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Uniform circular photonic bandgap structures (PBGSs) for harmonic suppression of a bandpass filter

Md. Nurunnabi Mollah[a,*], Nemai C. Karmakar[b], Jeffrey S. Fu[c]

[a]Department of Electrical and Electronic Engineering, Khulna University of Engineering and Technology (KUET), Khulna 920300, Bangladesh
[b]Department of Electrical and Computer System Engineering, Monash University, Victoria Australia
[c]Department of Electronic Engineering, Chang Gung University, Taiwan 333, Republic of China

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Abstract

Conventional 2-D uniform hole patterned photonic bandgap structures (PBGSs) have been replaced by 1-D uniform circular PBGSs as they provide very similar performances. This concept is utilized to investigate the effectiveness in harmonic suppression. They have been applied in harmonic suppression of an asymmetric coupled line bandpass filter (BPF). It can be seen that the proposed 1-D uniform circular PBGSs under the lines of a BPF yield performance better than other different designs such as conventional 2-D uniform PBGSs and dense PBG elements including few more designs. Such designs are more compact than available designs reported in the open literature.

Keywords: Compact; Harmonic suppression; Insertion loss; Photonic bandgap structures; Stopband

1. Introduction

In the new millennium, the explosions of info-communication technologies have brought many new broadband design challenges. To meet the challenge, designers require fulfilling more functionality per unit volume. For multi-channel/broadband operations more than one octave bandwidth from active and passive devices are demanded. Achieving such broad bandwidth from conventional MMIC integrated circuits is not a trivial task. Challenges also are to tackle the second- and third-order inter-modulation products of active devices and higher-order harmonics in passive devices such as filters. Mitigating these undesirable inherent characteristics of active and passive devices is the big challenge for broadband designs. Other challenges are the surface wave suppression in planar circuits such as amplifiers, oscillators and microstrip patch antennas. Surface waves propagating in high dielectric constant slabs carry substantial energy in unwanted directions and create unnecessary coupling between devices and reduce radiation efficiency in antennas. Planar photonic bandgap structure (PBGSs) can alleviate these problems by suppressing higher-order modes and surface waves [1,2]. Electromagnetic (EM) waves behave in photonic substrates as electrons behave in semiconductors. Under this consideration, they are also termed as electromagnetic bandgap structure (EBGS). They exhibit wide band-pass and band-rejection properties at microwave and millimeter-wave frequencies and have offered tremendous applications in active and passive devices. While various configurations have been proposed in literature, only the planar etched PBG configurations have attracted much interest due to their ease of fabrication and integration with other circuits. Due to stopband – passband properties of PBG

* Corresponding author. Tel.: +880 41 774782 (O), mobile: +880 1714 087325; fax: +880 41 774403.
E-mail addresses: headeee@mail.kuet.ac.bd, pk462796@ntu.edu.sg, mn_nabi05@yahoo.com (Md.N. Mollah).

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structures, they find potential applications in filter, antennas, waveguide, phased arrays and many other microwave devices and components [3–18]. Conventional PBGSs are 2-D periodic structures that satisfy Bragg's condition; the intercell separation (period) is close to a half-guided wavelength and they are not suitable for higher-order implementations in compact filters and amplifiers. To alleviate the problems F-R Yang et al. [19] proposed a compact uniplanar PBG structure (UC-PBGS). Some results are produced on the suppression of higher-order harmonics in UC-PBG engineered bandpass filter (BPF). UC-UPBGSs are 2-D in nature and occupy more space in the ground plane of a conventional BPF. Though they are compact in producing stopband when they are used under the standard 50 Ω transmission line but they are more complex in design aspects.

In this paper, we propose uniform circular PBGSs to be etched in the ground plane of a coupled line BPF to suppress harmonics. To see the effective role of 1-D uniform circular PBGSs in generating stopband compared to conventional 2-D uniform circular PBGSs, we have produced their *S*-parameters performances. We have investigated few designs with uniform circular PBGSs for harmonic suppression of a BPF. The designs differ from each other by the location of uniform circular PBGSs and number of PBG elements in the ground plane. We expect that when PBG elements are situated exactly under all lines of a BPF then they effectively suppress the harmonic owing to the fact that the EM field is highly concentrated under the microstrip line. Our proposed design is fabricated and measured with vector network analyzer. The performance of an optimized BPF is also reported.

2. Theory

The center frequency of the stopband of a PBGS that satisfies Bragg's condition is calculated approximately with the following expression:

$$\beta a = \pi, \quad (1)$$

where a is the period of the PBG pattern, β is the wave number in the dielectric slab. β is defined as

$$\beta = \frac{2\pi f_0}{c}\sqrt{\varepsilon_e}, \quad (2)$$

where f_0 is the stopband center frequency, ε_e is the effective relative permittivity of the dielectric slab and c is the speed of light in free space.

Using the above expression, the period for any stopband frequency can be determined. The fundamental frequency of the standard BPF is at 7.5 GHz. So we designed UPBGSs to suppress the signal propagating around 15 GHz.

The closed-form expression of the equivalent circuit and the dimension can be extracted from the standard microstrip line filter synthesis [20]. Numerical validity of the performance of the PBG-engineered structures can be achieved with immitance approach [21]. The PBG engineered structures can be modeled as π or T-networks. The equivalent circuit parameters can be extracted via ABCD parameters as the ABCD parameters are related with the series impedance and shunt admittance of the π or T-networks in the following manner:

$$Z_1 = (A-1)/C, \quad (3)$$

$$Z_2 = (D-1)/C, \quad (4)$$

$$Z_3 = 1/C, \quad (5)$$

$$Y_1 = (D-1)/B, \quad (6)$$

$$Y_2 = (A-1)/B, \quad (7)$$

$$Y_3 = 1/B. \quad (8)$$

The *S*-parameters can be found from the simulated or measured performances. The *S*-parameters can also be numerically calculated via full-wave analysis as return and insertion loss can be explained as the ratio of scattered field to incident field.

The *S*-parameters and ABCD constants are related in the following manner:

$$A = ((1+S_{11})(1-S_{22}) + S_{12}S_{21})/2S_{21}, \quad (9)$$

$$B = Z_0((1+S_{11})(1+S_{22}) - S_{12}S_{21})/2S_{21}, \quad (10)$$

$$C = (1/Z_0)(1-S_{11})(1+S_{22}) - S_{12}S_{21})/2S_{21}, \quad (11)$$

$$D = ((1-S_{11})(1+S_{22}) + S_{12}S_{21})/2S_{21}. \quad (12)$$

Eqs. (3)–(12) are very useful to extract the equivalent circuit parameter of any PBG-engineered structures simulated by EM software.

In the work the initial values are calculated based on the theory and the design is optimized with method of moment-based commercially available software Zeland IE3D.

3. Designs

We have designed a conventional 3-row circular patterned PBGSs to be etched under the standard 50 Ω transmission line. Then we have designed 1-D uniform circular patterned PBGSs to be etched under the same line. We have used Taconic substrate with dielectric constant of 10 and height of 25 mils. We are implementing uniform circular PBGSs to form different models. Finally, we implemented circular patterned 1-D uniform circular PBGSs under all the lines of an asymetric coupled line BPF.

3.1. Microstrip line with uniform circular PBGSs

The 50 Ω line over conventional 3 rows uniform circular PBGSs is shown in Fig. 1. This is infact 2-D uniform circular PBGSs as stated [22]. Total number of PBG elements are 27.