# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB NO. 0704-0188*



1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
[redacted]

4. TITLE AND SUBTITLE
TITLE ON [redacted]

5. FUNDING NUMBERS
DAAH04-96-1-0389

6. AUTHOR(S)
AUTHOR(S) ON [redacted]

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
University of California - Los Angeles

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 35875.116-PH-MUR

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

ABSTRACT ON [redacted]

20010618 125

14. SUBJECT TERMS

15. NUMBER IF PAGES

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OR REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

# Microwave Applications of Photonic Band-Gap (PBG) Structures

Yongxi Qian and Tatsuo Itoh

Electrical Engineering Department
University of California, Los Angeles
405 Hilgard Avenue, Los Angeles, CA 90095, USA
Voice: (310)206-5670, Fax:(310)206-4819, Email: yqian@ucla.edu

*Abstract* – **Photonic band-gap (PBG) structures are essentially periodic lattices which can provide effective and flexible control of the propagation of electromagnetic waves along specific or all directions. This paper gives an overview of a novel planar-oriented PBG structure developed recently at the authors group. This uniplanar compact PBG (UC-PBG) lattice is very simple to implement, and its usefulness has been demonstrated successfully by several application examples such as low and band pass filters, leakage suppression in CB-CPWs and striplines, as well as harmonic tuning for high efficiency microwave power amplifiers.**

## I. Introduction

Planar circuit technology, based on either microstrips or coplanar waveguides, has been the driving force for modern microwave and millimeter-wave application systems, because of its enormous advantages including greatly reduced hardware size and weight, easier integration with solid-state devices, low power consumption, and conformal implementation on moving platforms. However, it has also been recognized for a long time that integrated planar circuits or antennas will unlikely beat the bulky metallic waveguide systems in terms of insertion loss or radiation efficiency. Such deficiencies of planar circuits also cause tremendous burden to active devices (such as transistors). Realizing high performance microwave components in simple planar circuit technology, therefore, has been the dream of all RF design engineers since the early days of microwave monolithic integrated circuits (MMICs).

We have developed a revolutionary structure called the uniplanar compact photonic band-gap (UC-PBG) that substantially improves performance of many passive and active components, without significantly modifying existing fabrication processes [1]. This structure is essentially a two-dimensional lattice etched in the ground plane of microwave integrated circuits by the conventional photolithographic process already used for integrated circuit fabrication. Compared with conventional microstrip or coplanar waveguide (CPW) structures on solid ground plane, the UC-PBG offers several unique properties for the propagation and reflection of electromagnetic waves, including low insertion loss, slow wave effect, wide stopband, and easy realization of a perfect magnetic impedance surface.

A number of specific applications have been demonstrated thus far, including microstrip low and band pass filters, leaky wave suppressors, as well as harmonic tuners for high class power amplifiers. These successful demonstrations show great potentials of this new UC-PBG structure, even though we are still at the early stage of its development and optimization, and need more in-depth investigation to further expand its range of applications.

0-7803-5761-2/99/$10.00 

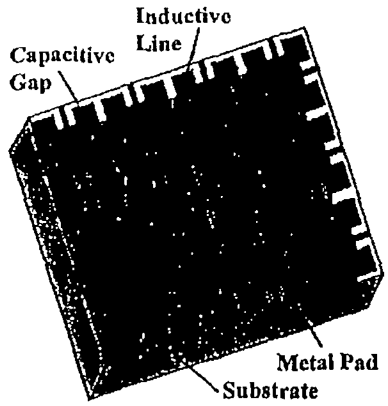


Fig. 1 Schematic of the uniplanar compact PBG (UC-PBG) lattice.

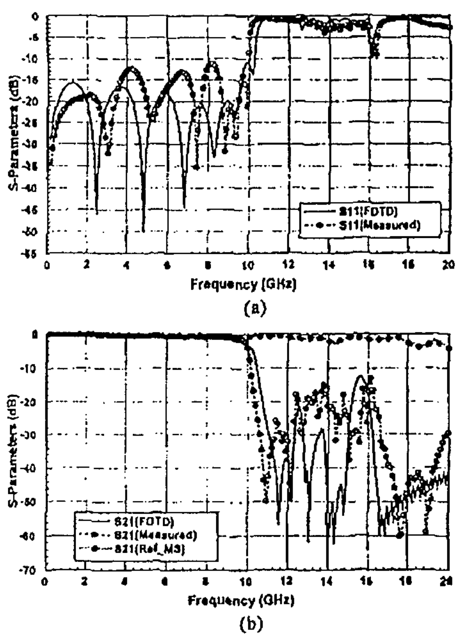


Fig. 2 FDTD simulation and measurement results of S parameters for a 50 Ω microstrip line on a UC-PBG ground plane.

## II. UC-PBG Concept

Fig. 1 shows the basic schematic of the UC-PBG lattice. Each element consists of a square metal pad and four connecting branches. The inset, narrow branches introduce additional inductance, and the gaps between neighboring pads increase the capacitance. The narrow inductive lines and small capacitive gaps form a two-dimensional LC network which greatly reduce the lower edge of the band gap, resulting in a PBG lattice which is significantly smaller in electrical size compared to our previous designs or any other structures reported so far [2-5].

Fig. 2 shows both FDTD simulation and measured results of the S parameters for a 50 Ω microstrip line fabricated on a ground plane with the UC-PBG lattice. It can be seen that at lower frequencies the line insertion loss is at the same level with a reference microstrip line on a solid ground plane and with identical dimensions. The structure exhibits a deep and very broad stopband above around 10 GHz. The excellent correlation between simulation and measurement indicates that this type of PBG structures can be characterized and designed with a high degree of accuracy.

## III. Filter Applications

Microstrip bandpass filters (BPF) are widely used in microwave integrated circuits. Conventional parallel-coupled BPFs, however, present spurious passbands at harmonic frequencies. Extra filters are usually required to suppress spurious transmissions and the insertion loss will be increased as a consequence. The advantages of UC-PBG can be applied to construct a compact microstrip bandpass filter with intrinsic spurious rejection. Furthermore, the slow-wave effect reduces the physical length of the filter circuit integrated with the UC-PBG structure.

Fig. 3 shows the schematic and pictures of a parallel-coupled bandpass filter using the UC-PBG structure in the ground plane [6]. Compared to a conventional design based on

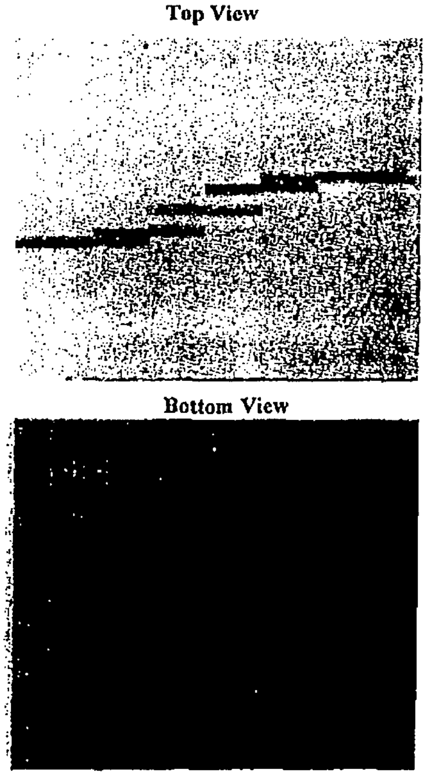


Fig. 3 A spurious-free microstrip bandpass filter built on UC-PBG ground plane.

solid ground plane, the microstrip bandpass filter using the UC-PBG gave immediate spurious rejection of over 30 dB at both the second and third harmonics, while retaining the same level of low insertion loss in the passband. Meanwhile, a microstrip step-impedance low pass filter built on UC-PBG was found to improve the stopband rejection level from –20 dB to below –50 dB [7].

## IV. Leakage Suppression Using UC-PBG

Coplanar waveguide (CPW) has been used popularly in modern microwave planar circuit designs. Very frequently the CPW is backed by a ground plane for heat sinking, packaging, enhancing mechanical strength, or other purposes. The conductor-backed CPW, or CB-CPW, however, will excite parallel-plate mode and deteriorate the CPW performance. Several approaches have been presented to overcome this leakage problem, such as using posts to short the unwanted mode or using multi-layered substrates to shift the dispersion curve of the parallel-plate mode.

The wide stopband of UC-PBG can be utilized to suppress leakage loss in CB-CPW structures [8]. The PBG lattice can be easily etched in the top ground planes of the CB-CPW circuit without using any extra masks or via holes. It was shown experimentally that the insertion loss of a CB-CPW can be improved significantly within the stopband of the UC-PBG. This novel CB-CPW structure shows potential for applications in various types of CPW-based circuits, such as CPW-fed slot antennas.

## V. Harmonic Tuning for Power Amplifiers

Advanced wireless communications systems require high efficiency, compact and low-cost transmitters. High efficiency power amplifiers are typically achieved by tuning harmonics. Traditionally, tuning of the second and third harmonics are done by adding open or short circuited stubs at the output. Recently, the UC-PBG has been used for harmonic tuning in a high efficiency S-band power amplifier [9]. Fig. 4 shows the photograph of the fabricated amplifier with PBG ground plane. The measurement showed an increase of 10 % in PAE and 1.3 dB in output power for the amplifier with UC-PBG. The maximum measured PAE was 65 % at an output power of 25.5 dBm. When compared to a reference amplifier, the PBG structure gave an additional suppression of 37 dB for the second harmonic, and at least 30 dB for the third harmonic.

Top View Bottom View

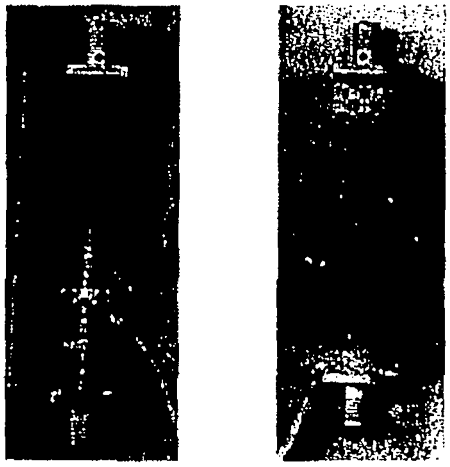

Fig. 4 A high efficiency S-band power amplifier using UC-PBG for second and third harmonic tuning.


## Acknowledgment

This work was supported by the ARO MURI under contracts DAAH04-96-1-0005.


## References


[1] Y. Qian, F. -R. Yang and T. Itoh, "Characteristics of Microstrip Lines on A Uniplanar Compact PBG Ground Plane," *1998 Asia-Pacific Microwave Conference Digest*, Yokohama, Japan, pp. 589-592, Dec. 1998.

[2] Y. Qian, V. Radisic and T. Itoh, "Simulation and Experiment of Photonic Band-Gap Structures for Microstrip Circuits," *1997 Asia-Pacific Microwave Conference*, Hong Kong, pp. 585-588, Dec. 1997.

[3] V. Radisic, Y. Qian, R. Coccioli and T. Itoh, "Novel 2-D Photonic Band-Gap Structure for Microstrip Lines," *IEEE Microwave and Guided Wave Letters*, Vol. 8, pp. 69-71, Feb. 1998.

[4] V. Radisic, Y. Qian and T. Itoh, "Novel Architectures for High Efficiency Amplifiers for Wireless Applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, no. 11, pp. 1901-1909, Nov. 1998.

[5] Y. Qian, R. Coccioli, D. Sievenpiper, V. Radisic, E. Yablonovitch and T. Itoh, "Microstrip Patch Antenna Using Novel Photonic Band-Gap Structures," *Microwave Journal*, pp. 66-76, Jan. 1999.

[6] F. -R. Yang, Y. Qian and T. Itoh, "A Novel Compact Microstrip Bandpass Filter with Intrinsic Spurious Suppression," *1998 Asia-Pacific Microwave Conference Digest*, pp. 593-596, Yokohama, Japan, Dec. 1998.

[7] F. R. Yang, Y. Qian and T. Itoh, "A Novel Uniplanar Compact PBG Structure for Filter and Mixer Applications," *1999 IEEE MTT-S International Microwave Symposium*, Anaheim, CA, pp. 919-922, June 1999.

[8] K. -P. Ma, F. -R. Yang, Y. Qian and T. Itoh, "Nonleaky Conductor-Backed CPW Using A Novel 2-D PBG Lattice," *1998 Asia-Pacific Microwave Conference Digest*, pp. 509-512, Yokohama, Japan, Dec. 1998.

[9] C. Y. Hang, V. Radisic, Y. Qian and T. Itoh, "High Efficiency Power Amplifier with Novel PBG Ground Plane for Harmonic Tuning," *1999 IEEE MTT-S International Microwave Symposium*, Anaheim, CA, pp. 807-810, June 1999.