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Novel Compact Photonic Band-gap Configurations using Multiple Slot Loading for Enhancement the Capacitance

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A novel photonic band-gap(PBG) structure for compactness is investigated. A comparison has been carried out between the proposed designs and the normal mushroom-like PBG structure. Experimental results show that a compact PBG configurations exhibit more excellent performances by suppressing ripple in the pass-band and stop-band return loss(RL). In the normal mushroom design, the stop-band extends from 3.63GHz to 6.18GHz. When the multiple slots are incorporated, the frequency band-gap position decreases to 3.27GHz-5.45GHz and 2.95GHz-5.07GHz, respectively. The presented structure also provides an additional degree of freedom to adjust the band-gap position, which is applied to design a novel reconfigurable multi-band PBG structure. Our proposed PBG designs may be used in various microwave integrated circuit(MIC), RF devices with highly compact size.

Introduction

In recent years, there has been a tremendous amount of research activity on utilizing photonic band-gap(PBG) and electromagnetic band-gap(EBG) structures in the microwave and millimeter-wave circuit[1][2][3][4]. But, practical applications of early EBG structures have difficulties in accommodating their physical sizes; the period of an EBG lattice has to be a half-wavelength at the stop-band frequency. Compared to other EBG structures, mushroom-like EBG structure designed by *Sievenpiper et al.*[5] has a winning feature of compactness. But, mushroom-type EBG structures have two fundamental limitations for low frequency applications. The center frequency of stop-band can only be reached by increasing either the inductance per unit area or the capacitance per unit area. Therefore, there has been substantial research work towards the design of compact electromagnetic band-gap structures(EBG) for low frequency designs, all of which was focused on enhancing the per unit area capacitance[6]. The capacitance enhancement was obtained by using double-layer patches. In this case, the fringing capacitance between adjacent unit cells is comparable to that of the parallel-plate capacitors. But, the method of this approach in standard PCB technology requires an increase of the number of metal layers.

In this paper, we propose a new PBG structure with simple process of making the PBG structure to increase capacitance for making resonant frequency lower and enhancement for stop-band performance.

Experimental Results for Compact Mushroom PBG Design

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In the mushroom-like PBG structure, the capacitance or inductance increases under the condition of fixed same size, the PBG structure can be used in lower frequency application for RF devices. A unit cell of the conventional mushroom-like PBG structure is illustrated in Fig. 1. There is a capacitance between the top plates, and there is an inductance from one top plate to the other top via the solid ground plate. The band-gap characteristics depend on the material structure such as dimensions, periodicity and permittivity. The capacitance, inductance and parallel resonant frequency in the conventional PBG structure are computed as follows[4].

$$L = \mu h(1/\omega) \tag{1}$$

$$C = \left(\frac{1}{\pi}\right)(\varepsilon_0 + \varepsilon_r)\cosh^{-1}(a/g) \tag{2}$$

$$\omega_0 = \sqrt{1/LC} \tag{3}$$

In this paper, new PBG structure for compactness consists of four parts, which are: 1) a solid ground plane; 2) a dielectric substrate; 3) connecting via-holes; and 4) metal patches with various shapes. The vane-like and interdigital patch with multi slots etched on the top patches introduce additional gaps between neighboring patches. These gaps significantly enlarge capacitance of the equivalent LC circuit and a distinctive improvement of compactness is observed. The unit cell schematic of the proposed compact EBG structure is shown in Fig. 1. The 9-array is built on a 1.6mm thick FR4 substrate with the relative permittivity $\varepsilon_r = 4.4$ and the area dimensions of the solid ground plane are 90×50mm. The radius of via-hole was 0.5mm, the design parameter of the square patch L=6mm and the period of the lattice 6.3mm(g=0.3mm: the distance between the adjacent patches).

In the vane-like design, four identical slots are cut on the normal mushroom-like patch for miniaturization. The slot length is 1.9mm, its width is 1mm and the distance between the slot and patch edge center is 1.5mm. These dimensions are selected from many parameter study EM-simulation(CST Microwave Studio 4.0) to achieve the optimum miniaturization. In the interdigital design, the center frequency of stop-band decreases by increasing the number of corrugations N. By adjusting the size and the position of the embedded slot, the coupling of the unit cell PBG patch can be varied and the stop-band position can be tuned over a wide range of frequency. The stop band-gap feature of the proposed PBG structure is depicted in Fig. 3, and it is compared to a normal mushroom PBG structure without multiple slots. In the normal mushroom design, the stop-band extends from 3.63 to 6.18GHz. When the multiple slots are incorporated, the frequency band-gap position decreases to 3.27–5.45GHz and 2.95-5.07GHz, respectively. As can be seen in Table I, the 20-dB isolation bandwidths for normal-type, vane-type, and interdigital-type are 2.55GHz, 2.24GHz, and 2.12GHz, respectively. Also, the first null return-loss near cutoff and peak return-loss for our proposed designs are -22.21, -6.33 and -20.68, -8.07 dB, respectively, whereas they for normal mushroom are -13.86dB and -4.82 dB, respectively. Figures 4 show a peak surface current for the proposed compact PBG design at the pass and stop-band region, respectively. It can be clearly seen that the level of surface current modes has dropped significantly in the band-stop region, which makes this compact PBG configuration a promising structure to avoid surface wave and mutual coupling in RF circuit.

Conclusions

A compact photonic band-gap(PBG) structures has been created and characterized. The proposed PBG structure can be easily scaled to other frequencies with highly compact size. These novel PBG structure, which also has lower cost and is easier to fabrication than most other multi-layer PBG structures with complex geometries, is suitable for integration in various microwave applications. Also, significant improvements over ripples and enlarged stop-band bandwidth are obtained. Therefore, the compact PBG structures may be used in various microwave integrated circuits(MIC), RF devices.

References

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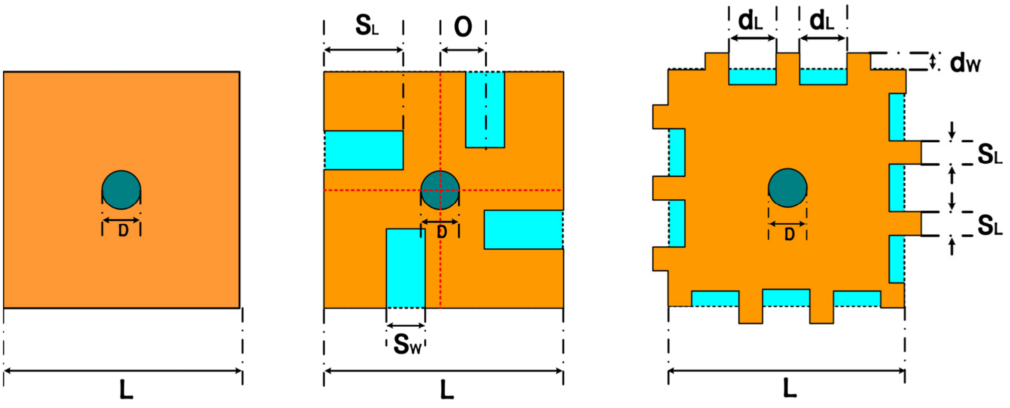


$L \times L = 6 \times 6mm$ $S_L \times S_W = 1.9 \times 1mm$ $d_L \times d_W = 1.2 \times 0.5mm$

$o = 1.5mm$ $S_L = 0.6mm$

(a) Normal mushroom (b) Vane mushroom (c) Interdigital mushroom

Figure 1. The schmetics for Unit cell of Mushroom-like PBG structure($D = 0.5mm$).

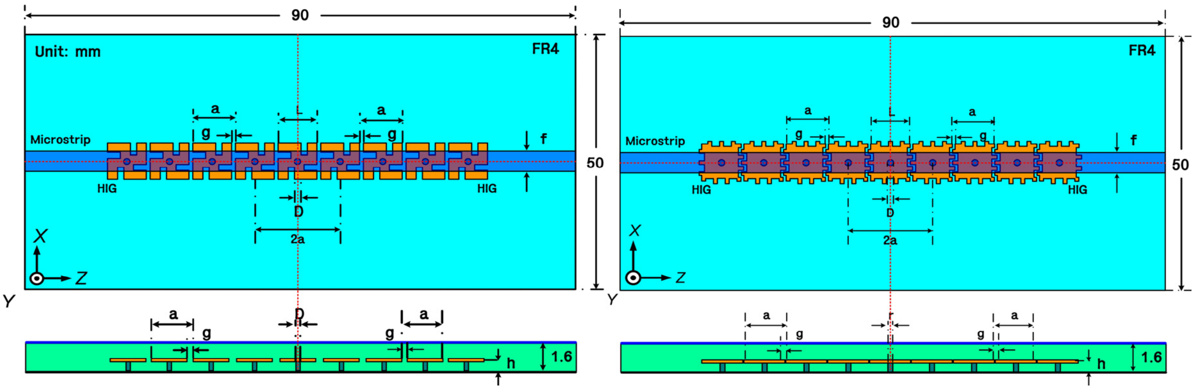


Figure 2. Configuration of our proposed compact mushroom PBG($a = 6.3mm$).

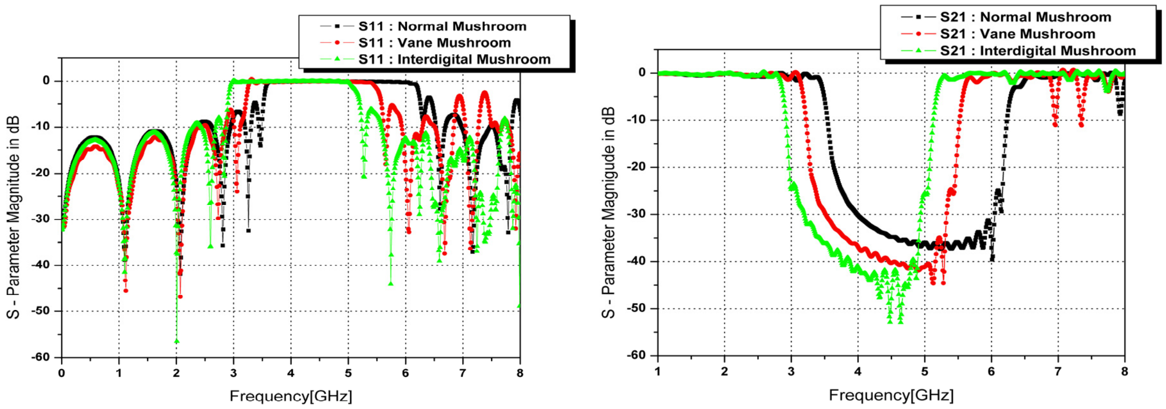
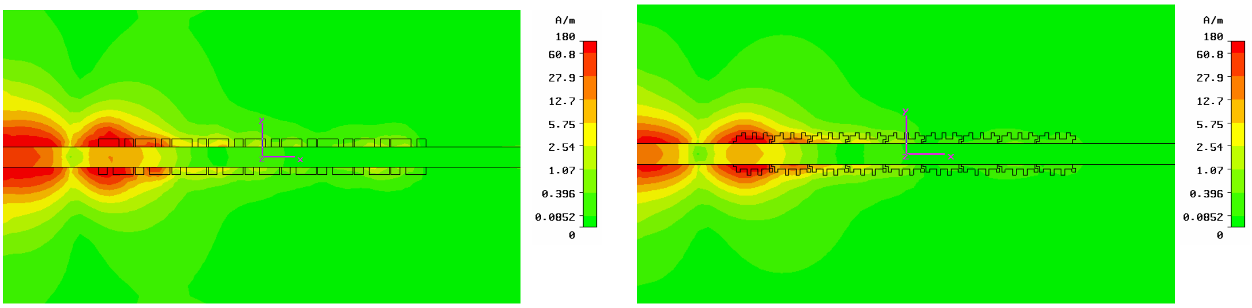


Figure 3. Comparison of simulated results of three mushroom-like PBG structures.

Table 1. Comparison of the proposed compact PBG designs and normal mushroom PBG.

Type	$20dB$ Stop-band Isolation		$20dB$ Isolation Bandwidth (GHz)	1'st Null and Peak RL (dB)	
	f_0 (GHz)	$S_{21(Max)}$ (dB)		Null (dB)	Peak RL (dB)
Normal	4.91	-39.7	2.55	-13.86	-4.82
Vane	4.45	-44.4	2.24	-22.21	-6.33
Interdigital	4.01	-53.1	2.12	-20.68	-8.07



(a) Vane-Mushroom($f_0 = 4.45GHz$)　(b) Interdigital-mushroom($f_0 = 4.01GHz$)

Figure 4. Surface current(peak) distribution on the propagation direction($\theta = 290°$).