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Spurious Suppression of a Microstrip Bandpass Filter Using Three Types of Rectangular PBG Loops

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***Abstract*—A novel microstrip bandpass filter with three types of rectangular, photonic bandgap (PBG) loops on a middle layer was designed and demonstrated using a full-wave electromagnetic (EM) simulator, with the predicted results verified by experiment. This investigation presents the configurations of conventional parallel-coupled 2 GHz filters with and without a PBG. The middle-layer of PBG loops adds an extra stopband-rejection mode to filter stopband; and it provides attenuation in excess of 25 dB at the second, third, and fourth harmonics, thus demonstrating that superior stopband characteristics at high frequency can be obtained using the proposed PBG loops in microwave filters.**

I. Introduction

Recent studies of microwave circuits have begun by designing a periodic configuration similar to a quantum-well, called a photonic bandgap (PBG) [1]. In particular, PBG structures can be integrated easily at low cost into various microwave circuits, including those with antenna applications. A novel configuration of the stacked, uniplanar, compact, photonic bandgap (UC-PBG) plane was published in [2]. Implementing PBG configurations for conventional microstrip filters usually results in practical difficulties with regard to evaluating relationships between the physical dimensions and half-wavelength or quarter wavelength.

Conventional planar microstrip filters, especially parallel-coupled filters, are more preferred for use in modern microwave and wireless local area network (WLAN) systems, because they are lightweight, low-cost, and easily integrated. However, the presence of spurious responses, particularly those occurring at multiples of the filter center frequency, constitute a well-known problem associated with the use of these filters. This problem can result in poor harmonic signal suppression when the parallel-coupled filters are used as output components of oscillators and amplifiers. Adequate suppression of spurious responses normally is essential for conventional microstrip filters using half-wavelength or quarter-wavelength coupled lines [3].

Various PBG structures of microstrip circuits have been proposed [2]–[6]. Yang *et al.* [2] presented a microstrip bandpass filter fabricated on the UC-PBG ground plane. They confirmed the slow-wave effect when the propagation characteristics of a UC-PBG structure were evident in the filter passband as their PBG structure was a slow-wave microstrip line. The slow-wave effect is also of great interest for its use in size reduction. The advantages of low loss, moderate impedance, and uniplanar features make the UC-PBG structure a very promising candidate for a slow-wave transmission line. However, because the aforementioned microstrip PBG structures have holes in the substrate or etched patterns in the ground plane, device packaging and realization in monolithic microwave integrated circuits (MMICs) constitute major disadvantages. The etched ground plane must be far enough from any metal plate in order to maintain functionality of the etched patterns.

Some microstrip filters have been designed and fabricated using series or parallel PBG structures in order to provide broad-stopband characteristics [4]–[6]. Such specific design and analysis are summarized in [7]. In contrast, this study deals with the design and fabrication of a novel microstrip bandpass filter with three types of rectangular PBG loops in the middle layer in order to avoid package problems and to achieve multiple transmission response suppressions, as shown in Fig. 1. The PBG loops are shown to improve both the simulated and experimental filter stopband attenuation. This structure can be designed simply and applied in modern microwave and WLAN system applications.

II. Design of the Novel PBG Filter

The proposed bandpass filter is primarily composed of a conventional parallel coupled filter on the top layer, three types of rectangular PBG loops for a middle layer, and the ground plane on the bottom layer, as shown in Fig. 1. This filter configuration suppresses spurious second, third, and fourth harmonics, yielding a broad stopband characteristic.

The proposed PBG cell consists of three types of rectangular loops, as shown in Fig. 2. The periodic cell for the PBG structure is characterized by two parameters—a spatial period that defines the lattice constant and the dielectric contrast between the constituent materials. The

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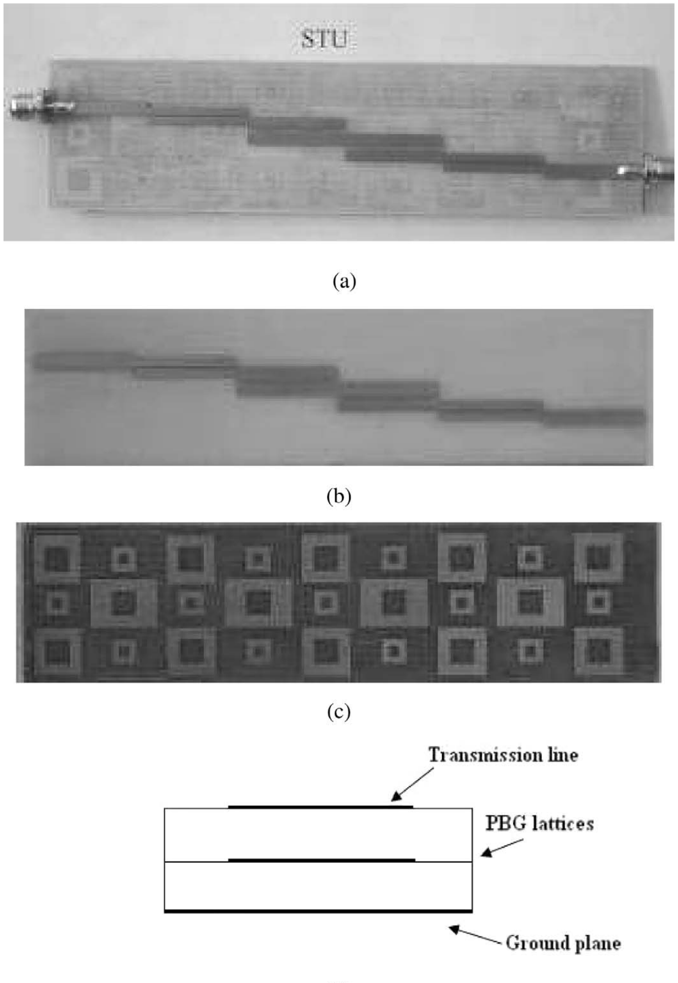

Fig. 1. Photograph of parallel-coupled bandpass filter with PBG loops in the middle plane. (a) Schematic, (b) top view, (c) middle layer view, (d) cross-section view.

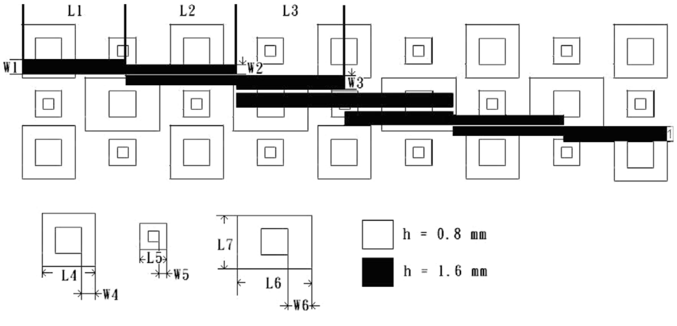

Fig. 2. The dimensions of parallel-coupled bandpass filter with PBG loops in the middle plane ($L_1 = 20.13$ mm, $L_2 = 20.95$ mm, $L_3 = 20.43$ mm, $L_4 = 10$ mm, $L_5 = 5$ mm, $L_6 = 14$ mm, $L_7 = 10$ mm, $W_1 = 2.88$ mm, $W_2 = 1.75$ mm, $W_3 = 2.79$ mm, $W_4 = 2.5$ mm, $W_5 = 1.5$ mm, $W_6 = 4.5$ mm).

three types of rectangular loops are designed to satisfy the Bragg reflection condition for multiple suppressions. These rectangular loops may result in additional inductive impedances, and the gaps between rectangular loops will cause additional capacitance [6]. Therefore, the series-reactive elements combined with the shunt capacitances determine the propagation constant (β), which is much larger than that of a conventional microstrip line [1]. The propagation constant in these PBG loops is increased substantially, so it is expected to be an ideal guide for designing such loops. The PBG loops will not increase the conductor loss because the PBG cells are constructed in the middle plane at which the current density is not highly concentrated. When the stopband condition is satisfied, the inductive and capacitive impedances produced by the three types of rectangular PBG loops cause the extra stopband-rejection mode to be excited. Then, the spurious response of the conventional parallel-coupled filter of the quasi-transverse electromagnetic (TEM) mode will be prohibited for a given center frequency, resulting in the excitement of an extra stopband-rejection mode.

The proposed PBG bandpass filter is designed to have a central frequency of 2.0 GHz, a 3 dB bandwidth of 15%, and an equal-ripple response of 0.1 dB. Fig. 2 shows the dimensions of the parallel-coupled filter with $W_2 = 1.75$ mm, $L_2 = 20.95$ mm, $W_3 = 2.79$ mm, and $L_3 = 20.43$ mm, respectively. The small uniform microstrip feed line has $L_1 = 20.13$ mm and $W_1 = 2.88$ mm, corresponding to a 50 Ω microstrip matching on the top layer. For spurious suppression at 4.0 GHz, 6.0 GHz, and 8.0 GHz, the periodic PBG rectangular loops are designed for $W_4 = 2.5$ mm, $L_4 = 10$ mm; $W_5 = 1.5$ mm, $L_5 = 5$ mm, and $W_6 = 4.5$ mm, $L_6 = 14$ mm, $L_7 = 10$ mm, respectively. The designed filter is fabricated on the two, FR4 GD (Kinsten Industrial Group, Taipei, Taiwan, R.O.C.) substrates with a relative permittivity of $\varepsilon'_r = 4.4$, a loss tangent of $\tan\delta = 0.0245$ and a thickness of 0.8 mm. The performance of the PBG bandpass filter was characterized using an Agilent 8753E (Agilent Technology Taiwan Ltd., Kaohsiung 802, Taiwan, R.O.C.) network analyzer.

III. Simulated and Measured Results of the Novel PBG Filter

The method of moments is effective for making a full-wave electromagnetic (EM) analysis of the PBG structure, but applying it is time consuming for the bandpass filter with the PBG structure. This study uses a full-wave EM simulator (IE3D Version 6.1, Zeland Software Inc., Fremont, CA, 1998) for the whole circuit. To enable a clear comparison, a parallel-coupled bandpass filter without PBG structures also was designed and fabricated. Fig. 3 shows the simulated and measured characteristics of the parallel-coupled bandpass filter without PBG loops. The simulated stopband attenuation of the parallel-coupled bandpass filter without PBG loops are −18 dB, −8.5 dB, and −12 dB at second, third, and fourth har-

TABLE I
THE COMPARISON OF THE CHARACTERISTICS BETWEEN THE PARALLEL-COUPLED BANDPASS FILTER WITHOUT PBG LOOPS AND WITH PBG LOOPS.

Circuit of the novel bandpass filter	Freq. = f_o S_{21} (dB)	Freq. = $2f_o$ S_{21} (dB)	Freq. = $3f_o$ S_{21} (dB)	Freq. = $4f_o$ S_{21} (dB)
Without PBG loops	1.956 GHz −5.611 dB	3.912 GHz −13.84 dB	5.868 GHz −23.252 dB	7.824 GHz −13.035 dB
With PBG loops	1.911 GHz −2.629 dB	3.822 GHz −25.796 dB	5.733 GHz −40.488 dB	7.644 GHz −34.182 dB
Comparison of the results	The characteristics of the parallel-coupled bandpass filter with PBG loops superior to without PBG loops			

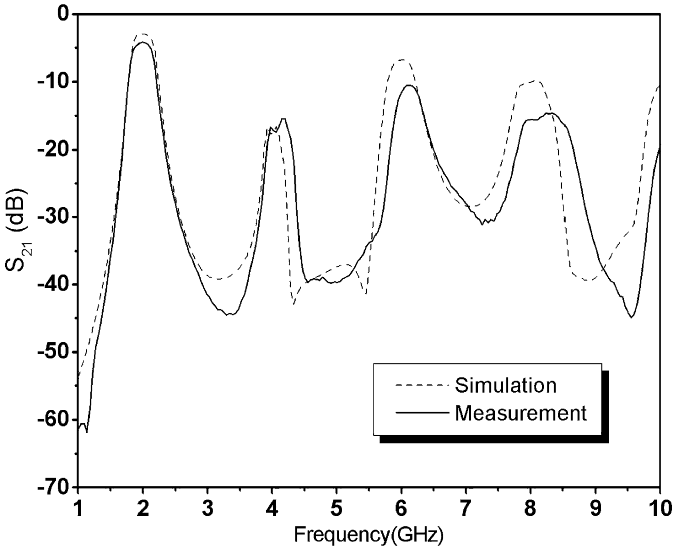

Fig. 3. Simulated and measured frequency response of the parallel-coupled bandpass filter without PBG loops.

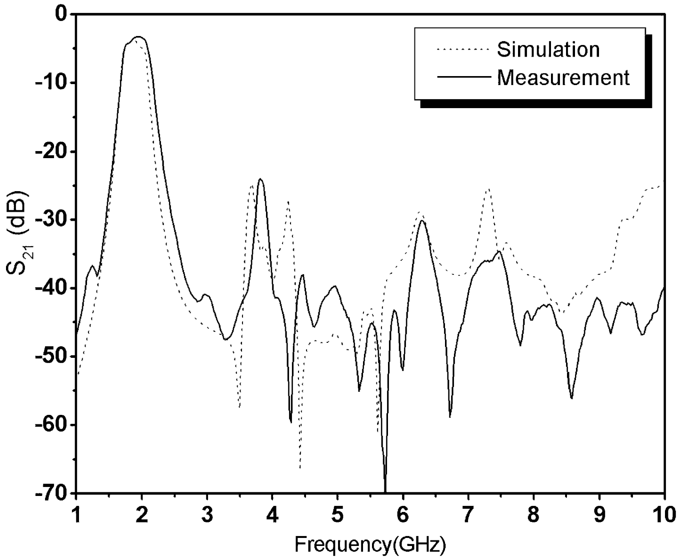

Fig. 4. Simulated and measured frequency response of the parallel-coupled bandpass filter with PBG loops.

monics, respectively. In contrast, the measured stopband attenuation of the parallel-coupled bandpass filter without a PBG structure is −13.84 dB, −23.25 dB, and −13.03 dB at the second, third, and fourth harmonics, respectively, as shown in Fig. 3. The slight differences between the simulated and measured results are attributable to the fabricated errors.

Fig. 4 shows the simulated and measured characteristics of the parallel-coupled bandpass filter with three types of rectangular loops on the middle layer as the PBG structure. The stopband attenuation (spurious suppression) of the parallel-coupled bandpass filter with PBG loops is all below −25 dB, as shown in Fig. 4. The third harmonics are suppressed below −40 dB. This characteristic is extremely beneficial when the filter is used at the output of the active devices. The parallel-coupled bandpass filter with PBG loops used for practical measurement has a central frequency of 1.91 GHz and an insertion loss of $S_{21} = -2.62$ dB. The slight difference between the measured center frequencies was believed to have resulted from the uncompensated fringing field. The spurious response of the parallel-coupled bandpass filter with PBG loops is −25.79 dB at $2f_o$ (3.82 GHz), −40.48 dB at $3f_o$ (5.73 GHz), −34.18 dB at $4f_o$ (7.64 GHz), and −40.2 dB at $4f_o$ (9.55 GHz), respectively. Electromagnetic waves that propagate in periodic structures are well-known to have discontinuous points or regions. Therefore, propagating waves can have energies or frequencies only at a certain wave vector, and their existence at other wave vector is forbidden. Table I compares the characteristics of the parallel-coupled bandpass filter without PBG loops, with those of the filter with PBG loops. The results demonstrate that the spurious characteristics of the parallel-coupled bandpass filter with our designed PBG loops are superior to that without PBG loops. All of the above effects also may be attributed to the slow-wave effect of PBG loops [1]. In particular, the designed PBG structure may exhibit an error in the form of shifted center frequency in the measured results. For example, in [4], the center frequency of the filter with the PBG structure was shifted to lower frequency by about 15%, corresponding to the original designed center frequency of the filter without the PBG loops. The center frequency of the filter with the PBG loops is shifted downward by about 4% from the original designed center frequency of the filter without the PBG structure. The proposed PBG periodic cells on the middle layer that depart from the microstrip do not significantly affect the original frequency response, unlike in [4]. The UC-PBG structures have holes in the substrate or etched patterns in the ground plane, and the disadvantages of the structures are associated with resultant packaging problems and realization in MMICs. The proposed PBG periodic cells on the middle layer avoid these disadvantages.

IV. Conclusions

A novel microstrip parallel-coupled bandpass filter with three types of rectangular PBG loops is proposed. The simplicity of design and fabrication gives this proposed PBG bandpass filter superior stopband attenuation (spurious suppression) at the second, third, and fourth harmonics, compared to conventional parallel-coupled bandpass filters having the same dimensions. Although the detailed theory has not been completely developed, this proposed PBG bandpass filter has great potential application in modern microwave and WLAN systems.

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