A Novel Microstrip Ring Hybrid Incorporating a PBG Cell

Kam Man Shum, Quan Xue, and Chi Hou Chan

***Abstract*—An experimental investigation of a novel compact microstrip 180° ring hybrid incorporating a one-dimensional (1-D) slow-wave structure, in the form of perforation on the ring itself, is presented. The size of the hybrid is reduced by 23% due to the slow-wave effect, and this size reduction technique has potential applications in MICs and MMICs. The measured insertion loss is comparable to that of a conventional microstrip hybrid.**

***Index Terms*—Microstrip, phonic bandgap (PBG), ring hybrid, slow-wave factor.**

I. Introduction

In MICs and MMICs designs, the dimension of the structure is always a concern due to circuit miniaturization and material cost reduction. A ring hybrid is widely used in both circuits and antenna design because of its simplicity and wide bandwidth in power division. A compact design for hybrid coupler using the folded line configuration has been proposed by [1]. An alternative approach is to entail the use of slow-wave effects in the design. Recently, we have demonstrated a novel one-dimensional (1-D) planar PBG cell structure in the form of perforations on the transmission line itself [2]. In contrast to the two-dimensional (2-D) PBG structure proposed in [3], where the slow-wave effects of the transmission line depend on the orientation and location of the line with respect to the principal axes of the periodic perforations on the ground plane, this 1-D PBG cell can be easily employed in curved structures, such as the ring hybrid under consideration.

In this letter, we present a new type of compact microstrip 180°-ring hybrid incorporating six curved PBG cells embedded in the ring. Simulation and experimental results reveal that the PBG cell proposed in [2] can be incorporated into the curved microstrip line, where it has no extra insertion loss introduced in the ring hybrid. In addition, the slow-wave effect generated by the periodic PBG cells reduces the overall physical size of the ring hybrid. This novel design is potentially useful for applications in microwave-integrated circuits.

II. Design of a Compact 180°-Ring Hybrid

The conventional 180° hybrid junction is a four-port network with a 180° phase shift between two output ports. A signal applied to port 4 will be evenly divided between ports 2 and 3, with a 180° phase difference between them, while port 1 is isolated. When the hybrid is operated as a combiner, with input signals applied at ports 2 and 3, the sum of the inputs will be obtained at the port 1, while their difference will be generated at port 4. There, ports 1 and 4 are referred to as the sum and difference ports, respectively.

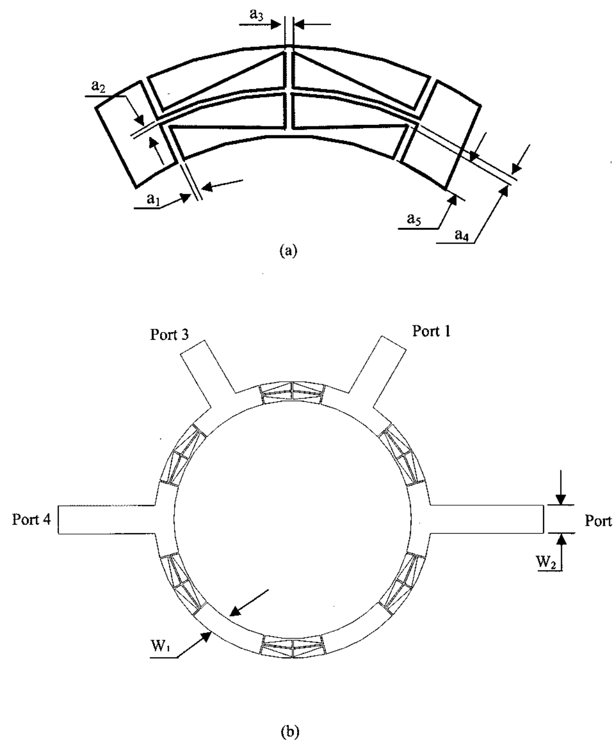

Fig. 1. (a) Curved PBG cell layout and dimensions used in this letter are: $a_1 = a_2 = a_3 = 0.15$ mm, $a_4 = 0.81$ mm and $a_5 = 0.95$ mm. (b) Layout of the ring hybrid with the proposed PBG cells.

Fig. 1(a) shows the curved PBG cell structure, which is modified from [2]. This is easily achievable only because the PBG cell is on the line itself. Here, the narrow connecting lines lead to the increase of series inductance. In contrast, the gaps across the width of the line enhance the shunt capacitance. The two narrow lines not only act as series inductance, but they also act as shunt resonant components combined with the triangular structure used to lower the resonant frequency. The width of each gap and the narrow line are chosen to be 0.15 mm. The substrate is Duroid 6002 with a dielectric constant of 2.94 and a thickness of 1.6 mm. The ring hybrid design follows the procedure described in [4]. The proposed hybrid with six evenly distributed PBG cells is shown in Fig. 1(b). The design frequency without the PBG cell is 3.5 GHz. The dimensions of the ring hybrid are

Manuscript received November 11, 2000; revised March 4, 2001. This work was supported by Hong Kong Research Council Grant 9040528. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

The authors are with Wireless Communications Research Center, Department of Electronic Engineering, City University of Hong Kong, Kowloon, Hong Kong.

Publisher Item Identifier S 1531-1309(01)05211-4.

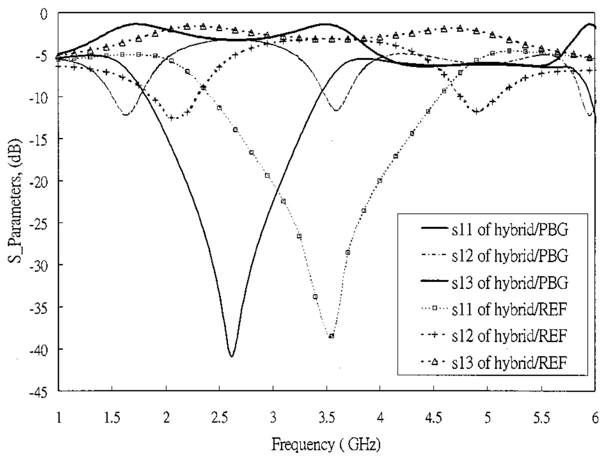

Fig. 2. Simulation results of the hybrid with and without the PBG cell.

$w_1 = 2.99$ mm and $w_2 = 2.05$ mm, which correspond to a conventional microstrip line without PBG cells.

In this letter, the performances of the hybrid with and without PBG cells have been simulated using *ENSEMBLE* Version 6.0 [5]. Fig. 2 shows the simulation result; it is observed that the resonant frequency is shifted from 3.5 GHz to 2.6 GHz (about 26%) when PBG cells are incorporated. The lowering in resonant frequency shows that these PBG cells generate the slow-wave effect. For a power divider, the output power is the main concern, and the newly proposed ring hybrid has no extra loss when these six PBG cells are introduced when compared to the conventional hybrid. In order to study the size reduction, we also simulated a conventional ring hybrid which operates at 2.6 GHz. The surface area of the ring hybrid operated at the same frequency with and without the PBG cell is 175.4 mm^2 and 236.25 mm^2, respectively. The size of the ring hybrid is reduced by 26% and, therefore, this new structure is suitable for compact circuit design.

III. Experiment Results

To confirm the simulation result, two 180°-ring hybrids using the same parameters with and without the PBG cell were fabricated. The experimental result is compared to the simulation result as shown in Fig. 3. It can be seen that the operation frequency is shifted from 3.5 to 2.7 GHz, which implies that the size is reduced by 23% when six PBG cells are introduced. The measured insertion loss is comparable to that of a conventional ring hybrid. In addition, the comparison of the bandwidth between the hybrid with PBG cells and the conventional hybrid operating at the same frequency is shown in Fig. 4. It can be observed that the bandwidth has no adverse effect when the PBG cells are incorporated. Good agreement between the experiment and simulated results is achieved. The deviation between the experiment and the simulation resonance frequency with the PBG cell is 3.7%. This slight shift is due to the fabrication tolerances. In addition, infinite dielectric and ground planes have been assumed in the simulation.

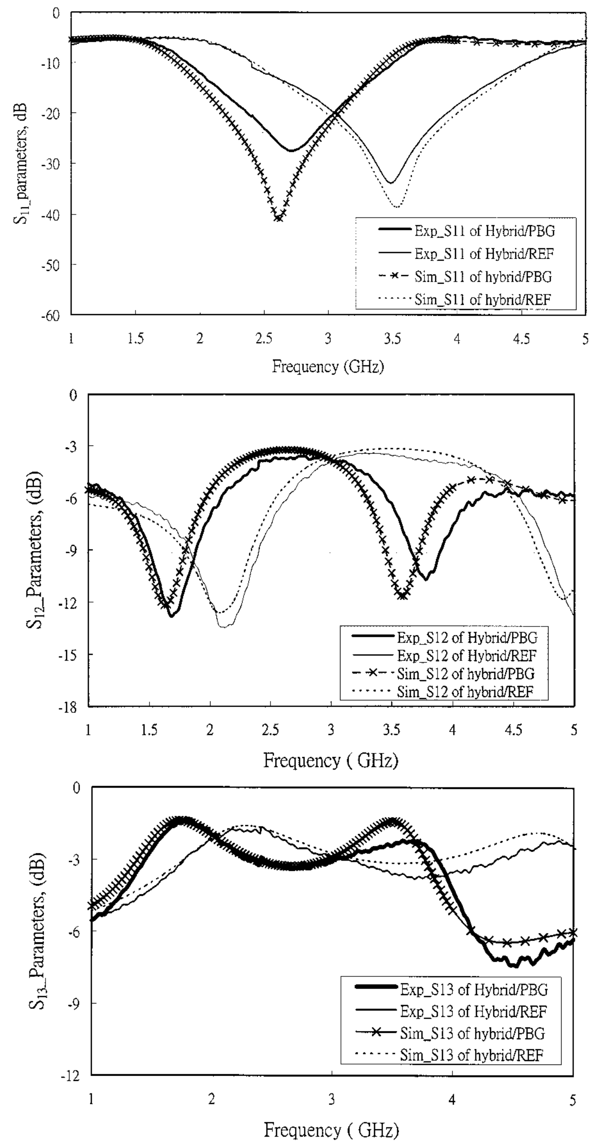

Fig. 3. Comparison of experimental and simulation results between proposed and conventional hybrid.

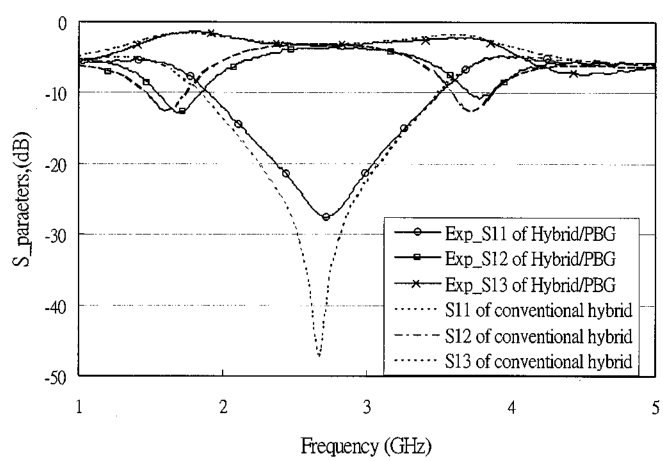

Fig. 4. Comparison of bandwidth of proposed and conventional hybrid operated at the same frequency.

IV. Conclusions

A novel, slow-wave microstrip ring hybrid has been proposed. Both simulation and experimental results reveal that the PBG cell proposed in [2] can be easily incorporated into curved microstrip lines. Both experimental and simulated results confirm that the size of the ring hybrid can be reduced by more than 20% when PBG cells are introduced. Moreover, the PBG cells do no affect the bandwidth and amplitude of the transmission coefficients when embedded into the microstrip device. Therefore, we can use conventional procedures to design the ring hybrid. Good agreement is obtained between the simulated and experimental results. These PBG cells have also been incorporated into the design of the Wilkinson power divider and obtained the similar conclusions, namely, the size reduction by exploiting the slow-wave effect, can be drawn.

References

[1] R. K. Settaluri, G. Sundberg, and V. K. Tripathi, "Compact folded line rat-race hybrid couplers," *IEEE Trans. Microwave Guided Wave Lett.*, vol. 10, pp. 61–63, Feb. 2000.

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

[3] F. R. Yang, K. P. Ma, and T. Itoh, "A uniplanar compact photonic-bandgap structure and its applications for microwave circuit," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1509–1514, Aug. 1999.

[4] D. M. Pozar, *Microwave Engineering*, New York: Wiley, 1990.

[5] ENSEMBLE is a trademark of Ansoft, Inc.