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Slot resonator-based electromagnetic bandgap coplanar waveguide and its filter application

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Abstract

One-dimensional (1-D) slot resonator-based electromagnetic bandgap coplanar waveguide (SR-EBG-CPW) is proposed in this Letter. First, the SR-EBG-CPW unit cell is discussed and exhibits bandstop performance without any periodic structure. Then, its circuit model is extracted from the full-wave simulations and the frequency characteristics are explained by employing the equivalent circuit parameters and field analysis. Finally, a miniaturized bandstop filter with SR-EBG-CPW is presented and fabricated. Measurement shows that the designed filter provides good bandstop and slow-wave performances as predicted and has potential applications to compact microwave designs.

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Keywords: Slot resonator; Electromagnetic bandgap; Coplanar waveguide; Bandstop filter

1. Introduction

The research history of electromagnetic (EM) wave propagation in artificial periodic structures can be traced back to half a century ago. In 1959, Oliner had studied the dispersive propagation and characteristic impedance of periodic structures in trough waveguide [1]. Recently, some novel periodic structures, such as photonic bandgap (PBG) and electromagnetic bandgap (EBG), have been applied popularly to microwave applications [2–4]. In 1998, Radisic proposed a planar microstrip line with photonic bandgap (PBG) etched on the backside ground plane [2], in which the novel process has no drilling through the substrate, so that the new process is used widely to microwave filtering circuits.

Generally, a microstrip filter consists of several PBG cells and the periodicity between the cells is directly proportional to the wavelength of the center frequency of the PBG. So, the miniaturization of microwave circuits is of great importance in the practical designs using PBG. Some researchers reported that a half-wavelength resonator can be folded to a quarter-wavelength hairpin resonator to reduce the circuit size [5]. The hairpin resonator can be further miniaturized to form a split-ring resonator for narrowband filtering [6].

Besides, the PBG or EBG structures for coplanar waveguide (CPW) have been studied extensively with advantages of the CPW, such as simple fabrication and without via holes. For example, Fu proposed a novel PBG CPW. However, the period distance is 24 mm and the period number is 5. Thus its total length is more than 120 mm [7]. Another CPW EBG low-pass filter was reported and its length was reduced to 92 mm [8]. Obviously, it is difficult to be used in practical microwave mobile communication systems. Then, some techniques were given to reduce the length of the CPW structures. Martin designed a periodic-loaded sinusoidal patterned EBG CPW with the length of 61 mm [9]. Yu proposed a CPW EBG filter using butterfly-radial slot with the minimum length of 30 mm [10].

To meet the requirement of reducing the circuit size, a compact slot resonator-based electromagnetic bandgap coplanar

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waveguide (SR-EBG-CPW) is introduced in this Letter. Also, a simple and accurate circuit modeling for the slot resonator is proposed. The modeling validity is verified by the excellent agreement between the EM simulations and circuit simulations within a wide frequency range. Furthermore, a bandstop filter using SR-EBG-CPW on ground plane was fabricated and measured to demonstrate the predicted results.

2. Theory and filter design

Based on the concept of folding, the SR-EBG-CPW cell is designed and shown in Fig. 1(a). Correspondingly, the equivalent circuit model with one *LCR*-network resonator is shown in Fig. 1(b). Two reference planes, A and A', are placed in Fig. 1. The SR-EBG-CPW cell is composed of a CPW line and slot defects on both ground plane. The SR-EBG-CPW cell has six variable dimensions, which are a, b, c, d, g_1, g_2, for controlling the transmission performances.

Actually, the slot on the ground plane disturbs the electric and magnetic field distributions of the transmission line. The disturbance can change the effective capacitance and inductance of the CPW line. Thus, the bandgap effect is obtained. Also, the existing of the cutoff frequency means that employing the SR-EBG-CPW cell increases the effective permittivity so that the slow-wave effect of the CPW line is improved.

To understand the abovementioned analysis, the SR-EBG-CPW cell circuit is studied and simulated by commercial EM simulator. The dimensions of the SR-EBG-CPW cell are chosen as follows: $a = 2$ mm, $b = 3$ mm, $c = 1$ mm, $d = 1$ mm, $g_1 = g_2 = 0.2$ mm. The dimensions of the CPW line are chosen to be the characteristic impedance 50 Ω with $w = 2.5$ mm and $s = 0.2$ mm. The substrate FR-4 with a thickness of 0.6 mm and a relative dielectric constant of 4.4 is used for simulations and measurement in this Letter. The circuit was simulated by Ansoft Ensemble 8.0 and the results are shown in Fig. 2. Without any periodic structure, the SR-EBG-CPW cell can provide cutoff frequency and attenuation pole.

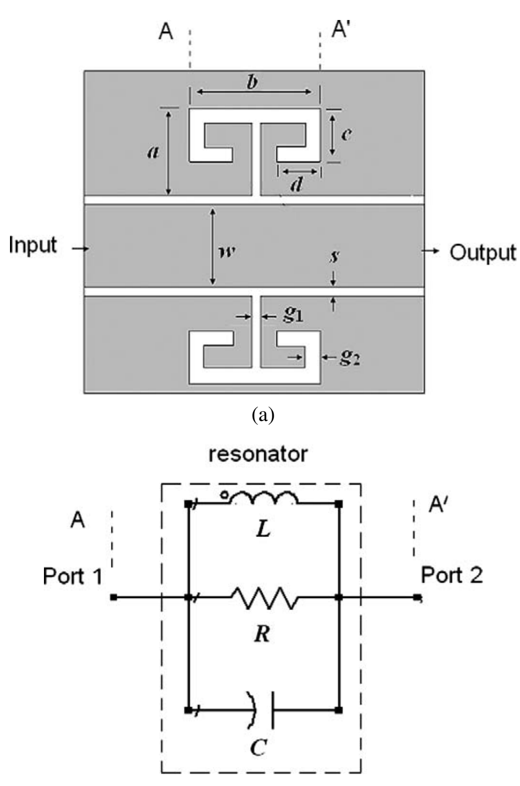

Fig. 1. The proposed SR-EBG-CPW cell (a) geometry, (b) equivalent circuit model.

In Fig. 1(b), the bandgap characteristics of the SR-EBG-CPW cell can be modeled by one *LCR*-network. The lumped capacitance, C, is mainly contributed by slot gaps while the inductance, L, is related to the magnetic flux passing through the apertures on the ground plane. The radiation effect and transmission loss are considered by including one resistor, R. Based on the transmission line theory and the spectral domain approach [11], the circuit parameters can be extracted using the following equations.

$$R = 2Z_0\left(1/|S_{21}| - 1\right)\big|_{f=f_0}, \tag{1}$$

$$C = \frac{\sqrt{0.25(R + 2Z_0)^2 - 4Z_0^2}}{3.464\pi Z_0 R \Delta f}, \tag{2}$$

$$L = \frac{1}{4(\pi f_0)^2 C}, \tag{3}$$

where Z_0 is the characteristic impedance of the transmission line, f_0 is the resonant frequency, S_{21} is the insertion loss and Δf is the −6 dB bandwidth of S_{21}.

Based on the EM simulations, the extracted R, L, C, are 2690 Ω, 0.9490 nH, 0.3601 pF, respectively. The circuit simulations using Agilent ADS is shown in Fig. 2. From 1 GHz to 15 GHz, an excellent agreement between the EM simulations and circuit simulations can be observed.

The proposed SR-EBG-CPW unit provides two important design parameters, g_1 and g_2, to adjust the etched area on the ground plane so that the effective capacitance and inductance of the CPW line are changed. Thus, the frequency characteristics of the CPW line can be controlled by g_1 and g_2.

Four SR-EBG-CPW cell circuits are simulated with different values of g_1 by keeping the other dimension parame-

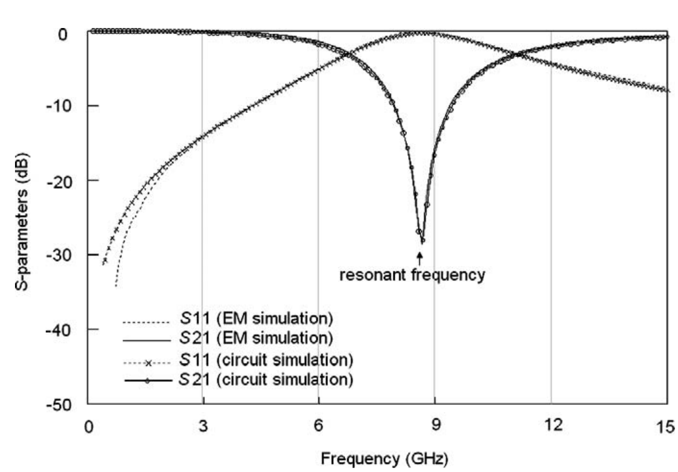

Fig. 2. Comparison of the S-parameters between EM simulations and circuit simulations.