DESIGN AND ANALYSIS OF MICROSTRIP LINES WITH EBG-BACKED GROUND PLANES OF DIFFERENT GEOMETRICAL SHAPES

Sreedevi K Menon, K. Vasudevan, C. K Aanandan, and P. Mohanan
Centre for Research in Electromagnetics and Antennas (CREMA)
Department of Electronics
Cochin University of Science & Technology
Kochi–682 022, India

Received 8 March 2005

ABSTRACT: *Propagation of electromagnetic waves through a microstrip line with 2D electromagnetic band gap (EBG) structures of different geometrical shapes in the ground plane is investigated in this paper. Using transmission-line theory. the design equations for EBG structures* *are calculated. The measured, numerical, and simulated results are in good agreement.* Microwave Opt Technol Lett 46: 544–546, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21044

Key words: *electromagnetic band gap (EBG) structures; microstrip transmission line; transmission-line theory*

1. INTRODUCTION

Propagation of electromagnetic waves through microstrip line can be manipulated and controlled by electromagnetic band gap (EBG) structures in the ground plane, as they exhibit both passband and stop-band in their frequency spectrum. The main attraction of EBG is that it can simultaneously act as filter [1] and can enhance antenna radiation properties significantly [2] for a certain frequency band.

In this paper, EBG structures that exhibit wide stop-band without an increase in the size of the unit cell are presented. Slots of six different geometrical shapes having the same area and period are studied in detail. The analysis and synthesis of these structures are conducted using transmission-line theory.

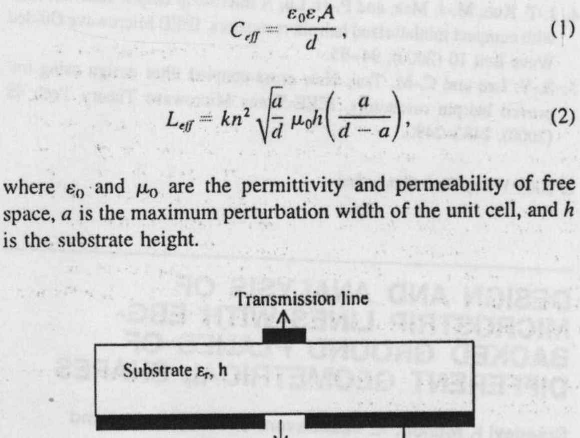
2. DESIGN OF MICROSTRIP EBG CELL

A model to design and analyze EBG structures having the etched periodic pattern of any arbitrary shape using transmission-line theory is presented. According to transmission-line theory, if the values of inductance L and capacitance C are varied periodically, the transmission line can exhibit band stop characteristics. So it is possible to derive an $L - C$ equivalent circuit for the EBG cell and, by connecting identical cells in series, the periodic structure will exhibit band-stop characteristics. The effective capacitance C_{eff} and inductance L_{eff} of the EBG-backed transmission line with n number of cells of any arbitrary area A and periodicity d on a substrate with dielectric constant ε_r is given by

$$C_{eff} = \frac{\varepsilon_0 \varepsilon_r A}{d} \tag{1}$$

$$L_{eff} = kn^2 \sqrt{\frac{a}{d}}\, \mu_0 h \left(\frac{a}{d-a}\right), \tag{2}$$

where ε_0 and μ_0 are the permittivity and permeability of free space, a is the maximum perturbation width of the unit cell, and h is the substrate height.



(a)

(b)

Figure 1 (a) Transmission line with EBG backing; (b) different unit cells used as EBG structures

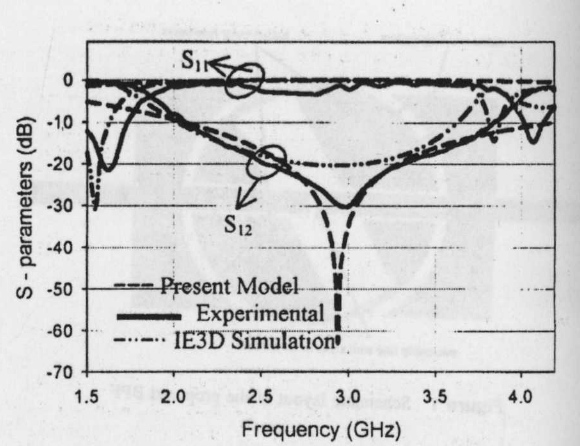


Figure 2 Stop-band characteristics for the 2D square lattice in the ground plane ($\varepsilon_r = 4.7$, $h = 1.6$ mm, $d = 30$ mm, $n = 3$, $A = 176.625$ mm^2)

The correction factor k is calculated as

$$k = 1.25 \text{ for } \varepsilon_r \leq 6,\ k = 1.2 \text{ for } 6 \leq \varepsilon_r \leq 9.8, \text{ and } k = 0.74 \text{ for } \varepsilon_r \geq 9.8. \tag{3}$$

Then the stop-band center frequency can be calculated from the equation,

$$f_0 = \frac{1}{2\pi\sqrt{L_{eff}C_{eff}}} \tag{4}$$

and the − 10-dB bandwidth is given as

$$\Delta f = f_0 \frac{\sqrt{\dfrac{L_{eff}}{C_{eff}}}}{\eta}, \tag{5}$$

where η is the characteristic impedance of free space.

The lower and upper frequencies are then given by

$$f_1 = f_0 - \frac{\Delta f}{2}, \tag{6}$$

$$f_2 = f_0 + \frac{\Delta f}{2}. \tag{7}$$

These equations facilitate the process of predicting the frequency response if the physical parameters are known or vice versa.

3. EXPERIMENTAL ANALYSIS

In this paper, 50Ω microstrip transmission lines with different geometrical EBG structures having the same area and period in the ground plane are studied. The EBG-backed transmission line is shown in Figure 1(a). The different unit cells used in the study are shown in Figure 1(b). The substrate used for the present study has a dielectric constant of $\varepsilon_r = 4.7$ and thickness $h = 1.6$ mm. The area and period of the geometrical slots are kept constant as follows: area $A = 176.625$ mm^2 and period $d = 30$ mm. The transmission characteristics of the periodic patterns predicted using the equations mentioned in section 2 are validated via IE3d simulation and experiment. The stop-band characteristics obtained for

TABLE 1 −10-dB Bandwidth Obtained for Different Slot Geometries (ε_r = 4.7, h = 1.6 mm, d = 30 mm, n = 3, A = 176.625 mm^2)

Slot Geometry	Stop-Band		
	Experimental	IE3D	Predicted
Circle	2.05–3.765	2.1–3.675	2.04–4.23
Cross	2.015–3.66	2.2–3.65	
Diamond	2.085–3.835	2.1–3.742	
Hexagon	2.015–3.94	2.05–3.62	
Square	2.05–3.730	2.0–3.575	
Triangle	1.98–3.8	2.0–3.85	

the 2D square lattice in the ground plane is shown in Figure 2. For all the periodic structures, the S-parameter characteristics show almost identical behavior, as compared with those of the circular patterns. The simulated values of the cutoff frequency and −10-dB bandwidth are found to be in good agreement with the predicted values and these results are given in Table 1. The slight change in the −10-dB bandwidth for different geometries may be due to the area approximation taken for the simulation and experiment.

Variation of the stop-band center frequency with dielectric constant is studied. The results obtained from the IE3D simulation are compared with the numerically predicted values and are depicted in Figure 3. The predicted and simulated −10-dB bandwidths are shown in Table 2.

4. CONCLUSION

An equivalence relation has been derived between the EBG parameters and the effective capacitance and inductance of the perturbed microstrip transmission line. The frequency response obtained via simulation, experiment, and numerical calculation are in good agreement, and thus validates the present design and analysis approach. S_{11} is found to be ~0 dB in the entire −10-dB stop band of S_{21}, which shows that there is little radiation loss and thus confirms the EBG property in the design and analysis. Although the relations obtained are implemented for band gaps centered around 3 GHz, the validity of this relation can be extended to other frequency ranges and substrates.

ACKNOWLEDGMENT

Sreedevi K Menon acknowledges Council of Scientific and Industrial Research (CSIR), India, for the award of a Senior Research Fellowship.

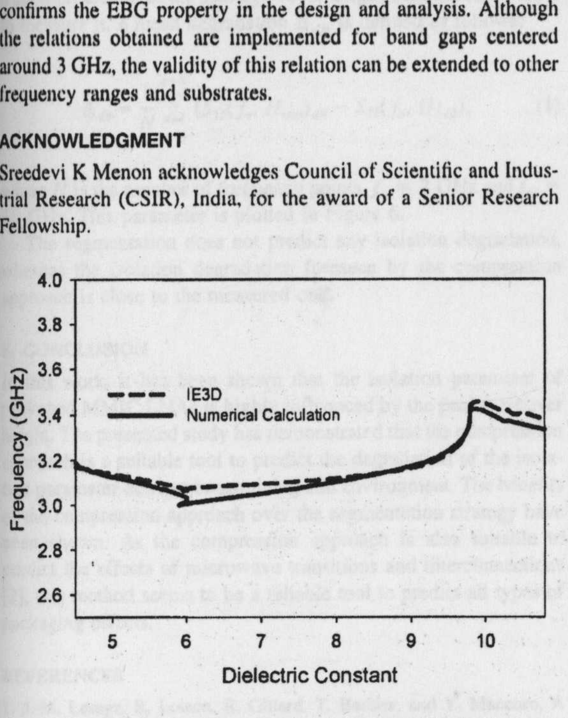


Figure 3 Variation of stop-band center frequency with dielectric constant for A = 157 mm^2

TABLE 2 Predicted and Simulated −10-dB Bandwidths $A = 157\ \mathrm{mm}^2$

	−10-dB Bandwidth	
Dielectric Constant	Numerical Calculation	IE3D
4.5	2.239–4.148	2.22–3.93
4.8	2.218–4.066	2.1–3.52
6	2.207–3.859	2.28–3.85
9.2	2.525–3.859	2.52–3.76
9.8	2.769–4.063	2.6–3.78
10.2	2.749–4.017	2.74–3.79
10.4	2.738–3.994	2.925–3.775
10.6	2.728–3.972	2.96–3.78
10.8	2.719–3.951	2.98–3.78

REFERENCES

1. V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, Novel 2D photonic bandgap structure for microstrip lines, IEEE Microwave Guided Wave Lett 8 (1998), 69–71.
2. R. Coccioli, F.-R. Yang, K.-P. Ma, and T. Itoh, Aperture-coupled patch antenna on UC-PBG substrate, IEEE Microwave Guided Wave Lett 47 (1999), 2123–2130.