Paper

Broadside coupled stripline with double-side UC-PBG structure

Paweł Meissner and Marek Kitliński

Abstract—A stripline waveguide with double-side UC-PBG pattern is considered. To verify usefulness of the stripline structure with UC-PBG a 3 dB coupler has been designed and fabricated. Reduction of the coupler size (due to slow wave effect) has been predicted and observed. Numerical and experimental investigation confirmed enhanced backward coupling phenomena.

Keywords— UC-PBG, uniplanar photonic bandgap, coupler, 3 dB coupler, broadside coupled line coupler, stripline coupler, slow-wave effect, photonic , PBG bandgap, electromagnetic bandgap, EBG.

1. Introduction

A large number of papers treating about uniplanar compact photonic bandgap (UC-PBG) have been presented recently. By affecting continuity of solid metallic ground plane there is possibility to influence wave propagation in the waveguide. It gives another degree of freedom in designing microwave devices. Usage of microstrip with UC-PBG has been well investigated [1–8]. In order to explain a shape and physical meaning of the etched structure the process of developing of the UC-PBG unit cell can be presented in few stages. In the first stage one can divide the ground plane to square patches (Fig. 1a). Adjacent edges of patches make a capacitance in the ground plane. In the second stage, in order to achieve certain inductance one can join adjacent edges of patches with narrow strips (Fig. 1b). Finally, it is possible to increase its inductive effect by making an insets in the patches (Fig. 1c) [2–4]. The microstrip line with a ground plane consisting of a two-dimensional periodic pattern in ground plane reveals slow-wave property and exhibits cut-off frequency [2]. Above the cut-off the propagation of electromagnetic wave vanishes (Fig. 5). It is possible to control cut-off frequency and slow-wave effect by changing dimensions of the structure (influencing inductance and capacitance per unit length of microstrip line [2, 3]). The series reactive elements combined with the shunt capacitances determine the propagation constant of the microstrip with UC-PBG. The propagation coefficient is higher than that of conventional microstrip line; this can be expressed in higher value of the effective permittivity ε_{eff} [1–3]. It was also shown that cut-off frequency and slow-wave factor SWF $= (\beta/k_0)$ are almost independent of alignment of the strip above the ground plane pattern. Moreover it was presented [2, 3] that insertion loss of the line is comparable to the classical microstrip. Additionally it was proved that slow-wave factor changes with frequency and achieves quite high values near cut-off frequency of UC-PBG structure [1–7]. For small frequencies SWF is higher than for microstrip with solid ground plane and is almost linear. In consequence low dispersion is ensured and the structure is suitable for broadband operation. For devices working near cut-off it is possible to obtain high degree miniaturization. Taking into account certain similarity of microstrip and stripline structures, the stripline waveguiding structure with UC-PBG operating below cut-off frequency is considered. To confirm usefulness of this modified waveguiding structure the stripline broadside coupler with UC-PBG periodic ground plane on both sides is presented. In the design procedure the enhanced backward coupling and a shortage of the $1/4\lambda$ section has been assumed.

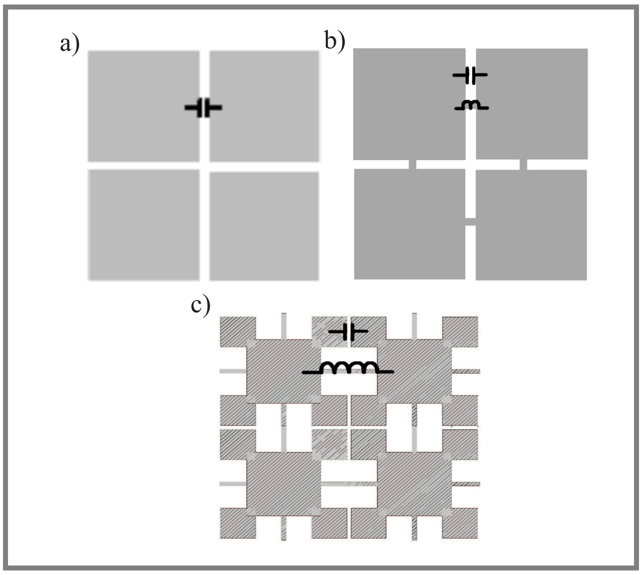

Fig. 1. An idea of developing four adjacent cells of 2D periodic pattern of UC-PBG: (a) adjacent edges of patches make a capacitance in the ground plane; (b) in the second stage, in order to achieve certain inductance one can join adjacent edges of patches with narrow strips; (c) finally, it is possible to increase its inductive effect by making an insets in the patches.

2. Broadside coupled stripline with UC-PBG – designing procedure

The slow wave effect and cut off frequency of UC-PBG depends mainly on the lattice dimensions. Simulation used in the construction is based on square lattice developed in UCLA [2], although the dimensions of lattice are results obtained for microstrip line can be adopted as a first step for designing process. The slow-wave structure slightly changed to achieve lower cut-off frequency, i.e., $f_c \approx 8.5$ GHz. Cut-off is defined as the frequency for which the insertion loss of the structure falls below –3 dB.

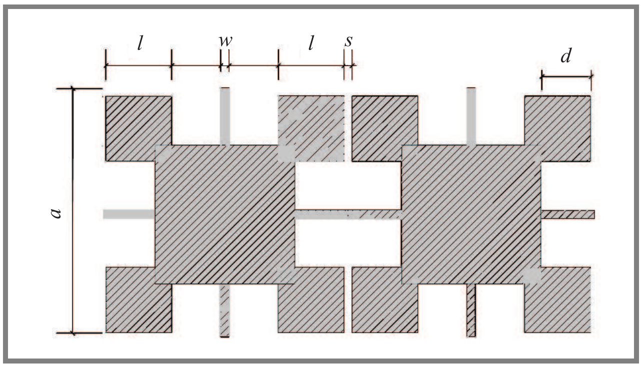

Fig. 2. Two adjacent UC-PBG cells. Dimensions: $a = 3$ mm, $d = 0.6$ mm, $l = 0.8$ mm, $s = w = 0.1$ mm.

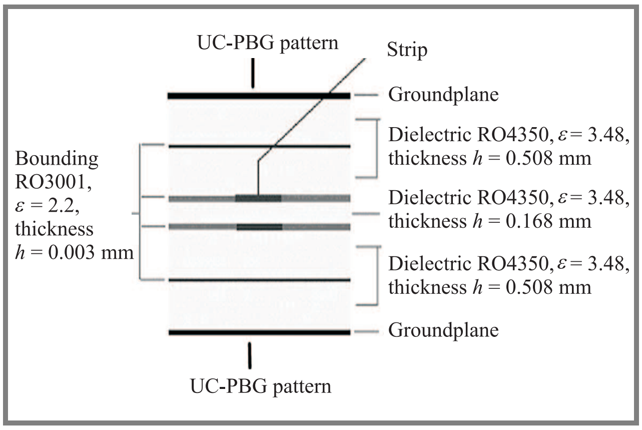

Fig. 3. A cross-section of the coupler, dielectric and metal layers.

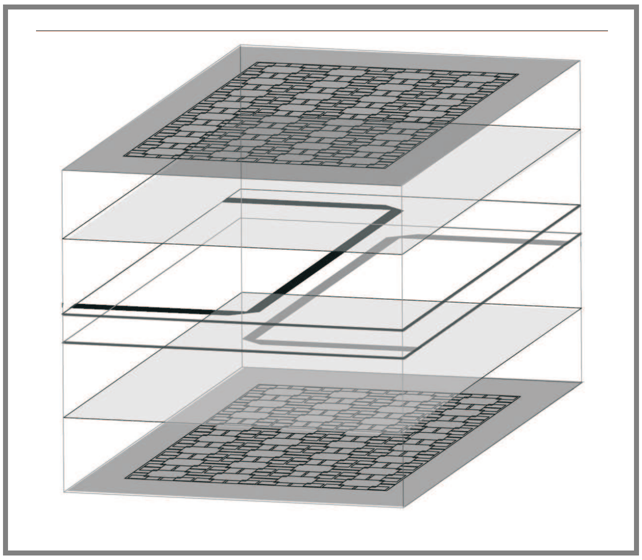

Fig. 4. A multilayer coupler with UC-PBG lattices etched in ground planes.

Spacing between cells and strips width (Fig. 2) are equal $s = w = 0.1$ mm, while in [2] $s = w = 0.25$ mm.

To prove usefulness of the broadside coupled stripline with UC-PBG a multilayer coupler has been designed and fabricated (Figs. 3 and 4). The main advantage of usage of the UC-PBG structure is the size reduction due to slow-wave phenomenon existing in the structure.

Measured cut-off frequency of the waveguide with lattice (Fig. 2) is about 8.5 GHz (Fig. 5). The center operating frequency of the coupler has been chosen as 1.4 GHz, which can ensure low dispersion (broadband operation).

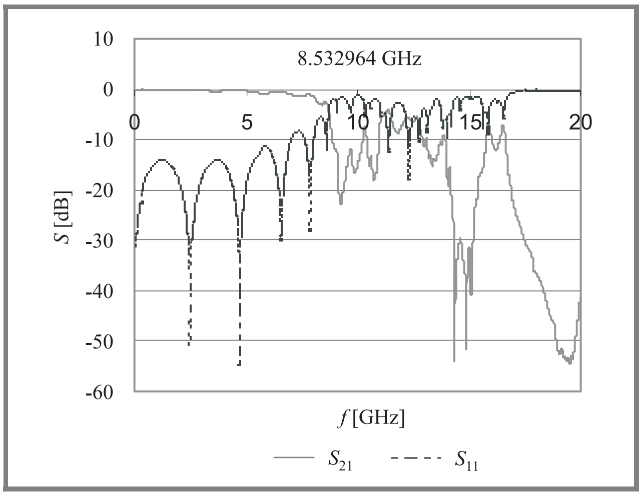

Fig. 5. Measured scattering parameters of the waveguide with the UC-PBG lattice dimensions from Fig. 2.

At the same time the slow-wave factor is relatively small, but measurements of the coupler shows that even for operating frequency far below the cut-off it is possible to obtain 20% miniaturization in comparison to a classical structure.

3. Electromagnetic simulations

Analyses has been performed using full-wave electromagnetic simulator Sonnet EM 9.52. Although the moment's method incorporated in the Sonnet EM is useful it requires

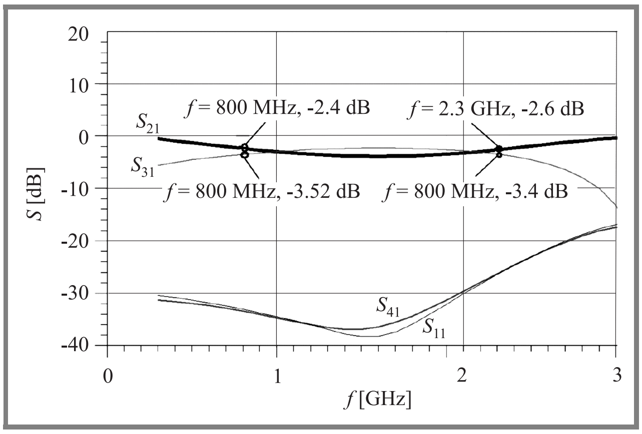

Fig. 6. Simulated characteristics of the stripline coupler with UC-PBG lattice in both ground planes.

a lot of RAM and time [9]. For obtaining some numerical results in reasonable time period (i.e., several hours for single frequency) whole structure has been divided into 4 symmetrical parts. Only one of them has been simulated using Sonnet EM 9.52 and then whole scattering matrix has been determined using circuit analysis (Agilent ADS 2002C [10]). Simulation results are presented in Fig. 6. To overcome influence of the package on the coupler performance some electromagnetic simulations have been done and minimal distance between UC-PBG and metal wall has been found as 2 mm (0.01λ in free space).

4. The coupler construction

The coupler consists of broadside-coupled striplines with UC-PBG lattice on the both ground planes. The dielectric layer between strips has been assumed as $h = 168$ mm thick Rogers substrate RO4350B. Dielectric layers relative permittivity is $\varepsilon = 3.48$ and bonding permittivity is $\varepsilon = 2.2$. The lattice dimensions are as follows (Fig. 2): $a = 3$ mm, $d = 0.6$ mm, $l = 0.8$ mm, $s = w = 0.1$ mm. Feeding sections has been considered as offset stripline with solid ground plane. The overall dimensions of the structure are 15.8 mm $\times$ 32.3 mm $\times$ 2.212 mm (Figs. 7 and 8). Layers were laminated under pressure with bonding RO3001 made by Rogers Co. Layers before lamination process are presented in Fig. 7. The connection of both ground plane layers is done on the edge of the structure.

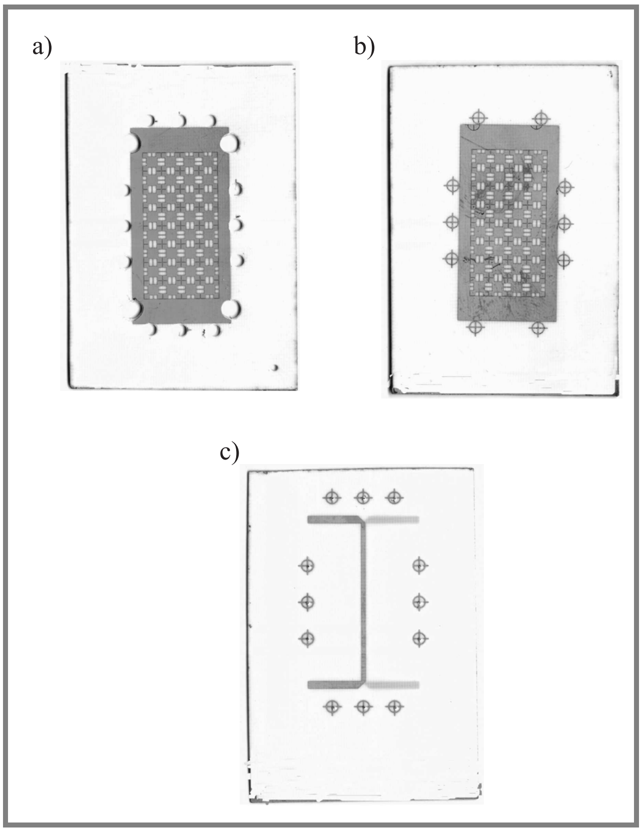

Fig. 7. Photographs of fabricated layers of coupler before lamination process: (a) and (b) UC-PBG lattice on 0.508 mm thick substrate; (c) strips on 0.168 mm thick substrate. Dimensions of the ground plane layer are: 15.8mm $\times$ 32 mm. Length of the coupled lines section is 26 mm.

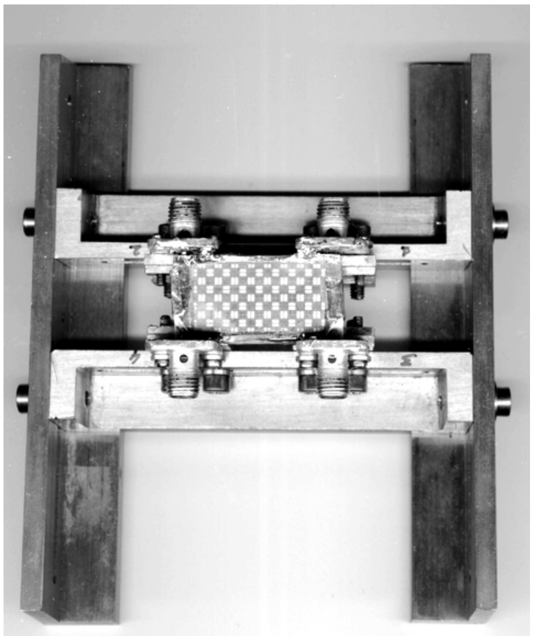

Fig. 8. Photography of fabricated coupler with SMA connectors prepared for measuring.

There is no need for via holes. Fabricated and prepared for measurement coupler structure is presented in Fig. 8.

5. Measurements

In Fig. 9 measured characteristics of the stripline coupler with UC-PBG lattice are demonstrated. The measurements have been performed by Wiltron 37269A VNA. The results

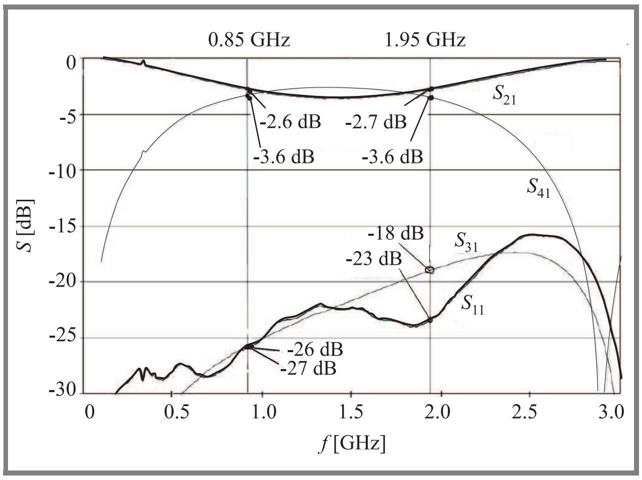

Fig. 9. Measured S – parameters of the broadside stripline coupler with UC-PBG.

show enhanced bandwidth up to 78% in comparison to 70% bandwidth of classical solid ground plane structure with the center frequency of 1.4 GHz. It is achieved by increasing of the coupling in the middle of the band. This structure has a 3 dB-coupling operating band (with +/–0.5 dB variation of the coupling coefficient) from 0.85 GHz to 1.95 GHz. The structure is about 20% shorter than comparable solid ground plane structure. It is necessary to underline that reduction of size is caused by the slow-wave effect generated by UC-PBG pattern.

6. Conclusions

Usefulness of the coupled stripline structure with UC-PBG lattice operating below cut-off frequency has been verified. Existing of slow-wave phenomena has been predicted end verified experimentally. Even for low operating frequency (far below cut-off, i.e., 1.4 GHz) it is possible to obtain 20% reduction of device size. Moreover one can expect that by choosing higher center frequency one can increase size reduction ratio. The package influence on stripline coupler characteristics was investigated. The results show that it is negligible if the distance between UC-PBG and metal wall is at least 0.01λ (center frequency) in the free space.

A 3 dB broadside coupled stripline coupler with UC-PBG was designed and fabricated. The coupler length is reduced 20% due to the slow wave effect. Results of simulation and measurement exhibit enhanced bandwidth up to 78% with center frequency 1.4 GHz. In addition the results confirm increasing of the coupling coefficient up to 2.5 dB in the center of the band.

References

[1] F. R. Yang, K. P. Ma, Y. Qian, and T. Itoh, “ A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuits”, *IEEE Trans. Microw. Theory Techn.*, vol. 47, no. VIII, pp. 1509–1514, 1999.

[2] C. C. Chang, R. Coccioli, Y. Quian, and T. Itoh, “Numerical and experimental charakterization of slow-wave microstrip line on periodic ground plane”, *IEEE MTT-S Int. Microw. Symp. Dig.*, 2000, vol. III, pp. 1533–1536.

[3] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, “Novel 2-D photonic bandgap structure for microstrip lines”, *IEEE Microw. Guided Wave Lett.*, vol. VIII, pp. 69–71, 1998.

[4] Y. Qian and T. Itoh, “Planar periodic structures for microwave and millimeter wave circuit applications”, *MTT-S Int. Microw. Symp. Dig.*, 1999, vol. IV, pp. 1533–1536.

[5] F. R. Yang, Y. Qian, and T. Itoh, “A novel uniplanar compact PBG structure for filter and mixer applications”, in *MTT-S Int. Microw. Symp. Dig.*, 1999, vol. VIII, pp. 919–922.

[6] C. C. Chang, Y. Quian, and T. Itoh, “Enhanced forward coupling phenomena between microstrip lines on periodically patterned ground plane”, in *IEEE MTT-S Int. Microw. Symp. Dig.*, 2001, vol. III, pp. 2039–2042.

[7] F. R. Yang, R. Coccioli, Y. Qian, and T. Itoh, “Analysis and application of coupled microstrip on periodically patterned ground plane”, in *IEEE MTT-S Int. Microw. Symp. Dig.*, 2000, vol. III, pp. 1529–1532.

[8] K. P. Ma, J. Kim, F. R. Yang, Y. Qian, and T. Itoh, “Leakage suppresion in stripline circuits using a 2D photonic bandgap lattice”, in *IEEE MTT-S Int. Microw. Symp. Dig.*, 1999, vol. 1, pp. 73–76.

[9] Sonnet EM 9.52. Application notes, 2003.

[10] Agilent ADS 2002c. Application notes, 2003.

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