Photonic Bandgap Dielectric Waveguide Filter

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***Abstract*—The application of photonic bandgap (PBG) structures as the sidewall of the printed circuit board (PCB) dielectric waveguide filter is investigated in this letter. The effect of different PBG parameter on the Q-value of PBG dielectric waveguide resonator is evaluated. A PBG dielectric waveguide three-pole Chebyshev bandpass filter is realized. The measured performance matched well with the calculated results. The newly proposed I/O coupling structure makes the filter much easier for mass production.**

***Index Terms*—Dielectric waveguide filter, PBG, PCB filter.**

I. Introduction

A photonic bandgap (PBG) structure is a periodic structure where electromagnetic wave can pass through it in some frequency bands and stop to propagate in some other frequency bands. Many applications using the 2-D PBG structures have been found.

Conventional metallic waveguide filter, although shows very good performance, is difficult to manufacture due to its large size and sensitive to fine-tuning. Yang *et al.* [1] proposed a metallic waveguide with UC-PBG sidewalls which are equivalent to magnetic walls rather than electric walls in conventional waveguide. However, it is not easy for mass production. Danglot *et al.* [2] proposed a PBG waveguide structure which uses several rows of plated-through-holes in a dielectric substrate to build a dielectric waveguide. This structure keeps almost all significant properties of a conventional metallic rectangular waveguide. In addition, it is much easier for mass production and its size is much smaller.

In this letter, a new PBG dielectric waveguide filter is proposed. Its guiding structure, similar to those reported in [2]–[4], comprises three rows of plated-through-holes at each side of the PBG dielectric waveguide. In our filter, two plated-through-holes are used as the coupling structure between two resonators. These two plated-through-holes can be fabricated using the same process as the PBG array. The input and output coupling structure is formed by two similar plated-through-holes. It directly couples the energy from the feeding 50 Ω microstrip lines, instead of tapered microstrip line transition proposed in [3], [5]. The radiation loss caused by wide microstrip width [4] is not a problem for the new filter, because its substrate dielectric constant, 10.2, is relatively high. Tuning is not required for this PBG dielectric waveguide filter because the fabrication tolerance of the PCB process can be controlled relatively well than that of the machined metallic waveguide.

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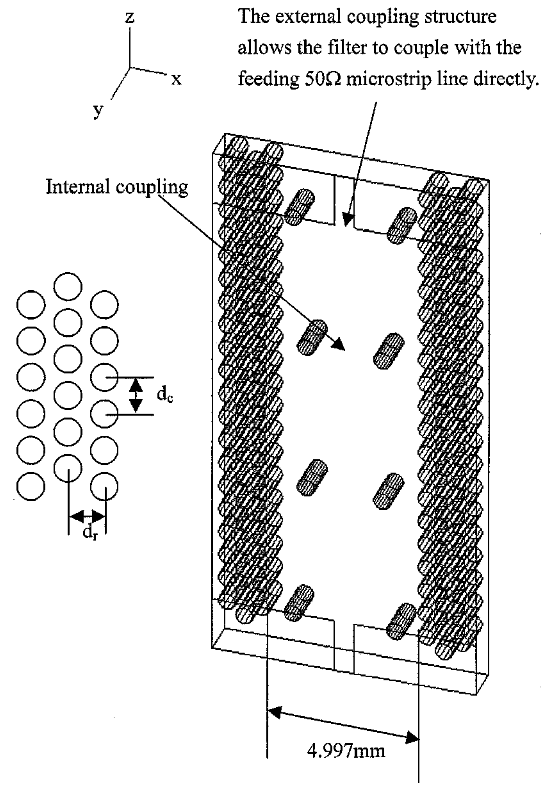

Fig. 1. Proposed three-pole PBG dielectric waveguide filter.

II. PBG Dielectric Waveguide Filter Design

The proposed three-pole PBG dielectric waveguide filter is shown in Fig. 1. The substrate used here is Rogers RT/duroid 6010 with dielectric constant of 10.2 and dielectric thickness of 1.27 mm. The copper clad is half ounce, which is equivalent to thickness of 0.7 mil and the dielectric loss tangent is 0.0023, according to the data sheet. The prototype circuit has the following filter parameters: the response is Chebyshev type, the number of resonator is three, the pass-band ripple is 0.01 dB, the fractional bandwidth is 3%, the center frequency is 12.5 GHz and the width of the waveguide is 4.997 mm.

A. Effect of PBG Parameters on Resonator Q-Value

In Fig. 1, a 2-D PBG array consisting of three rows of plated-through-holes forms the equivalent sidewalls of the dielectric waveguide. The top view of the PBG array shows that the distance between two adjacent rows is d_r and the distance between two adjacent holes in the same row is d_c. The radius of all of the plated-through-holes including the coupling structures is 0.3 mm. The cutoff frequency of the 2-D PBG array varies from 53 GHz to 24 GHz as d_c changes from 0.9 mm to 2.1 mm. It is much higher than the pass-band frequency of the proposed filter. The

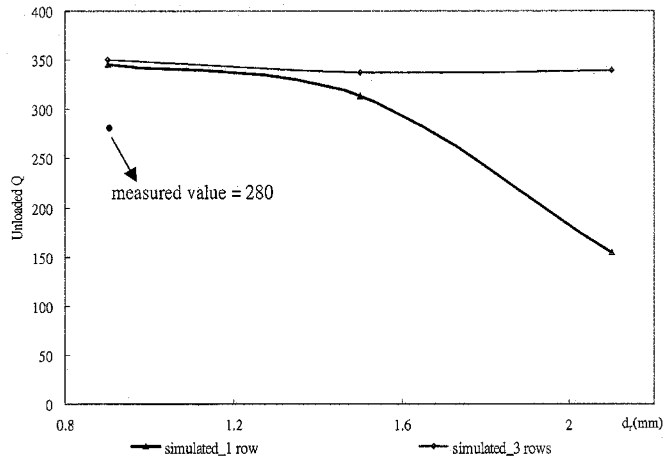

Fig. 2. Unloaded Q value of the PBG dielectric waveguide resonator.

waveguide previously reported in [3], [4] uses only one row of plated-through-holes and its simulated Q-value is lower than the waveguide with three rows of plated-through-holes.

Fig. 2 shows the calculated unloaded Q-value versus different d_c values and keeps d_r to be 0.6 mm. The Q-value of three-row sidewall waveguide is higher than the one of one-row sidewall waveguide, especially when d_c is large. The unloaded Q-value changes a little with respect to different d_c in three-row sidewall waveguide. However, it changes a lot in one-row sidewall waveguide. Therefore, a three-row sidewall with $d_c = 0.9$ mm is selected to build the trial filter for better Q-value. The measured Q-value is a little bit lower than the calculated one. However, the measured Q-value is higher than microstrip line resonator fabricated on the same substrate.

B. Filter Design

The filter is designed by finding the desired coupling coefficient between each resonator and by finding the external Q-value of the first and the last resonators loaded by feeding 50 Ω microstrip line. The physical length of each resonator should be adjusted according to the coupling strength to keep the resonant frequency be the same f_c. The internal and external coupling structures are described as follows.

1) Internal Coupling: The two plated-through-holes located at the intersection of the two adjacent resonators forms the internal coupling structure as shown in Fig. 1. Adjusting the distance between the holes changes the coupling value. The resonant frequency is changed accordingly, which needs to be compensated by adjustment of resonator length.

2) External Coupling: The external coupling of a filter is extremely important because it can change the transmission line from one type to another. In the proposed filter, the whole circuit is fabricated on a PCB whose simplest input and output transmission line is a 50 Ω microstrip line. Here, an external coupling structure as shown in Fig. 1, is proposed. It simply utilizes two plated-through-holes to accomplish the coupling between 50 Ω microstrip line and PBG dielectric waveguide resonator. The external Q-value changes in accordance with the distance between two holes. This external coupling structure can shrink the circuit size and simplify the fabrication. Again, the resonator length should be adjusted to compensate the frequency drift caused by the external coupling.

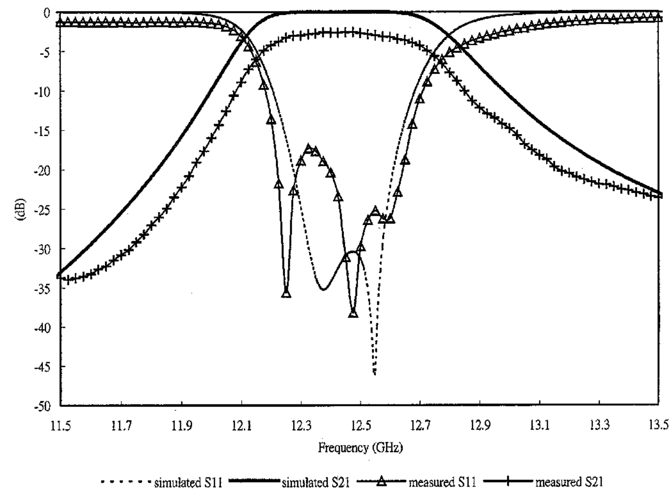

Fig. 3. Simulated and measured results of the PBG dielectric waveguide filter.

III. Results and Discussion

Here, the width of the PBG dielectric waveguide is 4.997 mm and its calculated cutoff frequency is 9.24 GHz. The cutoff frequency of this PBG dielectric waveguide is the same as the one of a metallic wall dielectric waveguide with the same thickness and dielectric constant but width of 5.08 mm. This implies that the electrical properties of a PBG waveguide are almost the same as those of the metal-wall waveguide as long as the frequency is much lower than the pass-band frequency of the 2-D PBG array.

We use three-dimensional (3-D) EM simulator HFSS from Ansoft, Inc. to simulate the unloaded Q of the resonator. The dielectric loss and the conductor loss are included and an absorbing boundary is used in the simulation. The measured Q-value is lower than the simulated one. The main reason for this may be from the defects of the surface of the plated-through-holes. First, the copper thickness of the plated-through-holes may possibly be thinner than 0.7 mil. Second, the surface roughness is quite high around the surface of the plated-through-holes. In our filter, the RF current flowing through some of the plated-through-holes could be very high. Above two increase the losses and are not included in the simulation.

The whole filter is simulated based on ideal model excluding the dielectric loss and conducting loss for saving simulation time. The measured result of the proposed prototype filter, as shown in Fig. 3, matches very well with the simulated one, except the insertion loss is 2.5 dB in measured results rather than about 0 dB in the simulated one. If it excludes the 0.9 dB of test fixture and feeding microstrip line losses, the pass-band insertion loss would be 1.6 dB. The measured return loss degrades to about 16 dB. This is possibly because some tolerances exist in the fabrication process and tuning is not allowed in our filter.

IV. Conclusion

A dielectric waveguide filter made by a two dimensional PBG structure has been proposed. Two 50 Ω microstrip lines incorporating with a newly proposed external coupling structure fed the filter. The measured performance of the trial filter well matched the simulated result. The design steps have been given in detail in this letter. This filter has demonstrated small size, low loss, and easy to manufacture.

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