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High Directivity at Broadside with New Radiators made of Dielectric EBG Materials

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Introduction

Electromagnetic Bandgap (EBG) materials have found possible applications in the antenna technology (see [1] as example) as substrates to improve performances like reducing mutual coupling between antennas or reduce side lobe effects due to truncated surface waves that would be excited in a standard antenna substrate. EBG substrates can also be used to eliminate scan blindness phenomena presented in array antennas [2], and in [3][4] EBG layers have also been used as a top cover of a Fabry-Perot Cavities to produce highly-directive radiators.

In this summary, two different kinds of EBG materials are considered that support slowly attenuating, very fast, leaky waves, such that they produce a narrow beam at broadside. Here, the EBG material is not used as a cover of a Fabry-Perot cavity, as in [3][4], but it is the EBG material itself that supports the excited leaky wave. The two proposed structures are planar and they are excited by a transverse elementary dipole, though other excitations like slots in the ground plane would lead to the same conclusions. The EBGs are made of only a dielectric material layer over a ground plane, though the same radiation performances could be achieved also without the ground plane in case an all-dielectric structure is required.

The proposed designs may lead to the following advantages: they can be made of only dielectric materials and they can be used at frequencies where metals have not negligible losses; they are planar and easy to build; they are excited by a single source so no complicated feeding network has to be designed; with a proper design very high directivity can be achieved, usually with the drawback of reduced frequency bandwidth.

Geometry of the EBG substrate

In Fig. 1 we show the two different EBG substrates of finite extent over a ground plane, both excited at the centre with a transverse short electric dipole. In Fig. 1(a), the first square EBG substrate, with 14 cm lateral size, consists of a certain number of Alumina dielectric rods inserted in a dielectric homogeneous host. In Fig. 1(b), the second square EBG substrate analyzed in this summary, with 5 cm lateral size, consists of high density homogeneous substrate with holes. A more detailed zoom of the basic cells of the two EBG substrates with square lattice is reported in Fig. 2. The first EBG material substrate in Fig. 2(a) is made of dielectric rods of Alumina ($\epsilon_r = 9.7$) embedded in Teflon material ($\epsilon_r = 2.1$), and the same structure has been used to design EBG waveguides in [7]. The second EBG material in Fig.2(b) is made of a ceramic ZrSnTiO_3 ($\epsilon_r = 37$) [8], with circular holes, also used in [2]. The dimensions of both structures are given in the

caption of Figure 2. There, a is the period of the rectangular lattice, r the radius of the Alumina rods or holes, and h is the height of the EBG substrate over the ground plane.

Fig.1(a): View of the EBG substrate made of square lattice of dielectric rods of Alumina in a Teflon host over a perfect electric conductor (PEC) plane.

Fig.1(b): View of the EBG substrate made of square lattice holes in a ceramic ZrSnTiO_3 host over a perfect electric conductor (PEC) plane.

Fig.2(a): Basic cell of the Teflon-Alumina EBG material over a perfect electric conductor: a (period)=1 cm, h (height) = 2 cm, r (radius of the Alumina rod) = 2 mm.

Fig.2(b): Basic cell of ceramic ZrSnTiO_3 EBG material over a perfect electric conductor: a (period)= 2.5 mm , h (height) = 4.5 mm, r (radius of the hole) = 1.078 mm.

Radiation patterns of short dipole inside the EBG substrates

An analysis in terms of dispersion diagram of both substrates in Fig. 1 has been carried out with the commercial software CST Microwave Studio and it is not reported here for space constraints. It is possible to obtain a complete bandgap for surface wave propagation along the substrate for the first EBG by properly choosing the height h and radius of the alumina rods. For the height considered in Fig.2(b), the second EBG substrate does not have a complete stop band since one type of polarized surface wave can still propagate though its effect can be strongly attenuated by using two exciting dipoles at a proper distance. Unfortunately CST Microwave Studio cannot be used to analyze the dispersion of leaky waves supported by the structure with open space over the substrate. The existence of leaky waves is inferred by analyzing the far field and recognizing some particular features proper of such waves. The difficulty is to find an operational frequency such that the leaky wave produces the desired directive radiation pattern, while being in the middle of a surface wave bandgap. The reciprocity theorem is used

to study the far field produced by the elementary dipole: the electric field, at different frequencies and at two observation points inside the basic cell is calculated when an incident wave plane impinges on the periodic EBG substrate of infinite extent, from a direction orthogonal to it; by reciprocity, the field evaluated, at the surface, or in the middle of the substrate, is equivalent to the far field excited by an electric short dipole placed inside the EBG material.

The radiated electric field at broadside by a transverse dipole placed inside the two EBG substrates of infinite extent is depicted in Figs. 3(a) and (b) for various frequencies; the units are arbitrary because they need to be multiplied by a proper coefficient given by the reciprocity theorem. The cases considered have the radiating dipole at a height h (dipole at the surface) and at $h/2$ (dipole in the middle). In Fig.3(a), a strong field at broadside is achieved for frequencies around 18.3 GHz when the substrate is excited in the middle, while in Fig 3(b), for the ceramic ZrSnTiO_3 case, a peak of the field is evident for frequencies around 5 and 14 GHz, especially when the excitation is in the middle of the substrate. In both cases the peaks of the field are likely to be associated to leaky waves excited in the EBG materials (see [9] for similar trends).

Fig.3(a): E-field at broadside, for the substrate depicted in Fig.1(a), at two different positions of the excitation. An arbitrary units is used.

Fig.3(b): E-field at broadside, for the substrate depicted in Fig.1(b), at two different positions of the excitation. An arbitrary units is used.

Next, a study is carried out for short dipoles in the middle of a the substrates of finite extent shown in Fig. 1. The E- and H-planes around 18.3 GHz for the case of Fig 1(a), and around 14 GHz for the case of Fig 1(b) are shown in Fig. 4. The E- and H-planes are reported from $\theta = 0^\circ$ to $\theta = 90^\circ$ because of the symmetry with respect to $\theta = 0^\circ$. In Fig. 4(a), a narrow beam at broadside is achieved for the three frequencies shown, for the geometry of Fig.1(a). In Fig. 4(b), some directivity is achieved at broadside, for the geometry of Fig.1(b). The EBG substrate made of Teflon and Alumina (Fig.4(a)) supports a leaky wave that is slowly attenuated since the directivity achieved at broadside is quit high. In Fig.4(b), the interpretation is more involved since the substrate is small in terms of free space wavelengths and truncation effects are important because there the leaky wave is not sufficiently attenuated.

Conclusions

We have demonstrated that in two types of dielectric EBG materials made of rods or holes inside a homogeneous host substrate of finite height, it is possible to generate a narrow beam in the broadside direction. This phenomenon is likely to be associated to the excitation of slowly attenuating and very fast leaky waves supported by the composite EBG substrate. In this way a large field “aperture” with a slowly varying phase is created that produces high directivity.

Fig. 4a: Radiation pattern on E- and H-planes for the substrate shown in Fig.1(a) when an electric short dipole is placed in the middle of the substrate. Fig. 4b: Radiation pattern on E- and H-planes for the substrate shown in Fig.1(b) when an electric short dipole is placed in the middle of the substrate.

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