Novel 1-D Microstrip PBG Cells

Quan Xue, Kam Man Shum, and Chi Hou Chan

***Abstract*—Novel one-dimensional (1-D) microstrip photonic bandgap (PBG) cells are proposed. They are sections of microstrip line with special perforation patterns etched on the line itself. As examples, two types of PBG cell are investigated. Simulation and experiments show that the cell exhibits remarkable slow-wave and band-stop effects. An equivalent L-C circuit is used to model the PBG cell. Several cells connected in series form an excellent band-stop filter.**

***Index Terms*—Filter, microstrip, photonic bandgap (PBG), slow-wave factor.**

I. Introduction

MICROSTRIP transmission lines incorporating a photonic bandgap (PBG) structure exhibit band-stop and slow-wave characteristics, which can be exploited to reject unwanted frequency and to reduce the dimensions of the microstrip structure. The PBG structure can be in the form of a periodic array of dielectric inclusions with a dielectric constant different from that of the host dielectric substrate [1] or a two-dimensional (2-D) periodic array of perforations in the ground plane of the microstrip line [2]. In the study of a microstrip transmission line over a periodically perforated ground plane, it is found that the propagation constant strongly depends on the orientation and location of the transmission line with respect to the two principal axes of the periodic perforations [3]. As the ground plane is perforated, the substrate must be suspended so that the circuits cannot be fixed on a metal base for mechanic robustness. Perforation on transmission line itself [4], [5] is a potential solution to these problems. In this letter, we propose two one-dimensional (1-D) microstrip PBG cells, which exhibit remarkable slow-wave and band-stop performance.

II. Design of 1-D Microstrip PBG Cell

By the transmission line theory [6], the propagation constant of a line without loss is $\beta = \omega_0\sqrt{LC}$, where ω_0 is the angular frequency, C and L are the distributed shunt capacitance and series inductance per unit length, respectively. It shows that slow-wave (large propagation constant) can be achieved by increasing C and L in the transmission line. If the values of C and L are not increased continuously but periodically, the transmission line is possible to form PBG structure. In view of these points, we propose two 1-D microstrip PBG cells, which are shown in Fig. 1. The cells are primarily a section of microstrip line with some metallic parts removed. The narrow connecting lines lead to the increase of series inductance. In contrast, gaps across the width of the line increase the shunt capacitance. By tuning the microstrip section length and the size of etched pattern, different slow-wave effects can be attained at different frequency. By comparing the structures in Figs. 1(a) and (b), it can be seen clearly that the two narrow lines that act as series inductance in Fig. 1(a) become one line in Fig. 1(b). This not only increases the series inductance, but also the resonant point of the shunt resonant components, which are formed by the triangles and the narrow connecting lines between the center narrow line and the triangular structures, shifted to lower frequency. With the width of gaps and lines of the perforation keeps the same, the cell in Fig. 1(b) provides a more effective slow-wave and bandgap than that in Fig. 1(a). These two cells can be used effectively as a component in microstrip hybrid and monolithic microwave integrated circuits (HMIC and MMIC) for size reduction and rejection of unwanted frequency. Based on the above discussions, an L-C equivalent circuit, as shown in Fig. 2 is derived for the PBG cell depicted in Fig. 1(b). Where the inductance L_0 and L_1 correspond to the transverse and longitudinal narrow strips, respectively. And the capacitance C_0 is the capacitance of the triangular patch, C_1 is the gap capacitance between the triangular patch and the microstrip line. Similar equivalent circuit can be derived for the cell shown in Fig. 1(a). By connecting identical cells in series, the periodic structure exhibits typical slow-wave and band-stop characteristics of the PBG. With the present HMIC and MMIC technology [7], fabrication of the PBG structures with lines and gaps at the size of micrometer level is achievable.

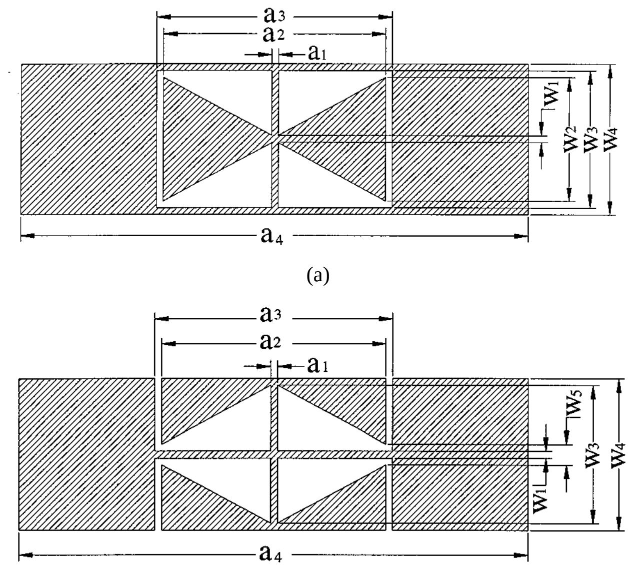

Fig. 1. One-dimensional (1-D) microstrip PBG cells. (a) PBG Cell 1. (b) PBG Cell 2.

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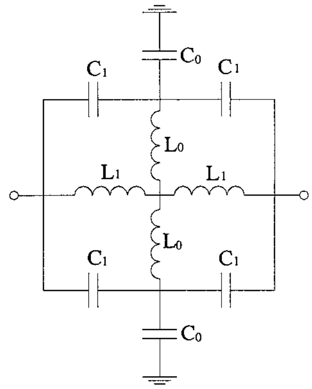


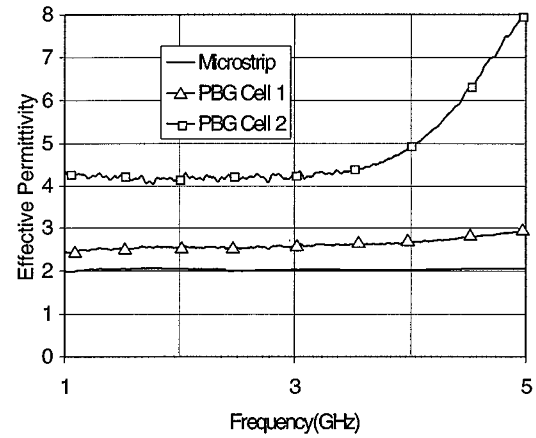
Fig. 2. L-C equivalent circuit for PBG Cell 2.

III. Numerical and Experimental Results

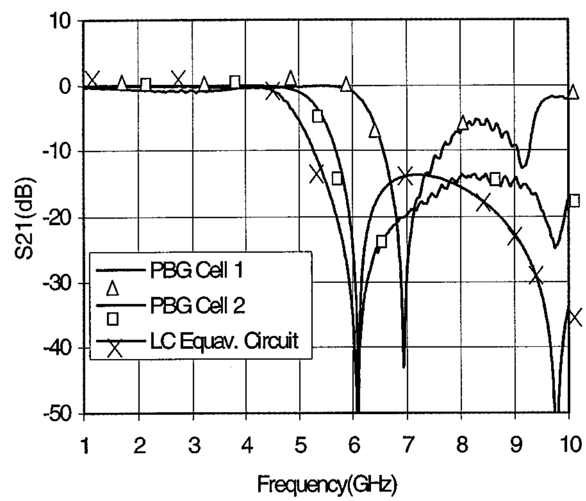
Fig. 2(a) and (b) show the measured relative effective permittivity and S_{21} of the PBG cells shown in Fig. 1. The circuit substrate is Duroid5870 with a relative permittivity 2.33 and height 1.524 mm. The cell parameters in Fig. 1 are $w_1 = 0.2$ mm, $w_2 = 3.7$ mm, $w_3 = 4.1$ mm, $w_4 = 4.5$ mm, $w_5 = 0.6$ mm, $a_1 = 0.2$ mm, $a_2 = 6.6$ mm, $a_3 = 7.0$ mm, $a_4 = 15$ mm. The width of the cells is identical to that of a 50-ohm microstrip line on the same substrate. The relative effective permittivity of the PBG cell depicted in Fig. 1(b) is 2.1 to 4 times higher than that of normal microstrip line for the frequency range shown. Fig. 2(b) shows both PBG cells in Fig. 1 have distinctive stop-band. The PBG cell in Fig. 1(b) has a 4.5 GHz stop-band (from 5.5 GHz to 10.0 GHz) with isolation more than 13 dB. Below 4.0 GHz, it is a very good transmission line with insertion loss less than 0.5 dB. By fitting the S_{21} curve of the Cell 2, the values of the equivalent circuit are obtained where $L_0 = 0.26$ nH, $L_1 = 1.05$ nH, $C_0 = 0.34$ pF, $C_1 = 0.18$ pF. With these parameters, we generate the S_{21} curve of the equivalent circuit, which is also shown in Fig. 3(b). It can be seen that this equivalent circuit accurately predicts the two resonances at 6.1 and 9.7 GHz. We cascade six units of the PBG cell of Fig. 1(b) to form a PBG structure. Fig. 4 shows the measured and simulated S_{21} values of the resulting PBG transmission line. The sum of the radiation loss, ohm loss and dielectric loss can be calculated by $1 - |S_{11}|^2 - |S_{21}|^2$. It can be seen that the loss is less than 9.5% from 1 GHz to 4.5 GHz, but near and inside the bandgap, the loss can be as high as 81%. This implies that these losses, especially the radiation loss, can be very large at the resonant band. Similar behavior can also be observed in the other PBG structures. The simulation was done using *ENSEMBLE 6.0* [8]. Good agreement between experimental and simulated results is achieved.

IV. Conclusion

We have presented two 1-D microstrip PBG cells. By cascading these cells, we form an effective PBG microstrip transmission line which exhibits slow-wave and stop-band characteristics similar to the other microstrip structures that entail the use of a PBG ground plane. The proposed PBG transmission line is more flexible in practical circuit applications because the dependence of the orientation and location of the transmission line with respect to the axes of periodicity of the PBG ground plane on the propagation constant is completely eliminated.



(a)



(b)

Fig. 3. Characteristics of the PBG cells. (a) Measured relative effective permittivities of the 1-D PBG cells and a normal microstrip line with the same width. (b) Measured S_{21} of the 1-D PBG cells in Fig. 1 and simulated S_{21} of the L-C equivalent circuit in Fig. 2.

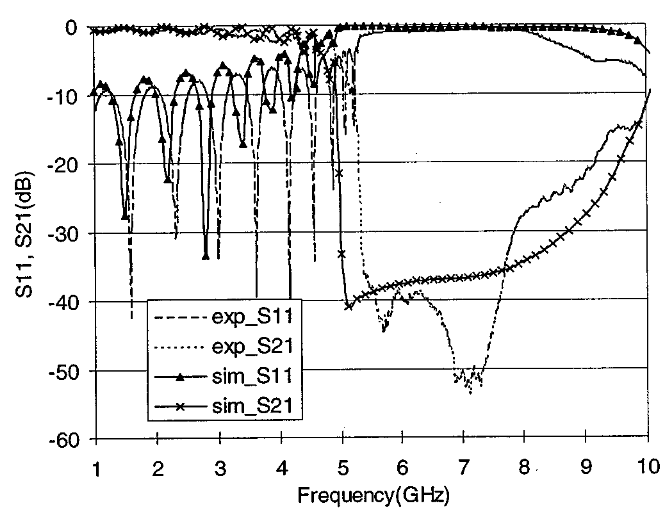


Fig. 4. Measured and simulated S-parameters for a PBG structure using 6 PBG cells shown in Fig. 1(b).

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