Enrichment of EBG Contents of Periodic Structures by Geometry Modulation

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Abstract – **Designing periodic structures with novel properties related to propagation of electromagnetic waves presents interest for applications in antenna technology, dispersion engineering, filtering, signal integrity etc. We consider a periodic structure built in stripline technology and assess the effect of geometry modulation on the dispersion diagram, including newly introduced modes and electromagnetic band-gaps. We relate the dispersion diagrams of the modulated and unmodulated structures. Results present interest for applications in the above mentioned fields.**

1 INTRODUCTION

Surfaces consisting of 2D periodic repetitions of unit cells that contain one or more metallic patches can be readily constructed in microstrip or strip-line technology [1]. If the surface is embedded between two dielectric layers and one or two metal planes border the sides of the structure, an inhomogeneous parallel-plate waveguide is obtained. Bloch waves are conducted in the parallel-plate waveguide at all frequencies. In order to stop the propagation of electromagnetic waves in one or more frequency bands, called electromagnetic bandgaps (EBGs), the metal patches from the unit cells must be connected to one of the metal planes (or both [2]) by one or several vias with metal walls. Such structures have found applications in antenna technology, multiband filtering, signal integrity in high speed circuits and various other situations for solving dispersion engineering related problems [3].

Periodic structures are used in various science and technology fields, such as Solid State Physics [4] and Optics [5]. Many applications from these fields have counterparts in Applied Electromagnetics. In this paper, we consider the possibility of enriching the EBG of periodic structures by modulating a geometrical parameter of the unit cell of the periodic structure. This possibility has been tackled in a microwave demonstration of band-splitting following modulation in [6], where the goal was to obtain the so-called "Hofstader Buttrefly" which is of interest to the quantum Hall effect. Our purpose is to exploit the geometry modulation for creating structures with EBG contents that can be tailored for meeting requirements of multiband filtering.

In order to demonstrate the creation of new EBGs by geometry modulation, we have chosen a basic structure that presents a dispersion diagram (DD) [7] with several modes that are separated by large EBGs. The large separation is achieved by a special design that introduces a sufficient number of resonance. The unit cell consists of three separate patches and two vias. We calculated the DDs associated with the unit cell for various material parameters of the dielectric layers that enter the composition of the structure by means of a commercial field solver [8]. The parametric data obtained in this way allow for gaining some insight into the electromagnetic behavior of the basic geometry build with technologically meaningful constitutive parameters. We then modulated the geometry by changing a geometrical parameter every other unit cell of the original structure in one of its principal directions. In this way, the modulated surface has a unit cell that is twice as large as the original one. We calculated the DDs of the new structure along the chosen direction and related it to the original DD, pointing out the band-splitting phenomenon. We then repeated the modulation process and the DD calculation by combining groups of three unit cells from the original structure. The results obtained by performing these operations are presented below.

2 THE BASIC STRUCTURE

The basic structure has been introduced in the past in view of filtering applications [9]. We review the DD of the structure since the dimensions of the patches have been changed in the present context and we report the EBG contents in table form.

The unit cell of the unmodulated structure is represented in Fig. 1 (a). It has the shape of a square with an edge d=2.5 mm. The center rectangular metallic patch has an edge parallel to the x axis of 0.9 mm and an edge parallel to the y axis of 1.5 mm, with

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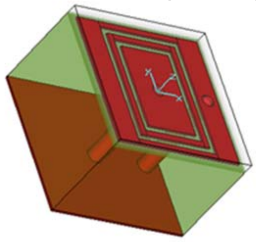
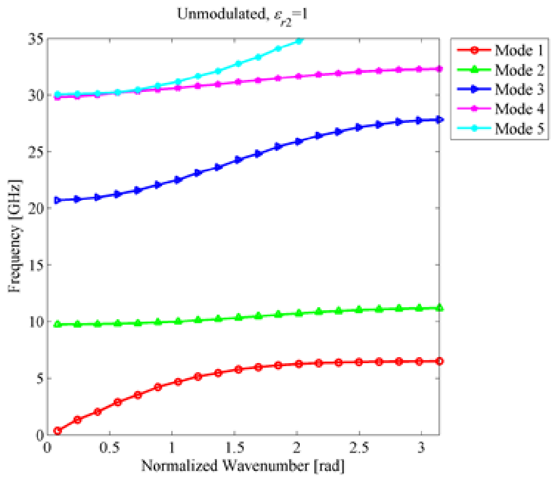
respect to the reference frame in Fig. 1 (a). The center of the patch is connected to the ground plane through a cylindrical via with metallic walls, of radius r=0.1 mm. The radius of this via will be subjected to modulation later in the manuscript. Two other hollow, rectangular patches have been impressed on the board. The inner one has a width of 0.1 mm in both directions and it is separated from the center patch and from the outer patch by 0.1 mm wide strips where metallization is absent. The outer patch has the metal strip parallel to the x axis 0.1 mm wide and the one parallel to the y axis 0.4 mm wide. The last one accommodates another via of radius 0.1 mm, placed at x=0.95 mm and y=0. The thickness of the metal sheets is 0.035 mm. This configuration of patches and vias has been selected after several trials as its EBG structure proved convenient for experimenting with the geometry modulation.



(a)



(b)

Figure 1: (a) Unit cell of the unmodulated structure. (b) DD for waves propagating parallel to the x axis.

The simulations above have been repeated for various values of the dielectric constant ε_{r2}. The results are reported in Table 1. The frequency bounds and the widths of the EBGs decrease when the dielectric constant increases, which is a normal behavior for such structures [10].

In the next section, we present the effect of geometry modulation on the DD.

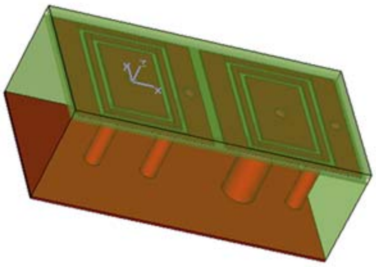
ε_{r2}	EBG1	EBG2	EBG3
1	6.49.. 9.74 (3.25)	11.19.. 20.71 (9.52)	27.83..29.81 (1.99)
3	5.73..8.60 (2.87)	9.32.. 18.87 (9.55)	23.44.. 27.62 (4.18)
5	5.46.. 8.20 (2.73)	8.75.. 18.17 (9.42)	21.95.. 26.67 (4.72)
7	5.33.. 7.99 (2.66)	8.47.. 17.79 (9.32)	21.21.. 26.16 (4.96)
9	5.25.. 7.86 (2.62)	8.30.. 17.56 (9.26)	20.76.. 25.85 (5.09)
11	5.19.. 7.78 (2.59)	8.19.. 17.41 (9.22)	20.46.. 25.64 (5.18)

Table 1 Frequency bounds and widths (in brackets) for the EBGs of the unmodulated structure (GHz)

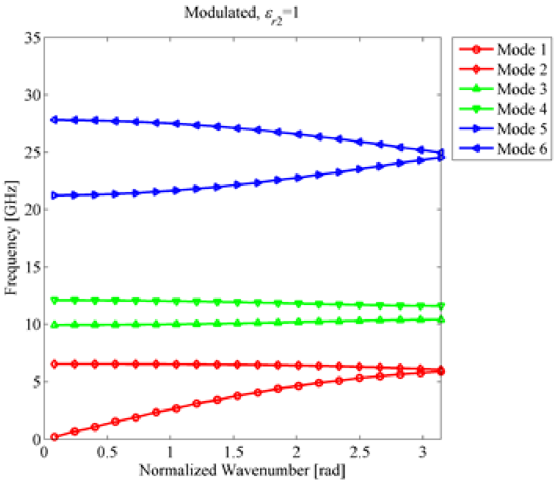
3 GEOMETRY MODULATION

Starting from the geometry introduced in the preceding section, we have increased the radius of the central via in each other unit cell in the x direction from r_1=0.1 mm to r_2=0.2 mm and kept the other parameters constant. This can be considered as a binary geometry modulation in the x direction, Fig. 2 (a). In this way, the dimension of the unit cell in the x direction has been doubled, while that in the y direction has remained the same. The DD corresponding to the binary modulated structure for an upper dielectric layer with ε_{r2}=1 is reported in Fig. 2 (b). Only the first six modes have been considered. However, we have kept the frequency span as in Fig. 1 (b) in order to provide a convenient way for comparing the two DDs. The normalization of the wavenumber on the horizontal axis of Fig. 2 (b) has been made with respect to the new dimension of the unit cell in the x direction, namely 5 mm. By comparing Figs. 2 (b) and 1 (b), it can be concluded that modes 1 and 2 of the modulated structure occupy approximately the same frequency band like mode 1 of the unmodulated one and the same is true for modes 3, 4 and mode 5, 6 in Fig. 2 (b) with respect to mode 2 and mode 3 in Fig. 1 (b) respectively. Furthermore, mode pairs in Fig. 2 (b) have opposite monotonicity and a new EBG occurs in between.

In order to demonstrate that the above presented relation between modes of the unmodulated and modulated structures is not a singular case, we have reported in Figs. 3 (a) and (b) the DDs corresponding to these structures for ε_{r2}=3. It can be seen that the same relation between the first three modes in Fig 3 (a) and the first six modes in Fig. 3 (b) is retrieved.



(a)



(b)

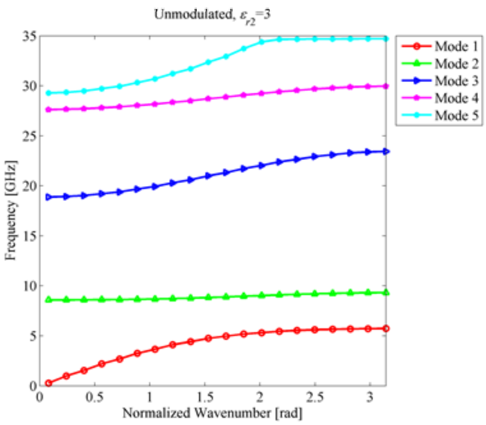
Figure 2: (a) Structure with binary geometry modulation and ε_{r2}=1. (b) DD for the structure in (a)

The EBGs that are obtained with the binary modulated structure for various values of the dielectric constant of the upper layer are listed in Table 2. EBGs 2, 4 and 6 in Table 2 are close to EBGs 1, 2 and 3 of Table 1, while EBGs 1, 3 and 5 have been introduced by geometry modulation.

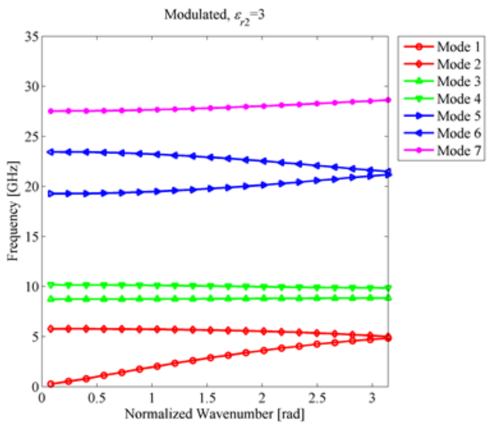
In order to get further insight on the impact of geometry modulation of the EBG contents, we calculated DDs for ternary modulation, by forming new unit cells consisting of groups of three unit cells from the unmodulated structure in the *x* direction. The geometrical parameter to be modulated has been again the radius of the central via. The succession of radii in Fig. 4 (a) has been 0.1, 0.1 and 0.2 mm (case 1), while that in Fig 5 (a) has been 0.05, 0.1 and 0.15 mm (case 2). In both cases, the dielectric constant of the upper layer has been ε_{r2}=1. The corresponding DDs are reported in Figs. 4 (b) and 5 (b) respectively. In both cases, modes are grouped by three and marked according to modes of the unmodulated structure, Fig. 1 (b). Each group of three modes occupy approximately the same frequency band as the corresponding mode of the unmodulated structure, the monotonicity alternates and EBGs are introduced in between. This indicates the existence of a pattern in the formation of modes and EBGs following modulation, which can be inferred easily from the discussion above.

ε_{r2}	EBG1	EBG2	EBG3	EBG4	EBG5	EBG6
1	5.88.. 6.05 (0.17)	6.56.. 9.95 (3.39)	10.42.. 11.60 (1.18)	12.10. .21.24 (9.13)	24.55.. 24.96 (0.41)	N/A
3	4.85.. 5.00 (0.15)	5.78.. 8.74 (2.96)	8.86.. 9.87 (1.01)	10.18.. 19.28 (9.10)	21.18.. 21.49 (0.31)	23.45.. 27.53 (4.08)
5	4.53.. 4.68 (0.14)	5.52.. 8.33 (2.81)	8.38.. 9.33 (0.96)	9.58.. 18.50 (8.92)	20.06.. 20.35 (0.28)	N/A
7	4.38.. 4.52 (0.14)	5.38.. 8.11 (2.73)	8.14.. 9.07 (0.93)	9.29.. 18.11 (8.82)	19.51.. 19.77 (0.27)	21.25.. 26.06 (4.81)
9	4.29.. 4.43 (0.14)	5.30.. 7.98 (2.69)	8.01.. 8.91 (0.91)	9.12.. 17.87 (8.75)	19.17.. 19.43 (0.26)	N/A
11	4.23.. 4.37 (0.14)	5.24.. 7.90 (2.65)	7.92.. 8.81 (0.89)	9.01.. 17.70 (8.69)	18.94.. 19.19 (0.25)	N/A

Table 2. Frequency bounds and widths (in brackets) for the EBGs of the binary modulated structure (GHz)

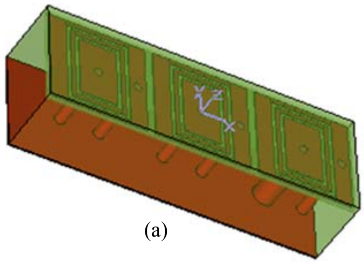


(a)

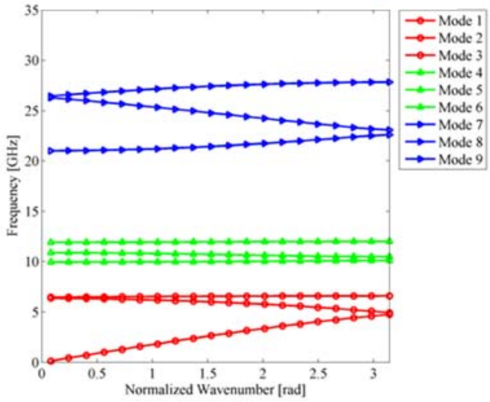


(b)

Figure 3: DDs obtained for a dielectric constant ε_{r2}=3: (a) unmodulated structure; (b) modulated structure

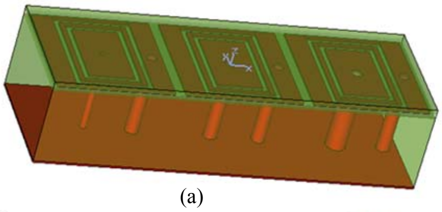


(a)

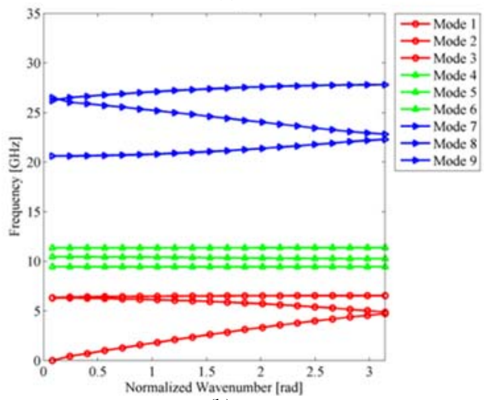


(b)

Figure 4. (a) Unit cell for ternary modulation, case 1. (b) DD for the unit cell in (a).



(a)



(b)

Figure 5. (a) Unit cell for ternary modulation, case 2. (b) DD for the unit cell in (a).

4 CONCLUSIONS

Using a 2D periodic structure built in stripline technology, we have demonstrated that EBG content featured by the DD of periodic structures is enriched following geometry modulation. The modulated structure resulted by grouping several cells of the original structure and altering in a periodic way the value of a geometrical parameter. As a result, every mode of the original DD has been split in a number of modes in the DD of the modulated case equal to the number of unit cells in the groups. Monotonous modes in the original DD give rise to monotonous modes in the new DD, with alternating monotonicity and occupying approximately the same frequency band. New EBGs are introduced by modulation.

Besides filtering applications, modulation can be used for various dispersion engineering applications since new modes with prescribed direction of the group velocity and occupying a smaller frequency span and new EBGs can be obtained.

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