Radiation from Ground-Plane Photonic Bandgap Microstrip Waveguides

Naoyuki Shino* and Zoya Popovic

Department of Electrical and Computer Engineering
University of Colorado, Boulder, CO 80309
Phone: (303) 492-0374, zoya@colorado.edu
*Kyocera Corporation, R&D Center Kagoshima
1-4, Yamashita-cho, Kokubu, Kagoshima, Japan

Abstract **— This paper presents an analysis of radiation of photonic bandgap (PBG) microstrip structures along with the pass and stopband behavior. Simulations are compared with measurements performed on a PBG microstrip waveguide with circular slots in the ground plane, designed to have a broad stop-band centered around 10GHz. Radiation can be significant at some frequencies for a microstrip PBG and should be considered when designing filters, harmonic terminations and antenna feeds. Radiation of –3.4dB was measured at 15GHz relative to the input power in the pass-band. Measurement data agree well with simulations.**

I. INTRODUCTION

The benefits of photonic bandgap (PBG) structures, also referred to as electromagnetic bandgap (EBG) structures, have been discussed often in the past years [1-9]. The motivations for using PBG substrates can be classified in two categories: eliminating substrate modes in antenna applications, and in guided-wave filters. In the latter application, the reasons for using PBG substrates are widening of deep stopbands [6,8], and achieving more compact circuits [5].

Microstrip planar PBG lines have been reported several years ago by a number of authors [2]-[9]. Most of the reported examples can be represented schematically as in Fig. 1, where slots are etched periodically in the ground plane of a microstrip line. The slots vary in shape from round [2,4], to almost rectangular for modifying the stopband shape [6,7], and more complex shapes that allow multiple or wide stop-bands [5,8]. In the literature, the insertion and return loss of these filter structures has been successfully analyzed, designed and implemented. However, to the best of our knowledge radiation from such slotted-ground plane structures has not been reported to date.

In this paper, we attempt to quantify the radiation in the pass- and stop-bands of microstrip PBGs. Most PBG microstrip circuits are proposed for filter applications in order to reduce the physical size of the filter. Filters are commonly used in close proximity to other circuit components, such as power amplifiers (PAs) in the transmitter part of a wireless front end, and low-noise amplifiers (LNAs) in the receiver part. Radiation from the filter is clearly undesirable.

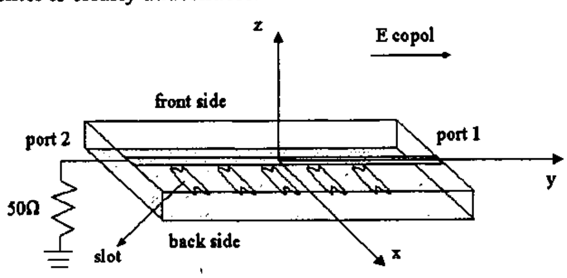


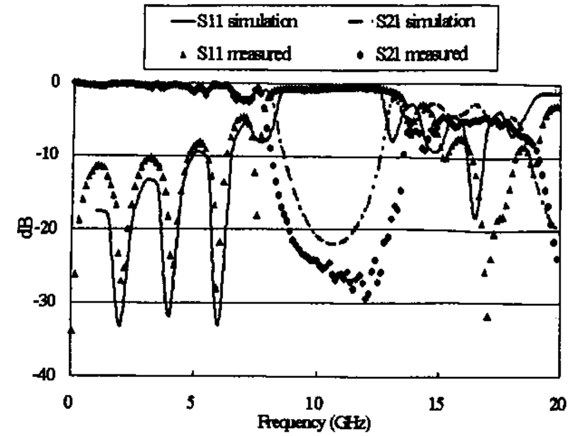
Fig. 1. Sketch of a microstrip PBG structure. Periodic slots in the ground plane result in a frequency-dependent transmission coefficient from port 1 to port 2.

II. RADIATION FROM A MICROSTRIP PBG STOPBAND

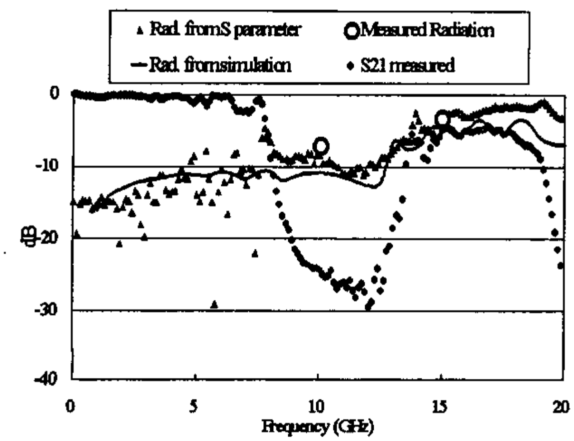
A PBG described in Fig. 1 with circular slots, similar to the one in [4], is used here as the first example. The slot radius is 2.5mm, the period is 10mm, and the microstrip is fabricated on a 0.787-mm thick substrate of ε_r=2.33. The distance between ports 1 and 2 is 70mm. The structure with 5 slot elements was analyzed using a commercial finite element solver, Agilent HFSS. The measured and simulated s-parameters are shown in Fig. 2(a). The PBG has a deep stopband from 8 to 13GHz and measured results agree with the simulation well. Fig. 2(b) presents radiation results from measurement and simulation, along with measured S21 plot for reference. The radiation is simulated in two ways. In the first case, the Poynting vector is integrated through the radiation boundary box in the finite element simulation. In the second case, the difference between the transmitted and reflected powers from the s-parameters was calculated. The two ways yield

0-7803-7239-5/02/$10.00 © 2002 IEEE

very similar results, and only the result from s-parameters is shown with solid line in Fig. 2(b) for clarity. The triangle symbol is the radiation calculated from measured s-parameters. The result has similar behavior as the radiation obtained from HFSS.



(a)

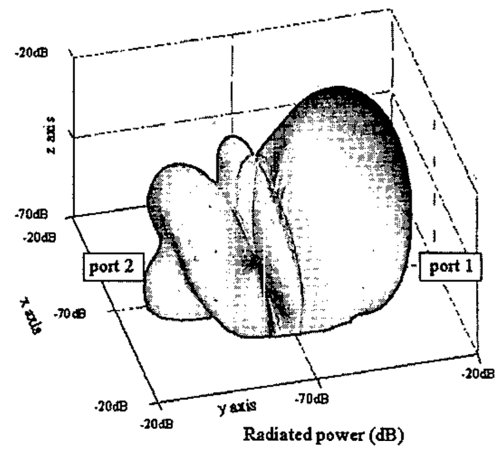


(b)

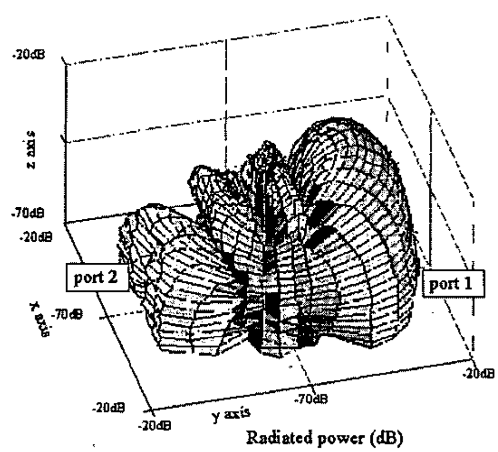
Fig. 2. (a) Simulated and measured s-parameters. (b) Simulated and measured radiation relative to s_{21}. The symbols (circles) indicate points for which radiation patterns are shown in Fig. 3 and 4.

Both results show significant radiation especially over 13GHz in the pass band. The radiated power is about 5dB below the input power. In order to eliminate the possibility that the radiation originated from the microstrip line itself, we simulated the radiation for several line lengths. The result showed that the radiation remained at the same value for all cases.

In order to prove the phenomena we measured radiation pattern at 10 and 15GHz. The large circle symbols in Fig. 2(b) indicate the measured radiated power obtained by integrating the co-polarized and cross-polarized radiation patterns of the back and front sides. The radiated power is –7.2dB at 10GHz and –3.4dB at 15GHz, which is consistent with the results calculated from measured and simulated s-parameters. Fig. 3(a) and (b) show the simulated and measured copolarized 3-D radiation pattern from back side at 15GHz. Notice that there is a strong lobe in the direction of about 35 degrees in both patterns. This lobe results from the phase progression in the slot array due to the microstrip "feed".



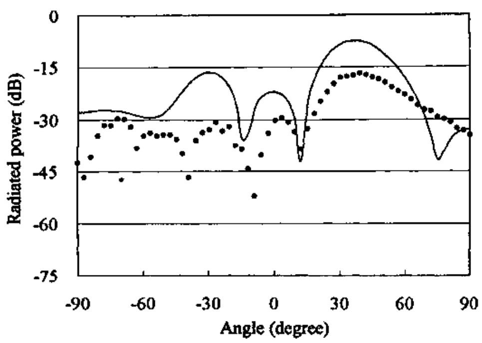
(a)



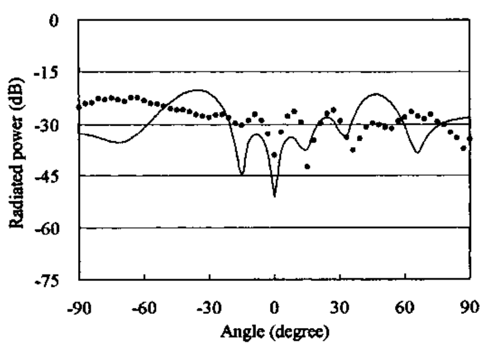
(b)

Fig. 3. Simulated (a) and measured (b) copolarized (along the microstrip line) 3-D radiation pattern at 15GHz from back side. The radiated power is normalized to 0dBm input power at port 1.

Fig. 4(a) and (b) show the co-polar E-plane cross-sections of back and front side patterns and provide a scale. The vertical axis represents the radiated power per solid angle, and is normalized to 0dBm input power into port 1.



(a)



(b)

Fig. 4. E-plane cross-section of the radiation pattern at 15GHz normalized to 0dBm input to port 1 for back side (a) and front side(b). The simulated results are presented in solid lines and dotted lines are measured results.

III. Discussion

This paper presents an example of a complete power budget consideration for ground-plane microstrip PBGs. Although this study presents data for circular slots in the ground plane of a microstrip 50-ohm line, the results are more general. For example, a commonly cited PBG structure [5] can be analyzed in the same way, and the results are shown in Fig. 5. There is evidently a peak in radiation in the transmission stop-band at 15GHz, which could potentially cause problems if such a device was included as a filter in an active front end.

We conclude that there can be significant radiation in both stop- and pass-bands of these guiding structures and needs to be considered in the design to avoid excessive radiation. For example, multilayer PBGs and specially designed slot shapes are subjects of our future work.

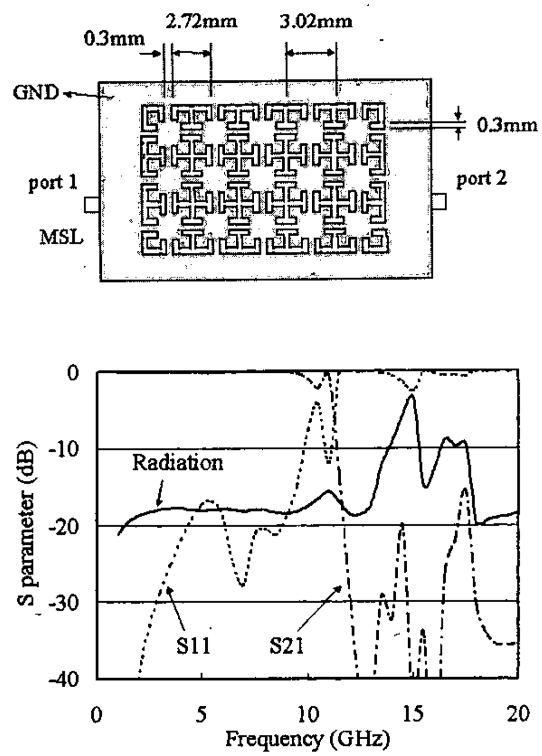


Fig. 5. Geometry of ground plane for the microstrip PBG described in [5] (top), along with simulated s-parameters and radiated power (bottom).

Acknowledgement

Naoyuki Shino thanks Kyocera for support, and Zoya Popovic thanks the support of the German Alexander von Humboldt Stiftung under a Humboldt Research Award for Senior U.S. Scientists.

References

[1] D. Sievenpiper, L.Z. Zhang, R.F.J. Broas, N.G. Alexopolous, E. Yablanovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory Techn., Vol.47, No.11*, pp. 2059-2074, Nov. 99.

[2] V. Radisic, Y. Qian, R. Coccioli, T. Itoh, "Novel 2-D photonic bandgap structure for microstrip lines," *IEEE*

Microwave and Guided Wave Lett., Vol. 8, No.2, pp.69-71, Feb. 1998.

[3] I. Rumsey, M. Piket-May, P.K. Kelly, "Photonic bandgap structures used as filters in microstrip circuits," *IEEE Microwave and Guided Wave Lett., Vol. 8, No.10,* pp.336-338, Oct. 1998.

[4] V. Radisic, Y. Qian, T. Itoh, "Novel structure for high-efficiency amplifiers for wireless applications," *IEEE Trans. Microwave Theory Techn., Vol.46, No.11,* pp. 1901-1909, Nov. 1998.

[5] F.-R. Yang, K.-P. Ma, Y. Qian, T. Itoh, "A uniplanar compact photonic-bandgap (UC-PBG) structure and its applicatins for microwave circuits," *IEEE Trans. Microwave Theory Techn., Vol.47, No.8,* pp. 1509-1514, Aug. 1999.

[6] T. Kim, C. Seo, "A novel photonic bandgap structure for low-pass filter of wide stopband," *IEEE Microwave and Guided Wave Lett., Vol. 10, No.1,* pp.13-15, Jan. 2000.

[7] C.-S. Kim, J.-S. Park, D. Ahn, J.-B. Lim, "A novel 1-D periodic defected ground plane structure for planar circuits," *IEEE Microwave and Guided Wave Lett., Vol. 10, No41,* pp.131-133, Apr. 2000.

[8] M.A.G. Laso, T. Lopetegi, M.J. Erro, D. Benito, M.J. Garde, M. Sorolla, "Multiple-frequency-tuned photonic bandgap microstrip structures," *IEEE Microwave and Guided Wave Lett., Vol. 10, No.6,* pp.220-222, June 2000.

[9] S.T. Chew, T. Itoh, "PBG-excited split-mode resonator bandpass filter," *IEEE Microwave and Wireless Components Lett., Vol. 11, No.9,* pp.364-366, Sept. 2001.