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Suppressing Mutual Coupling of Microstrip Antenna with Photonic Band-Gap Substrate

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Abstract – **In this paper is made a simulative investigation of suppressing mutual coupling of microstrip antenna array with photonic band-gap substrate (PBG). PBG substrate to minimize surface wave effects is analyzed for a high ε_r of the substrate. Conventional PBG with drilled dielectric substrate and 2-D PBG microstrip antennas are compared. The received results can be used of design of microstrip antennas with low mutual coupling between the elements.**

Keywords – **Microstrip antennas, mutual coupling, surface wave, Photonic band-gap structures**.

I. Introduction

Surface wave propagation in dielectric substrates often negatively affects the performances of microwave and millimeter wave circuits. For instance, it may reduce the efficiency of planar antennas on high dielectric constant substrates or may produce unwanted coupling between different parts of circuits. It is difficult to evaluate this latter effect in the design stage since it can be accurately assessed only using computational intensive full-wave: numerical techniques to analyze the whole circuit[1].

Suppression of unwanted surface waves and control of their propagation is desirable not only to improve circuits performances. It can also lead to realization of antenna arrays structures, particularly use at millimeter wave frequencies where metallic losses in microstrips or coplanar waveguide become significant.

The surface waves excited in the process of radiation of these antennas are radiated more efficiently into the structure than the air side. This due to the fact of the substrate dielectric constant to be greater than the unit. Thus, the substrate works as a storage device of propagating modes on the ground plane of the antenna. If the interface between two media is perfectly plane, these waves will not contribute to the radiation process. However, the antenna edges, in this case, diffract or scatter the waves that reach there, giving origin to end-fire lobules.

Further more, if a system is formed by multiple antennas (array), all sharing the same substrate and ground plane, the currents that will come up, due to the conducting properties of the ground plane, may cause coupling of fields, which reduce even more the efficiency of the antenna.

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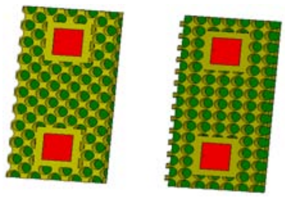
II. Design of Photonic Band Gap Substrate

Two different kinds of periodically loaded, grounded dielectric slabs have been investigated. The first kind is realized by drilling holes in the dielectric, while the second is with 2-D PBG structure with metal lattice.

The values of dielectric constant and thickness of grounded slabs used as substrates for microwave and millimeter waves circuits is such that only the fundamental TM_0 surface wave mode can propagate in the substrates when excited by discontinuities, or by planar antennas. Then, this is the mode that the designer may want to be able to forbid, without allowing propagation for the other modes at the same time. If we assume that f_0 is the center frequency of the desired stop-band so TM_0 can be suppressed by using triangular (fig.1 a) or square lattice of hole (fig. 1 b).



a b

Fig.1. Triangular lattice of holes 1a) and square lattice of holes 1b) in a grounded dielectric slab. The ground plane is not pierced;

The triangular lattice is chosen because it has proved capable, in the simpler case of a two-dimensional photonic crystal, of providing a stop-band for any in-plane direction of propagation due to the high symmetry of the Brillouin Zone (BZ) associated to it [2]. This latter is the hexagon shown in Fig. 2. The band-gap in the dispersion curves will show up at the edges of the BZ. We can focus our attention on the two directions of propagation corresponding to the edges ΓK and ΓM of the BZ. The gaps should appear at the vertexes M and K. Frequency values corresponding to a propagation vector pat points M or K are generally unknown for the actual periodic structure. In the case of small perturbations, i.e. for small values of the *R/a* ratio, they can be estimated using the propagation constant in the unperturbed structure.

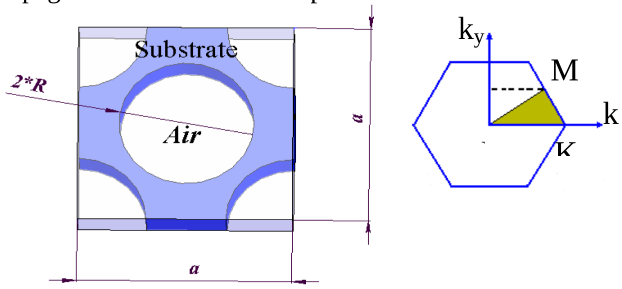


Fig. 2. Irreducible Brillouin zone in the ***k*** vector for triangular

Assessing the width of the band-gap is a more difficult task. However, the general trend is that the stronger the perturbation, the wider the band-gap. Thus, high values of the ratio are needed to realize substrates featuring a complete stop-band.

Another type structure is the 2-D PBG which will be analyzed (fig.3). It consists of four parts: a ground plane, a dielectric substrate, metallic patches, and connecting vias. This EBG structure exhibits a distinct stop-band for surface-wave propagation [3].

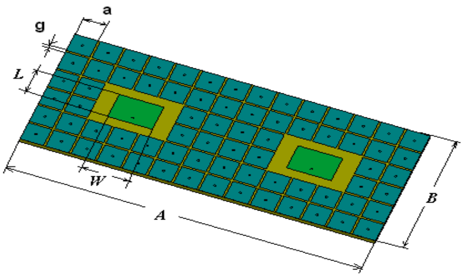


Fig.3 Two Elements microstrip antenna with 2-D PBG substrate

The operation mechanism of this EBG structure can be explained by an LC filter array: the inductor results from the current flowing through the vias, and the capacitor due to the gap effect between the adjacent patches. For an EBG structure with patch width, gap width, substrate thickness and dielectric constant, the values of the inductor and the capacitor are determined by the following formula [4]:

$$L = \mu_0 h \quad (1)$$

$$C = \frac{a(\varepsilon_1 + \varepsilon_2)}{\pi}.\cosh^{-1}\left(\frac{l}{g}\right) \quad (2)$$

$$\omega = \frac{1}{\sqrt{LC}} \quad (3)$$

where h is the high of the dielectric substrate, ε_1 and ε_2 relative dielectric permittivity of the air and substrate respectively, l is constant of lattice, g is the gap between patches of lattice and ω is the angular frequency.

III. Results

Two type antennas were designed one with PBG triangular lattice of holes (fig. 1a) and second planar PBG with 2-D metal rectangular lattice respectively (fig. 3). These antennas were optimized to suppress TM_0 mode of surface waves. The received results are compared with the classical microstrip antenna which is built on the same dielectric substrate.

The parameters of antenna with PBG triangular lattice of holes (fig. 1a) are the next: relative dielectric permittivity $\varepsilon_r = 10,2$; the normalize angular frequency $\omega_{norm} = a/\lambda = 0,23$; high of the dielectric substrate $h = 0,2a$; radius of the hole $R = 0,28a$;

The parameters of second structure (2-D metal lattice of patches, fig.3) are: width of patches $a = 3,26mm$; high of substrate $h = 1mm$; the gap between patches $g = 0,54mm$, $\varepsilon_r = 10,2$.

The microstrip resonators are placed in H-plane with distance between them $\lambda_0/2$.

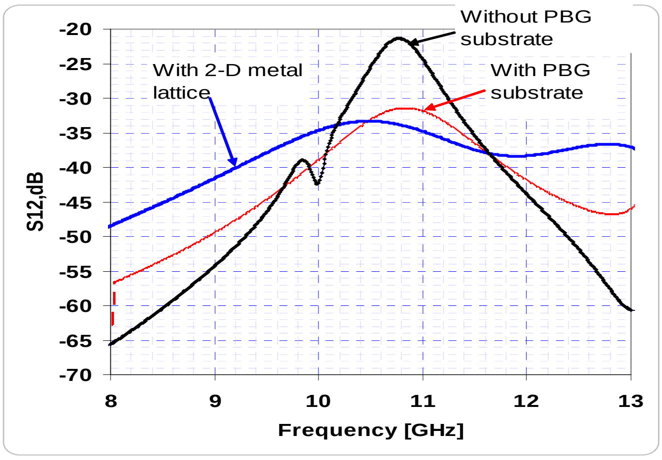


Fig.4. S-parameters of the tree microstrip antennas: the classical structure and antenna with triangular lattice of holes and with 2-D rectangular metal lattice

The mutual coupling results are shown in Fig. 4. Without the PBG structure, the antennas show a strong mutual coupling of 21 dB. If the PBG (EBG) structures are employed, the mutual coupling level changes. By using two kinds structure can by reached reducing of mutual coupling between the elements compared to the conventional antenna with above 10dB.

IV. Conclusion

In this paper, two type PBG structures are implemented in the design of microstrip antenna arrays to reduce the strong mutual coupling caused by the high permittivity substrate without sacrificing the compact size or bandwidth of the antenna elements. The PBG structures are analyzed using the FEM method. The strongest mutual coupling happens in the E-plane coupled antennas with high permittivity substrate due to the pronounced surface waves.

The PBG structure is then inserted around the antenna elements to reduce the mutual coupling. This mutual coupling reduction technique can be used in various antenna array applications.

References

[1]. H. Fernando, A. Roche, "Analysis of antennas wit PBG substrate", IEEE proceeding, MTT-IMOC 2003.

[2]. H. Rong, Z. Xuexia,"A novel 2-D PBG structure and its application in monopoles", 3rd International Conference on Microwave and Millimeter Wave Technology, Proceeding 2002

[3]. D. Debasis,Y. Ohashi,"A novel Electromagnetic Band Gap Metal Plate for Parallel Plate Mode Suppression in Shielded Structure," IEEE Microwave and Wireless Component Letters, vol. 12, No. 5, May 2002

[4]. D. F. Sievenpiper, "High-impedance electromagnetic surfaces," Ph.D. dissertation, UCLA, 1999.