Literature Review for the Project Topic "Design and comparison of a straight microstrip line and a periodic EBG structure microstrip line in HFSS"

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Abstract

This project aims at studying a straight electromagnetic bandgap (EBG) microstrip structure with *four* square patches inserted in the microstrip line at a period of length *a* (Fig.1). Comparisons with a straight microstrip line of the same length will be performed with respect to parameters such as, signal integrity, stop band performance, and applicability to monolithic circuits.

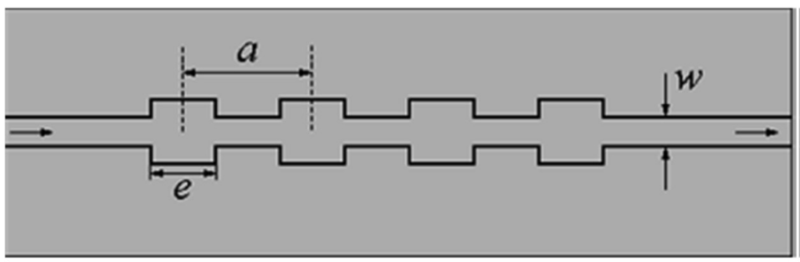


Figure 1. Straight EBG microstrip structure

Literature Review

[1] Nagesh, E., "Photonic Band Gap Studies at Microwave Frequencies", PhD Thesis, 2006, Indian Institute of Technology, Madras

This thesis studies the root causes behind the PBG behavior and the factors responsible for it. A PBG region is specifically defined as a range of frequencies over which the propagation of electromagnetic waves is forbidden. The formation of the band gap can be explained basically by two reasons: -

(1) The electromagnetic waves travelling through structures having periodic arrangement of dielectric or magnetic materials, experience a periodic variation of dielectric permittivity or magnetic permeability, similar to the periodic potential energy of an electron in an atomic crystal. Therefore, like the electronic state in an atomic crystal, the photonic state in a photonic crystal can be classified into bands and gaps.
(2) The electromagnetic waves scattered by these periodic structures form secondary sources, which interfere destructively (see Bragg Refraction condition in [3]) at the incoming power junction for certain frequency regions.

The main parameters that control the stop band can be outlined as: -

(1) Periodicity of the geometric arrangement
(2) Dielectric/impedance/effective refractive index constant
(3) Filling fraction (defined in [4])

(4) Geometry of the periodic structure

The major conclusions of this study were the following: -

(1) Microwave band gap structures can be constructed even with materials having low dielectric constants. An appreciable value of gap width can be obtained by properly choosing the lattice spacing.
(2) It is important to consider both refractive index (n) and impedance (η_0) of the material to analyze gap width and central frequency.

[2] Lancaster, G., "A tuneable EBG Microstrip Filter", PhD Thesis, 2013, California Polytechnic State University, San Luis Obispo

One of the sections in this thesis, deals with the quantitative explanation of the "band-gap" effect. When an incident wave encounters a boundary of two dielectric media, the wave is partially transmitted and partially reflected. The reflection and transmission coefficients may be calculated by applying EM boundary conditions at the dielectric boundary. According to Maxwell's equations, electric and magnetic fields have the following relationship:

$$B_0 = \frac{\hat{k} \times E_0}{v}$$

where:

E_0 = Electric Field Magnitude;

B_0 = Magnetic Field Magnitude;

$\hat{k}$ = unit vector pointing in the direction of propagation

v = phase velocity = $\frac{\omega}{k} = \frac{c}{\sqrt{\epsilon}}$

ω = angular frequency;

k = wavenumber = $\frac{2\pi}{\lambda_g} = \frac{\omega}{c}\sqrt{\epsilon}$;

ϵ = effective dielectric constant

Therefore, an incident wave propagating in the z-direction has electric and magnetic wave fields,

$$E(z,t) = E_i e^{j(k_1 . z - \omega t)} \hat{x}$$

$$B(z,t) = \frac{E_i}{v_1} e^{j(k_1 . z - \omega t)} \hat{y}$$

The reflected wave fields can be written as:

$$E(z,t) = E_r e^{j(-k_1.z-\omega t)}\hat{x}$$

$$B(z,t) = \frac{E_r}{v_1} e^{j(-k_1.z-\omega t)}\hat{y}$$

The transmitted wave fields can be written as:

$$E(z,t) = E_t e^{j(k_1.z-\omega t)}\hat{x}$$

$$B(z,t) = \frac{E_t}{v_2} e^{j(k_1.z-\omega t)}\hat{y}$$

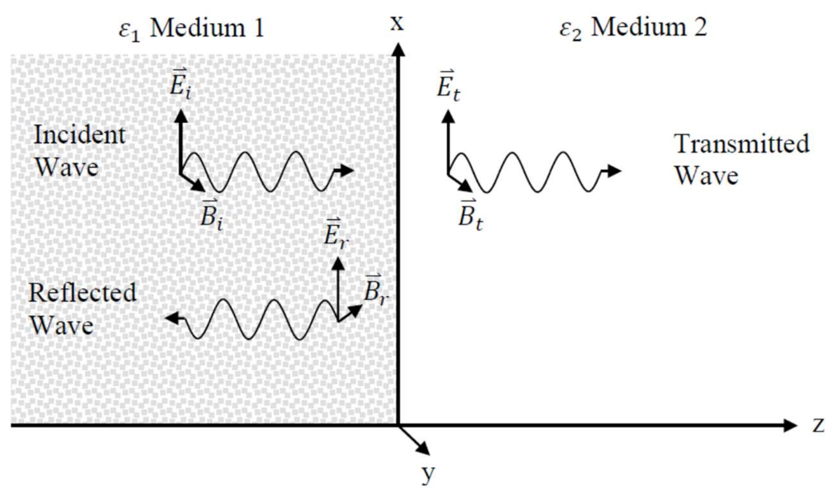


Figure 2. Incident and resulting reflected and transmitted waves at the boundary of two dielectric media

The reflection coefficient Γ and transmission coefficient T may be expressed as,

$$\Gamma = \frac{E_r}{E_i}$$

$$\mathrm{T} = \frac{E_t}{E_i}$$

Since the reflected and transmitted waves are produced from the incident wave,

$$E_i = E_r + E_t$$

By applying the boundary conditions, we have,

$$\frac{E_i - E_r}{v_1} = \frac{E_t}{v_2}$$

By substituting the velocity factor with its previously stated definition, we now have,

$$(E_i - E_r)\sqrt{\epsilon_1} = E_t\,\sqrt{\epsilon_2}$$

Normalizing the above equation with respect to the incident wave E_i, we have,

$$(1 - \Gamma)\sqrt{\epsilon_1} = \mathrm{T}\sqrt{\epsilon_2}$$

Finally, the reflection coefficient may be expressed in terms of the effective dielectric of the two materials,

$$\Gamma = \frac{\sqrt{\epsilon_1} - \sqrt{\epsilon_2}}{\sqrt{\epsilon_1} + \sqrt{\epsilon_2}}$$

The transmission coefficient can be expressed as,

$$\mathrm{T} = \frac{2\sqrt{\epsilon_1}}{\sqrt{\epsilon_1} + \sqrt{\epsilon_2}}$$

These results imply that a large dielectric constant between the two materials yields a greater reflection coefficient, hence greater band-gap rejection. Also, since the reflection occurs at the interface of each periodic cell, it may be surmised that more periodic cells results in greater band-gap rejection.

[3] Falcone, F., Lopetegi, T., Sorolla, M., "1-D and 2-D Photonic Bandgap Microstrip Structures", Microwave Opt. Technol. Lett., vol. 22, Issue 6, pp. 411-412, September 1999

This paper examines 1-D and 2-D photonic bandgap (PBG) microstrip structures. PBG (or EBG) structures are those which exhibit a bandgap, i.e. a band of frequencies in which electromagnetic propagation is not allowed. Due to this frequency-selective property, they can be employed as a band of reflectors, obeying the Bragg reflection condition.

The straight EBG microstrip structure to be analyzed in our paper has to satisfy the Bragg reflection condition, expressed by the following equation:

$$\beta . a = \pi$$

where β is the wavenumber of the substrate material and a is the period of the structure. Since $\beta = 2\pi/\lambda_g$, where λ_g is the guided wavelength corresponding to the center frequency of the stopband f_0, the center frequency is decided by

$$f_0 = \frac{c}{2a\sqrt{\epsilon_{eff}}}$$

where c is the speed of light in free space, and ϵ_{eff} is the effective dielectric constant.

[4] Radisic, V., Coccioli, R., "Novel 2-D Photonic Bandgap Structure for Microstrip Lines", IEEE Microwave and Guided Wave Lett., vol. 8, Issue 2, pp. 69-71, February 1998

This paper examines a novel 2-D lattice arrangement PBG structure for microstrip lines, in which a periodic 2-D pattern consisting of circles is etched in the ground plane of the microstrip line as shown in Fig. 2.

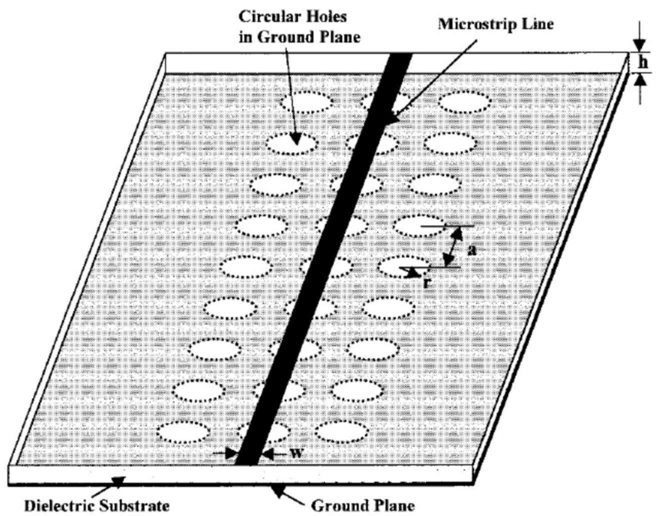


Figure 3. 3-D view of the proposed 2-D PBG structure. The lattice circles are etched in the ground plane of a microstrip line

A parameter involving the ratio of the circle radius r and the period of the lattice structure a was varied, and the stopband performance was analyzed. For small circle radii ($r/a \rightarrow 0$), there is no stopband, and the structure is a standard microstrip line. As, the circle radius is increased, the stopband becomes more distinctive. A tradeoff is that for a very large r/a factor, the ripple in the passband is also increased as shown in Fig. 3.

Based on this paper, we see that for $\frac{r}{a} = 0.25$ (Fig. 3b), we see a significant stopband depth, and very little or no passband ripple in S_{11}. Comparing this to our design of the straight EBG microstrip structure, we would ideally want to choose the edge of the inserted square patch, e, to be equal half of the period ($e = a/2$), which is equivalent to an optical filling factor of 0.25 (Fig. 1).

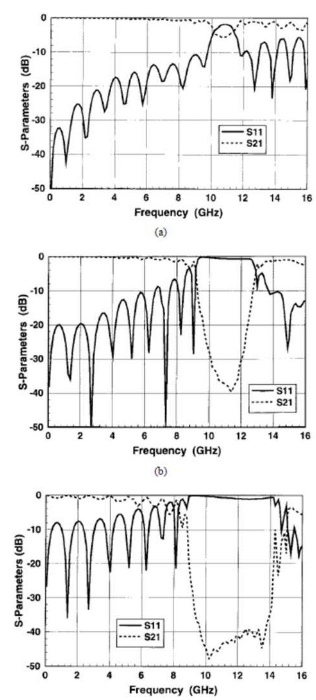
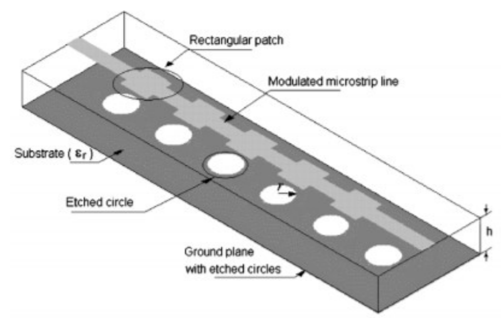


Figure 4. Measured S-parameters for the PBG microstrip transmission line. The ground plane has a square lattice with 3 x 9 etched circles. The hole radius is (a) r = 25 mil, (b) r = 50 mil, and (c) r = 90 mil. The period a is 200 mil for all cases

[5] Tapered Dual-Plane Compact Electromagnetic Bandgap Microstrip Filter Structures IEEE Trans. Microw. Theory Tech., vol. 53, no. 9, pp. 2656–2664, Sep. 2005.

This paper discusses the designs of two novel tapered dual-plane compact electromagnetic bandgap (C-EBG) microstrip filter structures are presented. With the dual-plane configuration, the proposed structure displays an ultrawide stopband with high attenuation within a small circuit area. Chebyshev distribution is adopted to eliminate ripples in the passband caused by the periodicity of the EBG structure. This gives rise to a compact EBG structure that exhibits excellent transmission and rejection characteristics in the passband and the stopband, respectively.



This paper discusses the effect on stopband performance of S21 with variation of the alignment of Central axis of the etched circles on ground plane wrt the longitudinal axis of the Microstrip (d^1) and also the distance between the etched circle and patch (d). The expected response are as shown below.

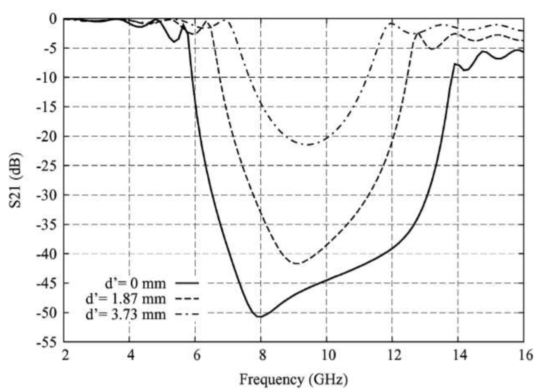


Fig. 2. Simulated S_{21} parameters of the dual-plane C-EBG structures with a varying d' and $d = 5.18$ mm.