CPW band-stop filter using unloaded and loaded EBG structures

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Abstract: Two different structures of unloaded and loaded electromagnetic bandgaps (EBGs) are proposed. The models of the unloaded and loaded unit structures are derived by equivalent circuit approach and full-wave electromagnetic simulation is used for extracting the values of the lumped elements in the circuit. A band-stop filter (BSF) has been designed with flat response at a selected frequency by cascading the unit EBG structures. The EBG filter is fabricated on high resistivity silicon substrate employing a microelectromechanical systems (MEMS) surface micromachining process. The measurement results for the loaded EBG reveals a 20 dB stop-band with a bandwidth of 13.2 GHz. The lower and the higher pass-band insertion losses are less than 2 dB and 4.5 dB, respectively. EBG band-stop filters fabricated by the MEMS process have immense potential to be integrated with CMOS devices owing to compactness and low cost.

1 Introduction

Periodic structures have recently attracted much attention in the microwave and millimetre-wave community owing to their filtering properties or inhibition of signal propagation in certain directions. These structures have been usually referred to as electromagnetic bandgaps (EBGs) or electromagnetic crystals. EBG structures can be embedded in the dielectric substrate or etched in the metal layer. An example is EBG structures with air holes embedded in the substrate to use as substrate for antennas. This will help to suppress the surface waves and result in a better radiation pattern and higher antenna efficiency [1]. EBG structures realised on metal layers are useful for constructing filters including band-stop filters, low-pass filter and band-pass filter [2, 3], phase shifters [4], and antennas [5]. Examples of EBG structures patterned on metal layers are the microstrip transmission line with EBG etched holes on the ground plane [6] or on the signal line [7, 8]. Other examples are the coplanar waveguide (CPW) with EBG etched holes on the ground plane [9], signal line [10] and on the ground and signal lines respectively [11]. CPWs offer greater design flexibility and require a single metal level compared to microstrip structures. The CPW structures are more attractive because of the ease of characterisation and fabrication, not forgetting promising applications in micro-wave integrated circuits (MMICs), monolithic microwave integrated circuits (MMICs), and microelectromechanical systems (MEMS) devices.

CPW EBG structures with rectangular aperture patterns etched on the ground plane and located adjacent to the gap between the signal and ground have been reported [12]. The dimensions of the rectangular aperture are the only parameters that can be adjusted. CPW defected ground structures (DGS) have been employed for bandpass filter applications [13]. Fortunately, there exists another CPW EBG structures that offer greater design flexibility, whereby a pattern consisting of slots and square apertures are etched on the ground plane [9]. Initial studies in EBG structures fabricated on the silicon substrate have been investigated [14]. Most researchers have focussed mainly on the possibility of obtaining a stop-band in EBG structures but little has been reported on the modelling and the performance of the band-stop filters.

In this paper, a new CPW EBG structure based on unloaded and loaded design is investigated. The frequency characteristics of the EBG will be demonstrated by employing different circuit parameters. An equivalent circuit model for unloaded and loaded unit structures will be derived based on circuit analysis theory. The dispersion diagram will be obtained for the both structures by combining the commercial software and the Floquet’s theorem in order to analyse the electromagnetic wave behaviour within a unit cell. The band-stop filter will be designed by cascading the unit EBG structures. The MEMS surface micromachining process will be used to fabricate the filter. Finally, the discussion on the measurement results in terms of flat responses for the stop-band and pass-band of the filter will be analysed.

2 Unloaded EBG structure

An unloaded lattice shaped unit EBG structure, as shown in Fig. 1, is proposed. The substrate is high resistivity silicon \((\rho = 4000 \Omega \cdot \text{cm})\) with dielectric permittivity of \(\varepsilon_r = 11.9\) and thickness of \(H = 200 \mu\text{m}\). The EBG structure is designed for \(50\Omega\) in CPW configuration, with a signal line width of \(W = 108 \mu\text{m}\) and the gap width, \(G = 60 \mu\text{m}\).

In the unloaded unit EBG structure, a square slot is etched in the ground plane with a side length, \(a\), and this is referred to as an unloaded structure. The square etched slot is connected to the gap by a narrow transverse slot with length of \(w_s\) and width of \(d_s\). The centre cut-off frequency,
which is the resonant frequency, depends on the transverse slot and the square etched hole of the ground plane. To investigate the influences of these parameters on the frequency characteristics, two separate designs have been constructed. The frequency characteristic for the proposed unit EBG structure is studied and analysed using (i) Momentum (an EM simulation tool by Agilent) and (ii) an equivalent circuit model.

### 2.1 Influence of the unloaded square aperture size

Three different sets of dimensions for the unloaded unit EBG structure are evaluated. The influence of the square aperture size, \( a \), on its frequency characteristic is investigated. The dimensions \( d_s = 60 \mu m \) and \( w_s = 200 \mu m \) are kept constant, for all the three different square aperture size, \( a = 350 \mu m, 500 \mu m \) and \( 600 \mu m \). From the simulation results shown in Fig. 2, the resonant frequency of the EBG cell decreases as the etched area of the square aperture increases. This frequency characteristic can also be explained using the parallel resonant circuit. As the size of the square aperture increases, the inductance also increases, whereas \( d_s \) and \( w_s \) are responsible for the capacitance. Since \( d_s \) and \( w_s \) are the same for all the three cases, the capacitance does not vary much compared to the inductance. This in turn reduces the resonance frequency of the equivalent parallel circuit.

#### 2.2 Influences of the transverse slot width

The influence of the transverse slot width \( d_s \) is investigated in this Section. The square aperture size, \( a \), is kept constant at \( 500 \mu m \times 500 \mu m \) and the length of the transverse slot, \( w_s \), is fixed at \( 200 \mu m \). The width of the transverse slot is allowed to vary and set at \( 10 \mu m, 60 \mu m \) and \( 200 \mu m \) respectively. The simulation results are obtained as shown in Fig. 2.

From Fig. 2, it can be observed that the resonant frequency shifts from \( 25.48 \text{GHz} \) to \( 37.98 \text{GHz} \) when \( d_s \) changes from \( 10 \mu m \) to \( 200 \mu m \). Since the size of the unloaded square aperture is fixed for all the three cases, the inductance variation is smaller. Thus, as \( d_s \) increases, the parallel capacitance decreases and the resonance frequency of the equivalent parallel circuit increases.

#### 2.3 Modelling of the unloaded EBG

An equivalent parallel \( LC \) circuit can be used to model the unloaded unit EBG structure as shown in Fig. 3. It consists of a series inductor and a parallel capacitor. From a practical point of view, the unloaded unit EBG structure can serve as a replacement for the parallel \( LC \) resonant circuit in many applications. To apply the unloaded EBG cell to a practical circuit, it is necessary to extract the equivalent circuit parameters, which can be obtained from the simulation result of the unloaded unit EBG structure. The lumped capacitance, \( C \), is mainly contributed by the transverse slot on the ground, while the inductance, \( L \), is related to the magnetic flux passing through the apertures on the ground.

The equivalent impedance equation of the single resonant model may be expressed as

\[
Z = \left( j\omega C + \frac{1}{j\omega L} \right)^{-1}
\]

(1)

The resonant frequency of the parallel circuit is defined as

\[
\omega_0 = \frac{1}{\sqrt{LC}}
\]

(2)

The \( 3 \text{dB} \) cut-off angular frequency, \( \omega_c \), can be determined by

\[
\left| S_{21} \right| = \left| \frac{2Z_0}{2Z_0 + Z} \right| = \frac{1}{\sqrt{2}}
\]

(3)

Substituting (1) into (3), the capacitance is obtained as

\[
C = \frac{\omega_0}{2Z_0(\omega_0^2 - \omega_C^2)}
\]

(4)
The inductance can be determined by

\[ L = \frac{1}{\omega_0^2 C} \quad (5) \]

\[ a, w_s, \text{and} \ d_s \text{ (see Fig. 1) are chosen at} \ a = 350 \mu\text{m}, \ w_s = 200 \mu\text{m} \text{and} \ d_s = 60 \mu\text{m} \text{to provide an example to the parameter extraction procedure. The equivalent circuit parameters are extracted and are presented in Table 1.} \]

The resonant frequency of the proposed unit EBG is affected by the variation of the unloaded square aperture dimensions. Based on the tabulated results (see Table 1) and the simulated results (see Fig. 2), it can be deduced that by varying from \( a = 350 \mu\text{m} \text{ to} 600 \mu\text{m} \), the change in capacitance is merely 15%. This is different from the case of inductance variation, where as much as 178% has been observed. The inductance variation rate is nearly 10 times greater than that of the capacitance. These observations verified that the dimension of the transverse slot is responsible for the parallel capacitor and the size of the square aperture relates directly to the series inductor. The series inductance is significantly affected by the size of the square aperture.

For the second design in which only transverse slot width, \( d_s \), is also allowed to vary, the resonant frequency of the proposed circuit changes slightly. Table 1 presents the extracted equivalent circuit parameters. The simulation result is shown in Fig. 2. From the case of \( d_s = 10 \mu\text{m} \) to the case of \( d_s = 200 \mu\text{m} \), the inductance varied by 5%, whereas the capacitance changes by almost 57%. The capacitance variation rate is nearly 10 times greater than that of the inductance. This again verifies that the dimension of the transverse slot controls the capacitance and the size of the square aperture affects the inductance in the equivalent circuit. Since the width of the transverse slot, \( d_s \), varied, the parallel capacitance should also change accordingly.

**Table 1: Extracted equivalent circuit parameters for the unloaded unit EBG structure, with variation in square aperture size, \( a \), and variation in the transverse slot width, \( d_s \)**

| \( d_s \) = 60 \( \mu\text{m} \), \( w_s \) = 200 \( \mu\text{m} \): |  |  |  |
| --- | --- | --- |
| Square aperture size, \( a \), \( \mu\text{m} \) | 350 | 500 | 600 |
| Resonant frequency, GHz | 38.79 | 30.6 | 27.13 |
| 3 dB cut-off frequency, GHz | 29.12 | 21.92 | 18.78 |
| Inductance, nH | 0.229 | 0.342 | 0.434 |
| Capacitance, pF | 0.073 | 0.079 | 0.079 |

| \( w_s \) = 200 \( \mu\text{m} \), \( a = 500 \mu\text{m} \): |  |  |  |
| --- | --- | --- |
| Transverse slot width \( d_t \), \( \mu\text{m} \) | 10 | 60 | 200 |
| Resonant frequency, GHz | 25.48 | 30.6 | 37.98 |
| 3 dB cut-off frequency, GHz | 19.38 | 21.92 | 24.56 |
| Inductance, nH | 0.339 | 0.342 | 0.357 |
| Capacitance, pF | 0.115 | 0.079 | 0.049 |

2.4 Propagation characteristics of unloaded EBG

The propagation characteristic of the unloaded EBG is analysed by Floquet’s theorem. By simply considering the unit structure, the EM simulation result of the method proposed by [15] can be used to get the dispersion diagram of the proposed unloaded EBG structure. The propagation factor in this case is \( e^{-\gamma L} \), where \( \Lambda = 2020 \mu\text{m} \) is the period of the EBG structure, and \( \gamma = \alpha + j\beta \) is the complex propagation constant in the direction of propagation and can be calculated by

\[ \gamma = \frac{1}{\Lambda} \cosh^{-1} \left( \left( \frac{1}{4} \frac{(1 + S_{11})(1 - S_{22}) + S_{12}S_{21}}{S_{21}} \right) \right) \]

where \( Z_{01} \) and \( Z_{02} \) are the impedances of port 1 and 2, in this study 50\( \Omega \).

The normalised phase constant \( \beta/\kappa_0 \) and the attenuation constant \( \alpha/\kappa_0 \) of a single EBG cell are illustrated in Fig. 4. When \( \beta/\kappa_0 \) is close to the Bragg condition (\( \beta \Lambda = \pi \)), the signal is highly attenuating. The stop band is very wide and within which the propagation is prohibited. The simulation result of the higher frequency band (i.e. larger than 43 GHz) is unfavourable when compared with those of the lower frequency band (i.e. less than 18 GHz).

3 Loaded EBG structures

In this Section, a loaded unit EBG structure is designed. A ring slot is etched in the ground plane with side length, \( a \) and ring width, \( r \). The ring slot is connected to the gap by a narrow transverse slot with length, \( w_s \) and width, \( d_s \). In addition, a square etched hole with side length, \( b \), is etched in the centre of the ring slot as shown in Fig. 5. As compared to the EBG structure without centre etched hole (i.e. unloaded), the proposed EBG structure includes a ring slot and a square etched hole and hence, is named as loaded EBG structure.

When the side length of the square etched hole and the ring slot side length are equal (i.e. at \( b = a \)), the square etched hole and the ring slot will merge to form a square aperture. When that happens, the unit cell becomes an unloaded EBG structure as mentioned in the previous Section. In this Section, the effect of the dimensions of the square etched hole (i.e. side length, \( b \)) on the frequency characteristic, the equivalent circuit model and the dispersion diagram of the loaded EBG are examined.
3.1 Effects of the square etched hole-loaded EBG structure

In this part of our study, four different sets of dimensions are chosen. The square aperture size, \( a \), is 500 \( \mu \text{m} \times 500 \mu \text{m} \), and the dimension of transverse slot is maintained at \( d_s = 60 \mu \text{m} \) and \( w_s = 220 \mu \text{m} \) for all the four cases. A centre etched square hole is added in the area of unloaded square aperture (see Fig. 5), while the width of the ring slot, \( r_s \) is chosen to be 30 \( \mu \text{m} \) for all the four cases, the length of the square etched hole, \( b \) is allowed to vary.

Based on the simulation results as shown in Fig. 6, all the three cases with \( b = 0 \mu \text{m}, 200 \mu \text{m} \) and 440 \( \mu \text{m} \) are noted to exhibit similar behaviour except for the case of \( b = 380 \mu \text{m} \). The resonant frequencies for all the four cases are almost identical, but the frequency response begins to drift after the resonant frequency. The loaded structures in the square aperture area is the main contributor to such a variation. It is widely known that low insertion loss and high return loss are expected in the pass-band of the band-stop filter. An optimum width of the square etched hole (i.e. at \( b = 380 \mu \text{m} \)) can clearly be deduced in Fig. 6 where the return loss is the highest and the insertion loss is the lowest among all the four cases. The existence of a loaded structure in the square aperture perturbs the whole circuit, which implies that the transverse slot is no longer the only factor contributing to the equivalent capacitor. Likewise, the square aperture can no longer act as the main determining factor to the equivalent inductor. Therefore, the additional structure in the square aperture area can significantly improve the pass-band insertion loss as well as the return loss. Single resonant equivalent circuit is no longer effective to model such loaded structure.

### 3.2 Modelling of the loaded EBG structure

In the previous Section, the single resonant parallel \( LC \) circuit model is employed to model the unloaded unit EBG structure. In the case of the loaded EBG cell, such a model would not be accurate. When the single resonant circuit model is used as shown in Fig. 3, the simulation results for the insertion and return losses cannot match with the EM simulation results especially when the frequency becomes greater than the resonant frequency. Hence, the loaded EBG cell has to be modelled using a different circuit. By cascading two parallel resonant circuits, the loaded unit EBG structure may be represented in Fig. 7.

The equivalent impedance of the cascaded parallel resonant circuits can be expressed as

\[
Z = \left( j\omega C_1 + \frac{1}{j\omega L_1} \right)^{-1} + \left( j\omega C_2 + \frac{1}{j\omega L_2} \right)^{-1}
\]  

(7)

where the subscripts '1' and '2' denote the two different resonant circuits.

The reflection coefficient, \( S_{11} \) is defined as

\[
|S_{11}| = \left| \frac{Z}{2Z_0 + Z} \right| = \frac{1}{\omega C_1 - 1/j\omega L_1 + \frac{1}{\omega C_2 - 1/j\omega L_2}} \sqrt{4Z_0^2 + \left( \frac{1}{\omega C_1 - 1/j\omega L_1 + \frac{1}{\omega C_2 - 1/j\omega L_2}} \right)^2}
\]  

(8)

The maximum value of \( |S_{11}| \) can be obtained by differentiating it with respect to the angular frequency, \( \omega \), and the two roots obtained are

\[
\omega_1 = (L_1C_1)^{-\frac{1}{2}}, \quad \omega_2 = (L_2C_2)^{-\frac{1}{2}}
\]  

(9)

The insertion loss is given by

\[
|S_{21}| = \left| \frac{2Z_0}{2Z_0 + Z} \right| = \frac{2Z_0}{\sqrt{4Z_0^2 + \left( \frac{1}{\omega C_1 - 1/j\omega L_1 + \frac{1}{\omega C_2 - 1/j\omega L_2}} \right)^2}}
\]  

(10)
By differentiating $S_{21}$, the first notch angular frequency, $\omega_n$, can be obtained as

$$\omega_n = \frac{\sqrt{L_1 + L_2}}{\sqrt{L_1/\omega_1^2 + L_2/\omega_2^2}}$$

(11)

The 3 dB cut-off angular frequency, $\omega_c$, can be determined as

$$|S_{21}|_{\omega = \omega_c} = \frac{2Z_0}{\sqrt{4Z_0^2 + \left(\frac{1}{\omega_c C_1 - 1/\omega_c L_1} + \frac{1}{\omega_c C_2 - 1/\omega_c L_2}\right)^2}} = \frac{1}{\sqrt{2}}$$

(12)

From (9), (11) and (12), the equivalent circuit parameters can be extracted, whereby

$$L_1 = \frac{2Z_0(\omega_1^2 - \omega_2^2)(\omega_2^2 - \omega_3^2)(\omega_3^2 - \omega_4^2)}{\omega_c \omega_1^2(\omega_2^2 - \omega_1^2)(\omega_4^2 - \omega_2^2)}$$

(13)

and

$$L_2 = \frac{2Z_0(\omega_2^2 - \omega_3^2)(\omega_3^2 - \omega_4^2)(\omega_4^2 - \omega_2^2)}{\omega_c \omega_2^2(\omega_3^2 - \omega_2^2)(\omega_4^2 - \omega_3^2)}$$

(14)

The capacitance values can be obtained as

$$C_1 = 1/\omega_1^2 L_1, \quad C_2 = 1/\omega_2^2 L_2$$

(15)

All the four parameters $L_1, L_2, C_1$ and $C_2$ can be calculated using (13), (14) and (15), respectively. To illustrate the parameter extraction procedure, the values of $a$, $r_r$, $w_s$, $d_s$ and $b$ are 500, 30, 220, 60 and 380 $\mu$m respectively. The parameters for both the single resonant circuit model and the cascaded circuit model are extracted and summarised in Table 2.

In order to determine the suitability of the two models for their possible application in the loaded EBG structure, both the simulation results of the single resonant and cascaded models are shown in Fig. 8. The cascaded circuit simulation results obviously provided good agreement with the EM simulation results at frequency, which is below the notch frequency (i.e. at 60.76 GHz). The simulation result for the single resonant circuit model drifts from the EM simulation result after 40 GHz. Thus, for the loaded EBG structure, the cascaded circuit model is more reasonable than the single resonant circuit model, and is valid up to the first notch frequency. The extracted equivalent circuit parameters that are simulated in Fig. 8 and the parameters for the single and the cascaded resonant model are listed in Table 2.

### Table 2: Extracted equivalent circuit parameters for the loaded EBG unit structure

<table>
<thead>
<tr>
<th>$d_s$ = 60 $\mu$m, $w_s$ = 220 $\mu$m, $a$ = 500 $\mu$m, $r_s$ = 30 $\mu$m</th>
<th>0</th>
<th>200</th>
<th>380</th>
<th>440</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square etched hole $b$, $\mu$m</td>
<td>29.24</td>
<td>29.24</td>
<td>29.24</td>
<td>29.19</td>
</tr>
<tr>
<td>First resonant frequency, GHz</td>
<td>22.42</td>
<td>22.42</td>
<td>23.20</td>
<td>22.34</td>
</tr>
<tr>
<td>First 3 dB cut-off frequency, GHz</td>
<td>81.77</td>
<td>81.42</td>
<td>77.26</td>
<td>77.77</td>
</tr>
<tr>
<td>Second resonant frequency, GHz</td>
<td>66.67</td>
<td>66.67</td>
<td>60.76</td>
<td>65.13</td>
</tr>
<tr>
<td>Single resonant model:</td>
<td>0.285</td>
<td>0.285</td>
<td>0.243</td>
<td>0.286</td>
</tr>
<tr>
<td>$L$, nH</td>
<td>0.104</td>
<td>0.104</td>
<td>0.123</td>
<td>0.103</td>
</tr>
<tr>
<td>$C$, pF</td>
<td>0.282</td>
<td>0.282</td>
<td>0.243</td>
<td>0.285</td>
</tr>
<tr>
<td>Cascaded model:</td>
<td>0.105</td>
<td>0.105</td>
<td>0.122</td>
<td>0.104</td>
</tr>
<tr>
<td>$L_s$, nH</td>
<td>0.023</td>
<td>0.022</td>
<td>0.028</td>
<td>0.021</td>
</tr>
<tr>
<td>$C_s$, pF</td>
<td>0.168</td>
<td>0.172</td>
<td>0.152</td>
<td>0.195</td>
</tr>
</tbody>
</table>

### 3.3 Propagation characteristics of the loaded EBG

The dispersion diagram of the loaded EBG structure which is useful in understanding the guided and leaky wave characteristics is shown in Fig. 9. The shaded region from 18 GHz to 42 GHz represents that the electromagnetic wave is prohibited in the periodic structures. There exist a spurious peak in the phase constant curve obtained through EM simulation and can be overcome by increasing the mesh resolution. The band gap region of the loaded EBG is less compared to the unloaded EBG.

### 4 Bandstop filter measurement results and discussion

The surface micromachining process is used for fabricating the band-stop filters. The process begins by growing a 0.5 $\mu$m-thick SiO$_2$ layer on a 200 $\mu$m-thick high resistivity silicon substrate that served as a buffer layer. A 1.5 $\mu$m aluminum layer is evaporated on the buffer layer, to define
the structure. Photoresist coating and device patterning are performed next. Finally, aluminum wet etching is performed to remove the aluminum thin film and to form the EBG structures. The process needs only one mask to fabricate the filters.

In order to show the validity of the equivalent circuit and the extracted parameters for the proposed unit EBG structure (both unloaded and loaded), band-stop filters are designed by employing the proposed EBG cell structure.

4.1 Unloaded EBG band-stop filter
Three unloaded EBG cells are cascaded to form a band-stop filter, which is fabricated and measured. These cells are periodically placed apart at a distance of 20 μm, which is equal to the half guided wavelength of the CPW at 30 GHz. The values of a, w, and d, for designing the filter are presented in Table 1. The measurement results are shown in Fig. 10. From the measurement results, one can notice that the 20 dB stop-band is from 24.4 GHz to 40.6 GHz. The stop-band return loss is less than 2 dB. For the lower pass-band, the return loss is greater than 10 dB but for the higher pass-band the return loss reaches to 6 dB. The lower pass-band insertion loss is less than 2 dB and the higher pass-band insertion loss is below 5 dB.

4.2 Loaded EBG band-stop filter
Three of the proposed loaded EBG cells are cascaded to form a band-stop filter. The SEM micrograph of the proposed three-cell EBG band-stop filter is shown in Fig. 11. The values of a, r, w, d, and b, for the loaded EBG are presented in Table 2. The measured results of the fabricated EBG band-stop filter together with its simulated data from both the EM software and the equivalent circuit are shown in Fig. 12. Both the simulation results and the equivalent circuit are in good agreement with the measured results, which show the validity of the proposed equivalent circuit. The measured results show a relatively wide 20 dB stop band, from 24.8 GHz to 38 GHz, with a return loss below 2 dB. For the pass-band, the return loss is higher than 10 dB except for those at the higher frequencies. The lower pass-band insertion loss is less than 2 dB and the higher pass-band insertion loss is less than 4.5 dB. The 2 dB insertion loss exhibited in the pass-band of the filter at frequencies below 5 GHz is a result of material loss, conductor/metallic loss and MEMS fabrication error.

A comparison on the performances of the loaded and the unloaded EBG band-stop filters shows that except for the 20 dB stop-band width, it is obvious that the performances of the unloaded EBG band-stop filter are more inferior compared to the loaded EBG band-stop filter in all aspects. In particular, the higher pass-band performances of the loaded EBG filter are better than those of the unloaded case. The reason for this improvement lies in the equivalent inductance of the loaded unit EBG structure, which is much lower than that of the unloaded unit EBG structure. As for the equivalent capacitance, the loaded cell yields higher capacitance than that of the unloaded cell. It should be noted that both the pass-band insertion loss and the stop-band return loss characteristics are very flat and contain less than 0.2 ripples for both filters, which is in fact a concern for band-stop filters realised using other EBG structures.

5 Conclusions
A new band-stop filter using unloaded and loaded structure has been investigated. The frequency characteristics of the EBG unit cell are studied by employing different circuit parameters. An equivalent circuit model has been derived for the unloaded and loaded EBG cell. The extracted parameters show that the bandgap effect of the EBG cells...
can be interpreted accurately based on the circuit analysis theory. The dispersion diagram obtained was useful for describing and understanding the propagation characteristics in the EBG unit cell. The complex characteristic impedance estimated was helpful for analysing the effect of impedance change in the EBG structure. A band-stop filter is designed by cascading the unloaded and loaded EBG cells. MEMS surface micromachining process is employed to fabricate the EBG structures and is compatible with the CMOS process, which can be integrated easily with CMOS devices for wireless front-end systems. The measured result of the loaded structures shows enhanced pass-band performance owing to higher equivalent capacitance and lower equivalent inductance, which are helpful to increase the insertion loss and decrease the return loss at higher frequencies. In addition, the proposed structure can also yield flat return loss performance in the stop-band. The 20 dB stop-band is as wide as 13.2 GHz. The lower pass-band insertion loss is less than 2 dB with 0.2 dB ripple, and the higher pass-band insertion loss is less than 4.5 dB.

6 References