Progress In Electromagnetics Research Letters, Vol. 9, 67–74, 2009

A NOVEL MULTI-BAND ELECTROMAGNETIC BAND-GAP STRUCTURE

H.-H. Xie, Y.-C. Jiao, K. Song, and Z. Zhang

National Key Laboratory of Antennas and Microwave Technology
Xidian University
Xi'an, Shaanxi 710071, P. R. China

Abstract—In this paper, a novel multi-band EBG structure is presented. By making slots on Sievenpiper High Impedance Surface (HIS) to increase the inductance and capacitance, the resonant frequency of the EBG structure can be significantly reduced. Transmission line method is used to determine the band-gap of the EBG structure. The simulated and experimental results show that the novel EBG structure can provide multiple band-gap. This proposed EBG can be usefully applied to multiple frequency antennas and low profile antennas.

1. INTRODUCTION

In recent decades, there has been increasing interests in investigating electromagnetic band-gap structures (EBG), and various EBG structures are suggested for the applications in microwave circuits and antenna systems [1, 2]. Generally, the periodic length of EBG structure is about a half-wavelengh with respect to the centre-frequency and the bandstop is narrow. So the investigations on the broadband and multi-band EBG structures have also been attractive to many researchers. Some new techniques, which are mostly to increase the inductance or capacitance, are utilized to reduce the resonant frequency and increase the band-gap of EBG structures [3, 4]. The convoluted metal strips of EBG cell is a effective structure, which is used to improve the characteristics of EBG structures [5]. [6] shows a slotted EBG with koch structure, which has two band-gaps. The slotted EBG with koch structure adjusts the resonant frequency by changing the dimension of the center square metal patch and the width of the slots. This

Corresponding author: H.-H. Xie (haobei1002@sina.com).

structure can't provides more band-gaps and its resonant frequency can't be adjusted conveniently.

In this paper, a novel EBG structure by making slots on Sievenpiper High Impedance Surface (HIS) is presented. The value of the capacitor and inductance can be increased effectively in this structure, which reduce the size of the EBG cell, and the simulated results show the first resonant frequency can be reduced from 2.3 GHz to 1.72 GHz. The slotted EBG can easily adjusts the resonant frequencies by changing the location of the slots on trapezoid metal patchs. The effects of the width of the slots on band-gap are discussed. We measure the band-gaps of the EBG by using Transmission Line method [7]. Measured results show the EBG structure has three band-gaps and the center frequencies are respectively 1.84 GHz, 5.0 GHz and 7.36 GHz.

2. STRUCTURE DESIGN

A high-impedance surface (HIS) EBG cell can be considered as an LC network model, its first resonant frequency $f_0 = \frac{1}{2\pi\sqrt{L \cdot C}}$. For the Sievenpiper structure as shown in Figure 1(a), the value of the capacitor is given by the fringing capacitance between neighboring coplanar metal plates. The value of the inductor is derived from the current loop consisting of the vias and metal sheets. The inductance

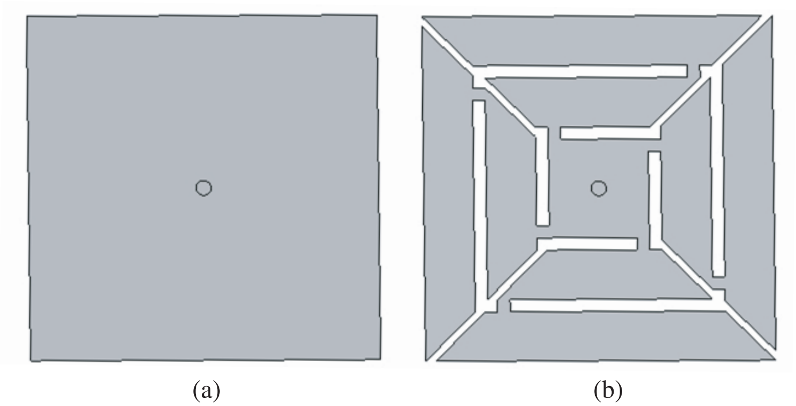


Figure 1. (a) Sievenpiper EBG structure, (b) slotted EBG structure.

L and capacitance C are given by the following equations [8]:

$$C = \frac{w\varepsilon 0(1+\varepsilon r)}{\pi}\cosh^{-1}\left(\frac{c}{c-w}\right)$$
$$L = \mu_0 \cdot h \cdot (\ln(1/\alpha) + \alpha - 1)$$

where α is the ratio of the via's metal pole cross sectional area to the unit cell area of EBG, h is the thickness of substrate. c is periodical length, w is the length of square metal.

To reduce the resonant frequency and the size of EBG structure, we make four slots at the diagonal line of Sievenpiper cell and the Sievenpiper structure is changed into four trapezoids and a conjoint small square. Then, we make two slots on each trapezoid and the structure is shown in Figure 1(b).

The model of transmission line is used to measure the band-gap of the EBG structure. The construction of transmission line for slotted EBG is shown in Figure 2. The proposed slotted EBG structures are printed on a dielectric slab with dielectric constant $\varepsilon_r = 3.2$ and thickness $h = 0.76$ mm. The length of the mcirostrip line and the ground $L = 47$ mm, the width of the microstrip line and the ground are assumed separately as $Wm = 4$ mm, $Wg = 15$ mm. The periodic spacing is c, the length of square metal is w and the diameter of via pole is d. The parameters of slotted EBG are marked in Figure 2. The parameters are set as $c = 15$ mm, $w = 14$ mm, $d = 0.6$ mm, $g1 = 1$ mm, $g2 = 0.4$ mm, $g3 = 0.5$ mm, $w1 = 4$ mm, and $w2 = 5$ mm.

3. ANALYSIS ON TRANSMISSION COEFFICIENTS OF THE SLOTTED MULTI-BAND EBG STRUCTURE

The simulations are conducted using a method of moments (MoM)-based software, IE3D.

3.1. Comparison of the S_{21} of Sievenpiper and Slotted EBG

We compare the transmission coefficient of sievenpiper EBG with slotted one. The simulated results are shown in Figure 3. The resonant frequency of sievenpiper EBG is 2.30 GHz and the bandwidth is 16.7%. For the slotted EBG, the first resonant frequency is 1.72 GHz and the bandwidth is 12.5%, the second resonant frequency is 4.74 GHz and the bandwidth is 13.27%, the third resonant frequency is 7.04 GHz and the bandwidth is 5.59%. The narrow bandwidth results from low dielectric constant and thickness.

3.2. Effect of the Width of the Diagonal Slots

While the width of diagonal slots is changed from 0.3 mm to 0.5 mm and the other parameters keep same, the resonant frequency of multiple stopband will be somewhat raise. When $g2 = 0.4$ mm, the bandwidth of EBG is larger than others. The simulated results are shown in Figure 4 and listed in Table 1 in detail. When $g2 = 0.3$ mm, there is a small stopband above the first stopband.

Table 1. Comparison of multi-band and stopband bandwidth for different width of diagonal slots ($c = 15$ mm, $w = 14$ mm, $d = 0.6$ mm, $g1 = 1$ mm, $g3 = 0.5$ mm, $w1 = 4$ mm, and $w2 = 5$ mm).

Width of diagonal slots ($g2$)	$f1$ (GHz) BW (%)	$f2$ (GHz) BW (%)	$f3$ (GHz) BW (%)
0.3 mm	1.70 12.06%	4.69 10.73%	7.0 4.4%
0.4 mm	1.72 12.5%	4.74 13.27%	7.04 5.59%
0.5 mm	1.73 11.3%	4.80 10.5%	7.21 3.59%

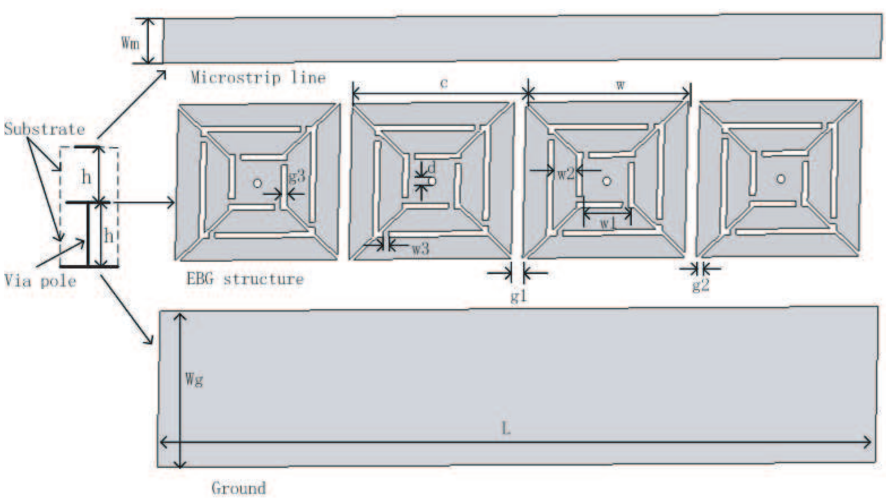


Figure 2. The model of transmission line for slotted EBG.

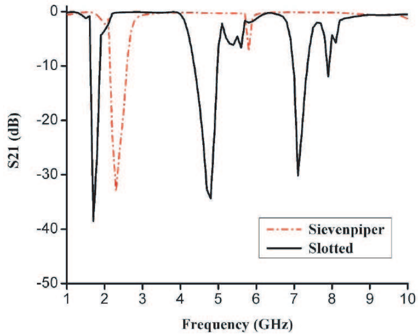


Figure 3. Comparison of S21 for sievenpiper and slotted EBG.

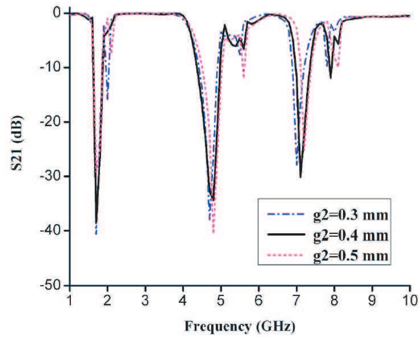


Figure 4. Comparison of S21 for different width of diagonal slots.

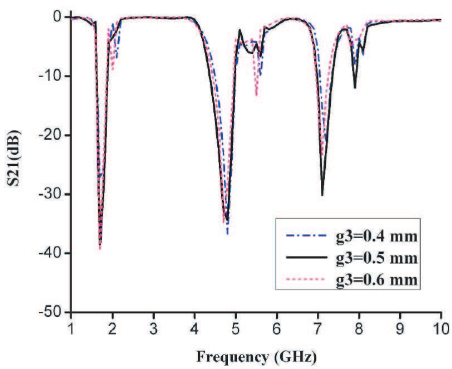


Figure 5. Comparison of S_{21} for different width of slots on trapezoids.

3.3. Effect of the Width of the Slots on Trapezoids

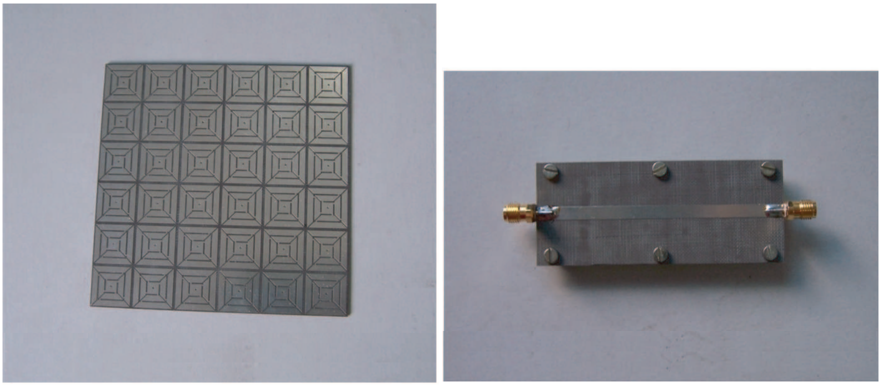
When the width of diagonal slots is fixed at $g2 = 0.4\,\text{mm}$, the width of the slots on trapezoids is changed from 0.4 mm to 0.6 mm, and the other parameters keep same, the resonant frequency of multiple stopband will be reduce. When $g3 = 0.5\,\text{mm}$, the bandwidth of EBG is larger than others. The simulated results shown in Figure 5 and listed in Table 2 in detail.

4. EXPERIMENTAL RESULTS

The fabricated slotted EBG is shown in Figure 6(a) and the photograph of transmission line for slotted EBG is shown in Figure 6(b). Two layers of PCB plane are sticked by six screws. The obtained

Table 2. Comparison of multi-band and stopband bandwidth for different width of slots on trapezoids ($c = 15\,\mathrm{mm}$, $w = 14\,\mathrm{mm}$, $d = 0.6\,\mathrm{mm}$, $g1 = 1\,\mathrm{mm}$, $g2 = 0.4\,\mathrm{mm}$, $w1 = 4\,\mathrm{mm}$, and $w2 = 5\,\mathrm{mm}$).

Width of slots on trapezoids ($g3$)	$f1$ (GHz) BW (%)	$f2$ (GHz) BW (%)	$f3$ (GHz) BW (%)
0.4 mm	1.73 11.9%	4.78 10.53%	7.16 3.75%
0.5 mm	1.72 12.5%	4.74 13.27%	7.04 5.59%
0.6 mm	1.70 11.49%	4.72 10.46%	7.02 3.94%



(a) (b)

Figure 6. (a) Photograph of slotted EBG, (b) photograph of transmission line for slotted EBG.

S parameter using WILTRON37269A vector network analyzer is presented in Figure 7. The measured center frequency is higher than the simulated one and the loss becomes larger with frequency increasing, which may be caused by the effects of SMA connectors and no tight stick of two layers of PCB plane. According to the Figure 7, we can see there are three band-gaps and their center-frequencies are respectively 1.84 GHz, 5.0 GHz and 7.36 GHz.

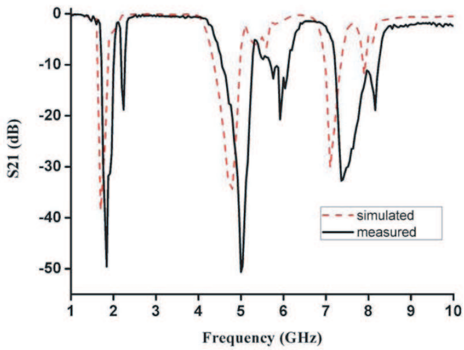


Figure 7. S_{21} of simulated and measured.

5. CONCLUSIONS

A novel multi-band electromagnetic band-gap (EBG) structure is presented. The transmission line method is used to simulate the transmission coefficients of the EBG structure. The effects of the width of the slots on stopband characteristics for the proposed EBG structure are studied in detail. This slotted EBG structure can provide multiple bandstops, which can be applied to multi-band antennas and low profile antennas.

REFERENCES

1. Wu, B., B. Li, T. Su, and C.-H. Liang, "Equivalent-circuit analysis and lowpass filter design of split-ring resonator DGS," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 1943–1953, 2006.
2. Fu, Y. Q., Q. R. Zheng, Q. Gao, and G. H. Zhang, "Mutual coupling reduction between large antenna arrays using electromagnetic bandgap (EBG) structures," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 6, 819–825, 2006.
3. Tse, S., B. S. Izquierdo, J. C. Batchelor, and R. J. Langley, "Reduced sized cells for electromagnetic bandgap structures," *Electronics Letters*, Vol. 39, No. 24, 1699–1701, Nov. 27, 2003.
4. Folayan, O. and R. J. Langley, "Wideband reduced size electromagnetic bandgap structure," *Electronics Letters*, Vol. 41, No. 20, 1099–1100, Sept. 29, 2005.
5. Zheng, Q.-R., B.-Q. Lin, Y.-Q. Fu, and N.-C. Yuan, "Character-

istics and applications of a novel compact spiral electromagnetic band-gap (EBG) structure," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 2, 199–213, 2007.

6. Yu, C.-C., M.-H. Haung, Y.-T. Chang, L.-K. Lin, and T.-H. Weng, "A novel Electromagnetic Bandgap (EBG) structure for Electromagnetic Compatibility (EMC) application," *PIERS Proceedings*, 581–584, Beijing, China, Mar. 23–27, 2009.
7. Remski, R., "Analysis of PBG surfaces using Ansoft HFSS," *Microwave J.*, Vol. 43, 190–198, 2000.
8. Sievenpiper, D. F., "High-impedance electromagnetic surfaces," Ph.D. dissertation at University of California, Los Angeles, 1999.