A Novel Periodic Electromagnetic Bandgap Structure for Finite-Width Conductor-Backed Coplanar Waveguides

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***Abstract*—The one-dimensional (1-D) periodic electromagnetic bandgap (EBG) structure for the finite-width conductor-backed coplanar waveguide (FW-CBCPW) is proposed. Unlike the conventional EBG structures for the microstrip line and the coplanar waveguide (CPW), which are typically placed on one of the signal strips and the ground plane, this EBG cell is etched on both the signal strip and the upper ground plane of FW-CBCPW, resulting in a novel circuit element. The equivalent circuit is also used to model the EBG cell. Measured and full-wave simulated results show that the cell exhibits remarkable stopband effect. The low-pass filter with lower cutoff frequency and wider rejection bandwidth is constructed from a serial connection of the EBG cells. The effect of back metallization on guiding characteristic is also discussed. Compared to the published EBG cells, the proposed structure has the advantages of relative flexibility, higher compactness, lower radiation loss, and easier integration with the uniplanar circuits.**

***Index Terms*—Electromagnetic bandgap, finite-width conductor-backed coplanar waveguide.**

I. INTRODUCTION

PERIODIC structure has long been an active subject in the microwave community and has currently attracted considerable attention due to the recently proposed electromagnetic bandgap (EBG) cell [1]. The periodic EBG structures exhibit stopband and slow wave characteristics which have been initially realized by implying micromachining holes or vias into dielectric slabs to create the two-dimensional (2-D) or three-dimensional (3-D) periodic variations of materials [2]–[4]. However, these configurations require a nonplanar fabrication process, which is not easily integrated in microwave and mm-wave circuits.

Several approaches have been proposed to produce the EBG cells in planar technology by etching periodic patterns on the ground plane or the signal strip of the microstrip line [5]–[7]. The substrate of the defected ground plane structure must be suspended so that the circuit cannot be placed on a metal base to provide mechanical support and to facilitate heat removal. Moreover, the etched pattern on the signal strip is restricted to the dimension on the line itself and excessive loss is generated due to the discontinuities which are mainly concentrated on the signal strip.

The uniplanar transmission lines, such as coplanar waveguides (CPWs), have proven to be more useful than the conventional microstrip lines for monolithic microwave integrated circuits (MMICs) and antennas [8]. In practice, the back metallization is required for mechanical and thermal factors, as well as the upper ground planes of CPW are usually of finite width [9], [10]. Therefore, the novel periodic EBG structure for finite-width conductor-backed coplanar waveguide (FW-CBCPW) is proposed. By narrowing the upper ground planes, the power leakage due to the unwanted parallel-plate mode created by the upper and lower ground planes is inhibited [11]. In addition, this structure, which is etched periodic patterns on both the signal strip and the upper ground planes, eliminates the requirements of the substrate suspending and the orientation of the transmission line must be aligned with the principle axes of periodicity. Furthermore, the layout of this 1-D periodic structure is notably more compact than that of the 2-D structure [12], making it more efficient and flexible in practical circuit applications.

II. EBG UNIT CELL CONFIGURATION

The periodic EBG structure is characterized by the shape, number, and separation of cells, as well as the relative volume fraction. Electromagnetic waves propagating in the structure with periodically varying electrical properties may have slow wave and stopband characteristics. To effectively realize the EBG structure in the circuit component, more flexible capacitance C and inductance L corresponding to cell configurations are required. In view of these points, the new EBG cell etching on both the signal strip and the upper ground planes of FW-CBCPW to produce arbitrary C and L is shown in Fig. 1(a). The equivalent circuit for the EBG cell is depicted in Fig. 1(b). The perforated patterns on the signal strip of FW-CBCPW, including a series narrow strips and step discontinuities, are modeled by a series inductance L_S and two shunt capacitance C_S. The shunt narrow strip and the gap capacitance between the rectangular patch and the upper/lower ground plane are corresponded to L_g and C_u/C_ℓ, respectively. Each element in the circuit model has a definite connection

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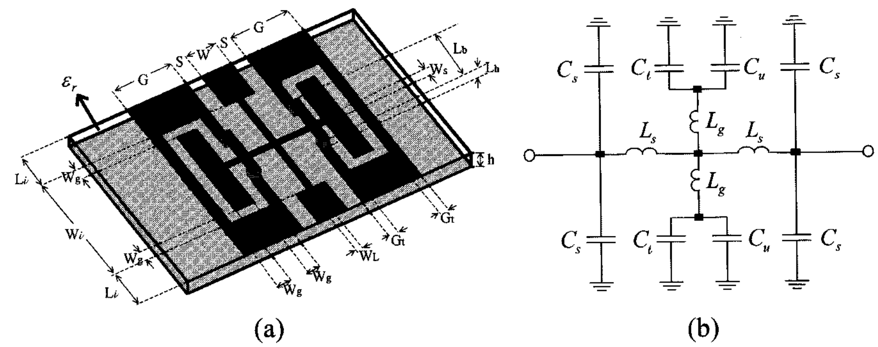

Fig. 1. One-dimensional EBG cell for FW-CBCPW. (a) Physical configuration. (b) Equivalent circuit.

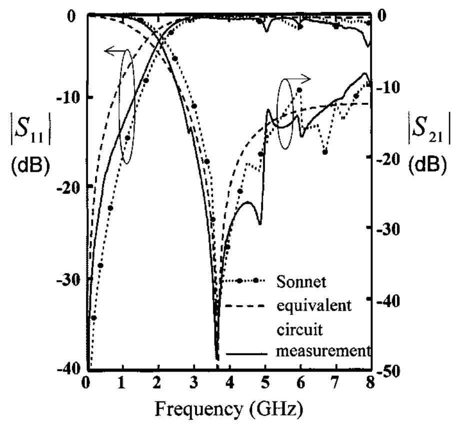

Fig. 2. S–parameters of the EBG cell for FW-CBCPW based on the equivalent circuit, sonnet *em* simulator, and measurement. (W_i = 12 mm, L_i = 5 mm, W = 3 mm, $W_g = S$ = 0.5 mm, G = 5 mm, $W_L = W_S$ = 0.6 mm, L_b = 3.6 mm, L_h = 2 mm, G_t = 1 mm, h = 1.6 mm, and ε_r = 4.4).

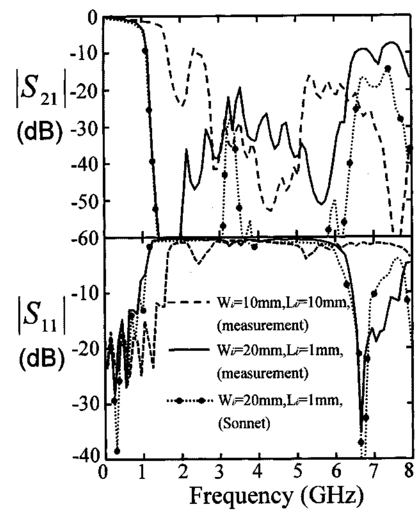

Fig. 3. Simulated and measured S–parameters of the periodic EBG structures by cascading six unit cells with the cell size W_i and cell spacing L_i as parameters (the other dimensions are the same as in Fig. 2).

with the physical dimension of the EBG cell such that the cutoff and stopband characteristics are easier to be controlled.

III. Simulated and Measured Results

The simulated S-parameters of the EBG cell obtained from the full-wave Sonnet ***em*** simulator and the equivalent circuit are presented and compared with the measured data, as shown in Fig. 2. All the circuits in this letter are fabricated on a 1.6 mm-thick substrate ($\varepsilon_r = 4.4$ and $\tan\delta = 0.022$) and have metallization thickness of 0.02 mm and conductivity $\sigma = 5.8 \times 10^7$ S/m. The repetition of an air bridge in the EBG cell is verified by measuring several circuits with the same dimensions. The circuit parameters for the derived equivalent circuit can be obtained by fitting the measured data, and then the simulated results using these values, where $L_S = 1.146$ nH, $C_S = 0.026$ fF, $L_g = 1.015$ nH, $C_u = 1.399$ pF and $C_\ell = 0.437$ pF, are depicted in Fig. 2.

The measured and simulated S-parameters of the periodic EBG structures by cascading six unit cells are shown in Fig. 3. The measured S_{21} curve for the cell size $W_i = 10$ mm and the cell spacing $L_i = 10$ mm has a cutoff frequency at 1.5 GHz and a spurious response at 2.3 GHz. As W_i is increased and L_i is decreased, the cutoff frequency becomes lower and the spurious passband can be suppressed to form a flatter stopband. Good agreement between the measured and simulated results for $W_i = 20$ mm and $L_i = 1$ mm is presented to verify the above qualitative analysis.

Experimental results of the six-cell EBG structures with fixed $L_i = 1$ mm and varied W_i are displayed in Fig. 4. Note that the cutoff frequency and the bandwidth of stopband decrease as W_i increases. The measured data of the cascading EBG cells for the finite-width coplanar waveguide (FW-CPW), which is the structure of FW-CBCPW but removing the lower ground plane, is also plotted in Fig. 4 for comparison. It is noticed that the resonant frequency $f_r = 4.25$ GHz can be predicted by

$$f_r = \frac{c}{2W_i\sqrt{\varepsilon_{\text{eff}}^{\text{cell}}}} \tag{1}$$

where C is the velocity of light, and $\varepsilon_{\text{eff}}^{\text{cell}}$ is the effective permittivity of the EBG cell for FW-CPW determinated from measurement. Additionally, the calculated loss factor $1 - |S_{11}|^2 - |S_{21}|^2$ from the measured data shows that the cell resonator for FW-CPW presents greater radiation loss at f_r than the one for FW-CBCPW. Similar resonant phenomenon can also be observed in the other periodic EBG structures for FW-CPWs with various W_i. Consequently, the lower ground plane in the configuration of FW-CBCPW is required to eliminate the undesired radiation of the EBG cell. This is because the radiation element

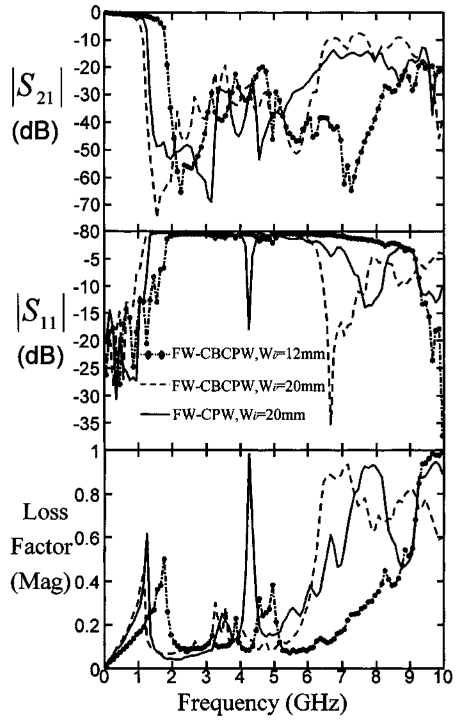

Fig. 4. Measured S-parameters and loss factor $1-|S_{11}|^2-|S21|^2$ of the six-cell EBG structures for FW-CBCPW and FW-CPW with $L_i = 1$ mm and varied W_i as parameters (the other dimensions are the same as in Fig. 2).

on the EBG cell of FW-CBCPW is too close to the conductive surface, and the image currents cancel the currents in the element, resulting in poor radiation efficiency. Therefore, the utilization of the lower ground plane of FW-CBCPW not only enhances mechanical strength and facilitates heat sink, but also suppresses the radiation mechanism of cell resonator.

IV. Conclusion

In this study, a novel 1-D periodic EBG structure for FW-CBCPW has been proposed. This new EBG cell, which is etched on both the signal strip and the upper ground planes where the field is mostly confined, is more efficient and flexible in the implementation of circuit components. Moreover, this structure with additional degree of freedom is easier to control the cutoff and bandstop characteristics. By connecting the EBG cells in series, the lowpass filters with wider stopband and lower cutoff characteristics are implemented. The adoption of back metallization also shows that the reduction in radiation loss is remarkable. This structure, with the advantages of compactness and uniplanar configuration, is attractive in the high-performance MIC/MMIC applications such as filters, amplifiers, mixers, and antennas.

References

[1] F. R. Yang, R. Coccioli, Y. Qian, and T. Itoh, "Planar PBG structures: Basic properties and applications," *IEICE Trans. Electron.*, vol. E83-C, pp. 687–696, May 2000.

[2] R. Gonzalo, P. D. Maagt, and M. Sorolla, "Enhanced patch-antenna performance by suppressing surface waves using photonic-bandgap substrates," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2131–2138, Nov. 1999.

[3] D. Sievenpiper, L. Zhang, R. F. J. Bross, N. G. Alexopoulos, and E. Yablonovitch, "High-impedance Electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2059–2074, Nov. 1999.

[4] I. Rumsey, M. P. May, and P. K. Kelly, "Photonic bandgap structures used as filters in microstrip circuits," *IEEE Microwave Guided Wave Lett.*, vol. 8, pp. 336–338, Oct. 1998.

[5] D. Ahn, J. S. Park, C. S. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 86–93, Jan. 2001.

[6] M. J. Hill, R. W. Ziolkowski, and J. Papapolymerou, "Simulated and measured results from a duroid-based planar MBG cavity resonator filter," *IEEE Microwave Guided Wave Lett.*, pp. 528–530, Dec. 2000.

[7] Q. Xue, K. M. Shum, and C. H. Chan, "Novel 1-D microstrip PBG cells," *IEEE Microwave Guided Wave Lett.*, vol. 10, pp. 403–405, Oct. 2000.

[8] S.-G. Mao, C.-T. Hwang, R.-B. Wu, and C. H. Chen, "Analysis of coplanar waveguide-to-coplanar stripline transitions," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 23–29, Jan. 2000.

[9] L. Zhu and K. Wu, "Model-based characterization of finite-periodic finite-ground coplanar waveguides," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1999, pp. 112–115.

[10] G. F. Ponchak and L. P. B. Katehi, "Open- and short-circuit terminated series stubs in finite-width coplanar waveguide on silicon," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 970–976, June 1997.

[11] W. H. Haydl, "Resonance phenomena and power loss in conductor-backed coplanar structures," *IEEE Microwave Guided Wave Lett.*, vol. 20, pp. 514–516, Dec. 2000.

[12] K. P. Ma, F. R. Yang, Y. Qian, and T. Itoh, "Nonleaky conductor-backed CPW using a novel 2-D PBG lattice," in *Asia-Pacific Microw. Conf. Dig.*, 1998, pp. 509–512.