length of the PBG structure were studied using a finite-difference time domain simulation and experimental measurement. A low pass filter with a very wide high frequency rejection bandwidth was constructed from a serial connection of different PBG structure [16].

Taesun Kim and Chulhun Seo proposed a novel photonic bandgap structure for increasing the stopband of a low pass filter without increasing the circuit size for applications in microstrip circuits. The proposed structure has two periodic
structures connected in parallel with different centre frequencies of stopband, resulting in a wide band [17].

Miguel A.G Laso and researchers designed a novel pattern with addition of various sinusoidal functions for the PBG microstrip ground plane structure. These continuous patterns can be considered as network topology counterpart in microstrip, in contrast with the convention at discrete pattern that can be seen as cermets topologies. Measurements show that the proposed device behaves as a multiple frequency tuned band reflector [18].

A. Ibanez and his co-worker proposed a new analytical method to design stopband filters combining the Bragg’s condition and resonant effects. The proposed circuit has been designed using eight shunt stubs.[19]. Lio Tao and his team also designed and characterized a curved EBG structure. In this, they etched the EBG structure on a cylindrical substrate, and used a suspended microstrip line to characterize the effect of designed EBG structure. It shows a deep and wide band stop response [20].

V.I Esenko and G.V Tkachenko presented two sided one dimensional photonic bandgap microstrip structure. The structure was obtained by etching a periodic pattern of circles in the ground plane of a microstrip line and by variation of the characteristics impedance as a function of length of microstrip line. These structures show the characteristics of bandstop filter. Felix D Mbairi also investigated a bandstop filter using EBG structures. In this paper three types of microstrip structures using periodically modified trace width, patterned dielectric substrate and periodically modified ground plane were designed and analyzed [21].
M.F Karim and researchers presented an innovative design of a hybrid electromagnetic bandgap structure based on non uniform period and dimensions. A high rejection bandwidth was achieved when the non uniform period and dimensions follow the Kaiser distribution. The EBG structures are fabricated on the transmission line and the ground plane. The measurement results show a low pass filter response up to the C-band with low insertion and rejection band width above 12 GHz [22].

M.M Kubassian and his co-workers proposed two different uniform photonic bandgap structures, used as stopband filters and microstrip line at 5.4 GHz, which were proposed and compared in terms of the pattern shape effects on the s-parameters. This suggests the use of 1D pattern to reduce the transversal size of the filters [23].

This technology is becoming popular in domain of planar circuits, using this technology in our research work, a broadband filter in Ka band region is designed.

4.3 **Ka Band Region: The vicinity of concern**

In the past few years, we have witnessed an emergent amount of interest in Ka frequency band region. With the rapid growth of wireless market mobile communication, wireless local area network (WLAN), global positioning system (GPS) services and radio frequency identification (RFID) applications, radio frequency (RF) engineers are facing continued challenges of small volume, wide band width, power efficient and low cost system designs. Scientfic community
also finds the higher frequency range for fast processing of the systems; as the C and Ku bands begin to become congested, significant interest has been generated in Ka band for commercial satellite communication applications [24].

Ka band systems have a number of advantages, perhaps the most significant is increased bandwidth. Ka band satellites usually transmit more power than C band satellite. The Ka band is primarily used for two-way consumer broadband and military networks. Ka band dishes can be much smaller. This is a new constellation of broadband commercial satellites on track to provide faster communication speeds to remote users. Ka band has twice the band width of Ku band. There is not anything that we can do in Ku band that we cannot do in Ka band with more efficiency [25].

4.4 **Honeycomb EBG Structures**

The honeycomb structure is derived from the triangular lattice by removing every third basis point of the triangular lattice. It has been shown that the honeycomb lattice has a considerably wider band gap than both squares and triangular lattice for a given r/a ratio [26][27].

The primary honeycomb gap open up at much lower r/a ratio and occurs at much lower normalized frequencies then both the square and triangular lattice [28]. Besides, the size of honeycomb lattice is only 84% of square lattice and just 33% of the triangular. There is a clear advantage that honeycomb lattice is smaller and
highly integrated, where size and integration are essential [29]. Broad band devices can be easily fabricated using honeycomb lattice.

A honeycomb lattice generates a larger gap, even for the smaller index contrast. Since the hexagonal structure has a more circle like Brillouin zone, the gaps are more likely to open across all the symmetry points [29].

4.5 **Mechanical Tuning**

Different methods have been proposed in the literature, whereby the EBG frequency response can be tuned over the entire frequency band of interest, so that the same EBG structure can be utilized for several wideband structures.

The frequency response of an EBG structure can also changed by changing its dimensions. However, the EBG patch width cannot be changed after construction. A number of methods on increasing the frequency agility of the EBG structures have been reported in the literature, include which the addition of varactor diodes between the metallic patches, micro electro-mechanical systems (MEMS) actuators and using ferrite substrates are included. However, adding loading components such as varactor diodes and their attendant biasing circuits make the resultant EBG structures much more complicated than the conventional EBG structures.

Furthermore, at higher microwave frequencies, the EBG dimension is very small and it is difficult to settle the diodes between the patches. On the other hand, the high-quality ferrites cannot be employed as a substrate in microwave region. In addition, the required external magnetic source makes it large and bulky.
A suitable method for tuning the resonant frequency, is to insert an adjustable air gap beneath the EBG substrate. It is economical and feasible to use with any EBG structure of any arbitrary shaped patch.

### 4.6 Design and Analysis

In the present work the classical bandstop filter with EBG structures are achieved by microstrip technology with the 2D hexagonal basis points in a honeycomb lattice that are etched on the ground plane of microstrip feed lines with impedance 50 Ω as shown in the figure 4.1(a) and 4.1(b). This structure is designed on the RT-Duroid (6002NS) substrate with dielectric constant 2.94. Calculated dimensions of the strip are 10.289 mm, the length of the microstrip line and the period of a is 1.7 mm and radius of the hexagon basis points r is 0.86 mm.

#### 4.6.1 Design of Microstrip Line:

Effective dielectric constant of microstripline is approximately given by:

\[
\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2} \frac{1}{\sqrt{1+12d/W}}
\]  

(4.1)

The effective dielectric constant can be interpreted as the dielectric constant of a homogeneous medium that replaces the air and dielectric regions of the microstrip.

Characteristic impedance: gives the dimensions of the microstripline, it can be calculated as

\[
Z_0 = \frac{60}{\sqrt{\varepsilon}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) \text{ for } W/d \leq 1
\]
\[
\frac{W}{d} = \frac{120\pi}{\sqrt{\epsilon \left[ \frac{W}{d} + 1.393 + 0.667 \ln\left(\frac{W}{d} + 1.444\right) \right]}} \quad \text{for } \frac{W}{d} \geq 1
\] (4.2)

For given characteristic impedance \(Z_0\) and dielectric constant \(\varepsilon_r\), the \(w/d\) ratio can be calculated as follows:

\[
\frac{W}{d} = \frac{8\varepsilon_r^A}{\varepsilon_r^{2A-2}} \quad \text{for } \frac{W}{d} < 2
\]

\[
= \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r^{-1}}{2\varepsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \right] \quad \text{for } \frac{W}{d} > 2
\] (4.3)

Where

\[
A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r^{-1}}{\varepsilon_r + 1} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right)
\]

\[
B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}
\]

And for the microstrip line length

\[
k_0 = \frac{2\pi f}{c}
\] (4.4)

Then by using equation (4.4) the length is

\[
l = 90^\circ \frac{\pi}{180^\circ} / k_0 \lambda
\] (4.5)

and width of the microstrip line is calculated using equation (4.3).
4.6.2 Designing of EBG Structure

In order to make a reflecting structure, we need to choose a crystal geometry that provides a photonic band gap. Dimensions of the EBG structure have been calculated using the gap map. In this section the gap map for the honeycomb lattice presented. The gapmap for the honeycomb lattice (shown in figure 4.2) with the hexagonal basis points are generated by the band solve analysis. Band solve analysis is done by using the RSoft Band Solve. The gapmap for both TE and TM polarization is plotted. In figure 4.2, horizontal axis represents radius of the hexagonal patch and vertical axis represents the frequency. The locations of the band gaps are outline for both TE and TM polarization. In the gapmaps the blue shaded area shows the region where TE wave cannot exists and the red area shows

Figure 4.1 (a) Geometry of the proposed EBG structure, 1(b) experimental setup of cavity with EBG structures.
the region where TM mode cannot propagate and in the green shaded area both TE and TM mode will not propagate.

The first two dimensional photonic crystal that we will consider, consists of parallel columns arranged in a honeycomb lattice. The columns have a radius ‘r’ and the lattice constant ‘a’. The case of dielectric $\varepsilon_r=2.94$ is considered and following formula for finding the value of ‘a’ is used

$$\frac{\omega a}{2\pi c} = \frac{a}{\lambda}$$  \hspace{1cm} (4.6)

To calculate the radius and distance of the required EBG structure region which is thickest (large band gap) is selected and noted the value of r/a. Then by calculating the value of ‘a’ and by putting value of ‘a’ in equation 4.6 one can calculate the value of ‘r’.

![Graph](image-url)

**Figure 4.2.** Gap map for a honeycomb lattice with hexagonal basis points

### 4.7 Simulations and Analysis
Experimental measurements were carried out using (Rohde & Schwarz ZVA 50). Simulations and eigen mode analysis were performed on CST Microwave Studio. EBGs are designed for TE mode due to large band gaps for electric field as observed in the gap map in figure 4.2. Upper and lower band stop band edge frequency was calculated from figure 4.2 [3] as 33.13 GHz and 42 GHz respectively.

Transmission response of the fabricated planar EBG structure is measured by placing it in an aluminium cavity as shown in figure 4.1(b). Experimentally an 8 GHz wide band gap from 33.14 to 42 GHz is observed with isolation of 32 dB as shown in figure 4.3. Time domain analysis of the experimental setup on CST Microwave Studio was in close agreement with the band edge frequencies obtained from bandgap analysis and experiment.
Figure 4.3. Experimental and simulation analysis of $S_{21}$ and $S_{11}$ parameters of Honeycomb EBG structures with Hexagonal basis points.

Results thus obtained from gapmap, experiment and simulation are compared in Table 4.1. Minor variation in lower band edge frequency is observed.

**TABLE 4.1 Comparison of Experimental, Simulated, and Gap map results**

<table>
<thead>
<tr>
<th>Results Obtain</th>
<th>Lower Cut-off Frequency (GHz)</th>
<th>Upper Cut-off Frequency (GHz)</th>
<th>Band Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>By Experiment</td>
<td>33.25</td>
<td>42</td>
<td>8.75</td>
</tr>
<tr>
<td>By Simulation</td>
<td>33.14</td>
<td>42</td>
<td>8.86</td>
</tr>
<tr>
<td>By Gap map</td>
<td>33.16</td>
<td>42</td>
<td>8.84</td>
</tr>
</tbody>
</table>

Eigen mode analysis is carried out using CST Microwave studio to understand the nature of field distribution in these structures. In the bandgap region cross coupled polarized mode can be seen in the slot between two adjacent hexagonal patches as shown in figure 4.4. At the band edges, clear transmission modes are observed. At some frequencies in the bandgap region, enhanced transmission is observed this is due to the electric field trapped in the hexagonal dielectric patch naturally present in the honeycomb structure. This trapped field across the dielectric patch results in decreased isolation in the bandgap region. Structures designed and presented here have band gap for electric fields and thus are not complete bandgap structures.
Performance analysis of the honeycomb structure was carried out by introducing a mechanical perturbation near planar EBG at varying height. Perturbation was introduced by using the metallic spacer attached to 1 mm pitch screw attached to the top plate of the cavity. The experimental setup is shown in figure 4.5. Experimental and simulation results clearly indicate shift in band edges on bringing the mechanical spacer near planar structure.

**Figure 4.4:** Electric field distribution in x-y plane of Honeycomb EBG structure

**Figure 4.5:** Experimental Setup for mechanical (spacer) tuning.
S\textsubscript{21} parameters are measured by keeping mechanical spacer at different heights. Maximum sensitivity is observed when perturbing element is closest to the planar EBG structure. Experimental observations show a shifting of 200 MHz at a distance of 1.2 cm above the EBG, 500 MHz shift at 0.9 cm and 1.25 GHz shifting at 0.6 cm respectively. Experimental results are cross validated with simulations and shown in good agreement as shown in figure 4.6 (a) and 4.6 (b).

![Figure 4.6](image)

**Figure 4.6** (a) Experimental Analysis of S\textsubscript{21} parameter of the metallic spacer tuning
Mechanical perturbation resulted in decreased isolation. To understand the behaviour of perturbed planar EBGs, eigen mode analysis is carried out and field distribution was analysed in the xy-plane. On comparing figure 4.4 with figure 4.7, it can be seen that perturbation results in decreased localization of crossed coupled polarization, thus resulting in some attenuated leaky mode within the bandgap region. Further, analysis of field distribution in the cross-sectional plane shows formation of mono polarized mode and formation of a capacitance across the spacer (figure 4.8).

The above Figure 4.6 shows the shift in band edge towards lower frequency on decreasing the spacer distance from the EBG surface. This decreasing distance will lead to decrease in over all capacitance thus its pushes the band edge frequency to lower values.
**Figure 4.7(a).** Electric field distribution in x-y plane with the spacer at height 0.6 mm.

**Figure 4.7 (b).** Electric field distribution in x-y plane with the spacer at height 0.9 mm.
Figure 4.7(c). Electric field distribution in x-y plane with the spacer at height 1.2 mm.

Figure 4.8 (a) (b) (c) Cross-sectional View of electric field distribution in x-y plane with spacer at height 0.6 mm, 0.9 mm, 1.2 mm respectively.
Comparative bar plot depicting the effect of perturbation on upper and lower band edge by experimental and simulation analysis for EBG system are shown in figure 9(a) and 9(b). The analysis presented here, clearly shows that the honeycomb structures can find application as low noise tunable band stop filters. Presence of appreciable cross coupled mode ensures surface wave suppression thus honey comb planar EBG lattice can be used in the design of efficient antenna systems.

(a)

**Figure 4.9 (a)** Band edge tuning at different heights of metallic spacer achieved experimentally.
Figure 4.9 (b) Band edges tuning at different heights of metallic spacer achieved by simulations

Results obtained herein are compared with results obtained by other groups worked on EBG tuned band stop filter using different technologies described in table 4.2. Comparison brings forth the wide-band feature of the designed structures with efficient surface wave suppression. Effect of mechanical perturbation as tuning element also shows appreciable losses and controlled tuning.

**TABLE 4.2. Comparison of the obtained results with the results reported in the literature**

<table>
<thead>
<tr>
<th>Tuning Element</th>
<th>Reference</th>
<th>Tuning GHz</th>
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</thead>
<tbody>
<tr>
<td>Metallic Plate</td>
<td>Present work</td>
<td>1.25 GHz</td>
</tr>
</tbody>
</table>
4.9 Conclusion

A planar metallodielectric 2-D Honeycomb EBG lattice structures with hexagon basis points is designed and analyzed. The measurements show deep and wide stop band of 8 GHz from 33.25 to 42 GHz regions. The results were confirmed by the simulation and gap map methods. Further, tunability using metallic spacer was also studied. Structure proposed is simpler to fabricate, cost effective, compact in size and has shown good isolation and wide band stop region. Possible applications of these structures include filter, frequency selective surface, and efficient antennas.

<table>
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<tr>
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<tr>
<td>MEMS</td>
<td>C. Musoll-Anguiano, I. L. Garro, Z.B. Brito [12]</td>
<td>0.074 GHz</td>
</tr>
</tbody>
</table>
References


