Ku BAND ELECTROMAGNETIC BANDGAP ANTENNAS

Andrew R. Weily(1), Karu P. Esselle(1), Barry C. Sanders(2),(3), and Trevor S. Bird(4),(5)

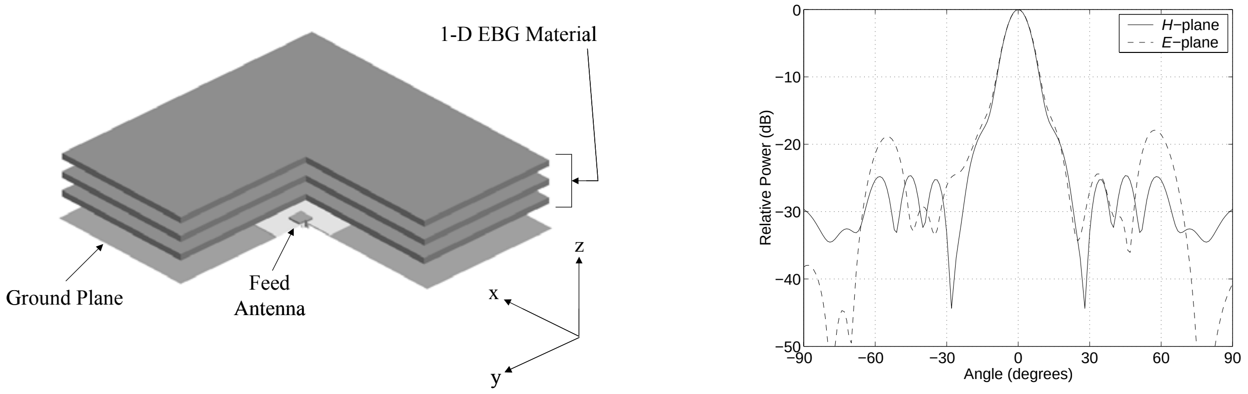
(1)Department of Electronics, Macquarie University, Sydney, NSW 2109, Australia
Email: aweily@ics.mq.edu.au
(2) Centre of Excellence for Quantum Computer Technology, Macquarie University, Sydney, NSW 2109, Australia
(3)Institute for Quantum Information Science, University of Calgary, Alberta T2N 1N4, Canada
(4)CSIRO ICT Centre, PO Box 76, Epping, NSW 1710, Australia
(5)Visiting Professor at the Dept. of Electronics, Macquarie University, Sydney, NSW 2109, Australia

ABSTRACT

Electromagnetic bandgap (EBG) materials, also known as photonic crystals, have created new innovative methods for controlling the electromagnetic behaviour of antennas and other electronic devices. Created from periodic dielectric and/or metallic structures these materials are characterized by a band of frequencies where no propagating modes exist, known as the EBG. In different implementations, the EBG properties may be used to guide, filter, store, reflect or collimate electromagnetic waves. In this paper we provide a brief review of several EBG antenna designs from our research, describe their operation, and highlight the advantages and potential applications of each device.

INTRODUCTION

Since the introduction in 1987 of the concept of omnidirectional electromagnetic bandgaps in two and three dimensions there has been a tremendous amount of research on EBG materials [1]. A large number of devices operating from microwaves to optical frequencies that use EBG technology have been presented. Some applications recently reported at microwave and millimeter wave frequencies include antennas, waveguides and filters [2]. EBG antennas operating at microwave frequencies can be broadly grouped into four different categories: (1) antennas with EBG substrates that reduce surface waves and increase radiation efficiency [3]; (2) antennas that use EBG materials as reflectors [4]; (3) EBG resonator antennas that create high directivity via the angle dependent properties of the EBG material [5-8]; and (4) directive EBG horn antennas that use EBG materials to create the tapered walls of the antenna [9]. In this paper, we present theoretical results on EBG antennas from our research that fit into categories (3) and (4). These antennas exploit the properties of both 1D and 3D EBG materials, where these materials are periodic in one- and three-dimensions respectively. We examine two configurations of high gain 1D EBG resonator antennas. The first configuration is linearly polarized (LP) while the second uses a sequentially rotated array of slots to generate circular polarization (CP). In the next section we present another resonator antenna, only this time a woodpile 3D EBG material is used to provide the angle dependent coupling to free space. Finally, a sectoral horn antenna with an electromagnetic confinement mechanism that relies wholly on the 3-D EBG of the woodpile material is described.



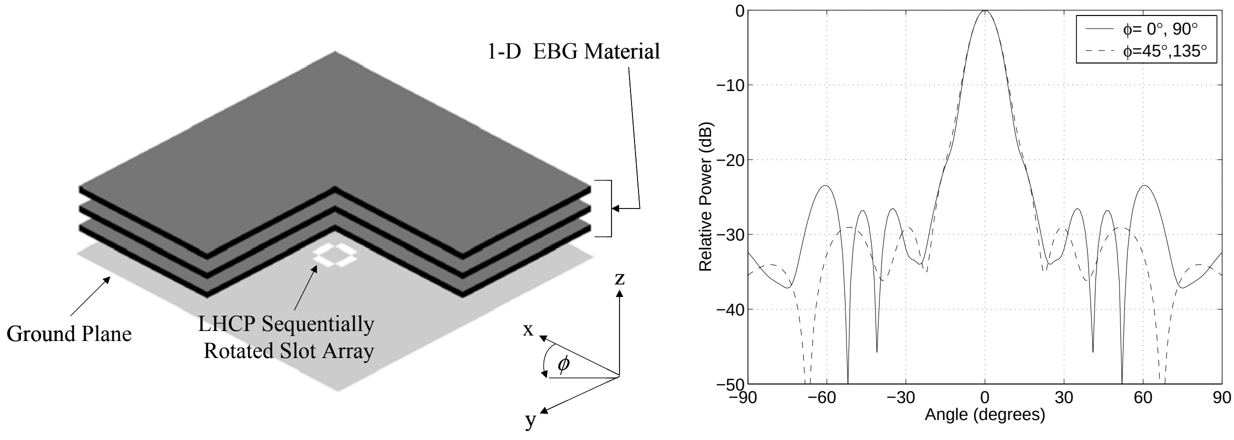
(a) (b)

Fig. 1. (a) Cutaway drawing of the linearly polarized 1-D EBG resonator antenna with microstrip patch feed. (b) Computed linearly polarized radiation pattern for the antenna at 12.144GHz.

LINEARLY AND CIRCULARLY POLARIZED 1D EBG RESONATOR ANTENNAS

The configuration of a LP 1D EBG resonator antenna is shown in the cutaway drawing of Fig. 1(a) [6]. The EBG material used in the antenna consists of three TMM4 substrates (ε_r=4.4, tanδ=0.002) with dimensions 152mm × 152mm × 3.2mm, with an air gap of 6.4mm between each TMM4 layer. This material is placed approximately 12mm above an aluminium ground plane to form a resonator. This spacing corresponds to approximately half a wavelength at the operating frequency of the antenna. The transmission from the resonator to free space is angle-dependent; for normal incidence the transmission is 100% while for other angles there is significant attenuation. It is this property that gives the resonator antenna its high directivity. Radiation patterns for this antenna have been computed using the finite-difference time-domain (FDTD) method [10] and are shown in Fig. 1(b) for the two principal planes of the antenna. The computed directivity of the antenna is 24.5dBi at its operating frequency of 12.144GHz, while that of a typical microstrip patch antenna (the feed element) is approximately 7dBi. Hence the use of the EBG superstrate has increased the directivity of the antenna by 17.5dB and the aperture dimensions, while maintaining fairly low sidelobes.

We can create CP radiation from the 1D EBG resonator antenna by simply modifying the feed structure [8]. A suitable feed structure is shown in Fig. 2(a). It consists of four LP slot antennas that have been sequentially rotated about the center of the ground plane. The phase of each slot is sequentially increased by 90° as they are rotated (ie 0°, 90°, 180°, 270°). To generate left-hand circular polarization (LHCP) the phase should be rotated in a counter clockwise direction when viewed from above. This method of generating CP from LP elements is well known and is described in more detail in the literature [11]. The LHCP radiation patterns computed using FDTD for the antenna are shown in Fig. 2(b). Note that due to symmetry the ϕ=0° and 90° radiation patterns are identical, as are the ϕ=45° and 135° patterns. The computed directivity for the antenna at 12.15GHz is 21.3dBic and the sidelobe levels are lower than −23dB. Both the LP and CP 1D EBG antennas have the advantages of high gain, low sidelobes, simplicity of design, low cost and high efficiency and are suitable for applications that include satellite reception, point-to-point radio links and use as a feed element in larger reflector antennas. The main disadvantage of these antennas is their narrow operating bandwidth.

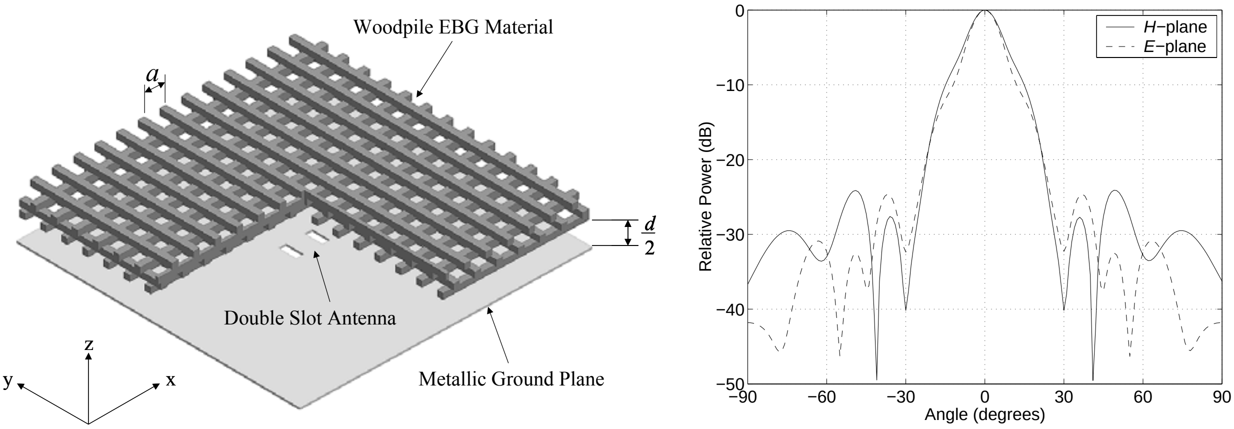


(a) (b)

Fig. 2. (a) Cutaway drawing of the circularly polarized 1-D EBG resonator antenna with sequentially rotated slot array feed. (b) Computed circularly polarized radiation pattern for the antenna at 12.15GHz.

WOODPILE 3D EBG MATERIAL RESONATOR ANTENNA

Instead of using a 1D EBG material to create a resonator antenna as discussed in the previous section, it is also possible to use a 3D EBG material such as the woodpile [7]. The configuration for such an antenna is shown in Fig. 3(a). The woodpile material [12] is implemented using alumina rods (ε_r=8.4, tan δ =0.002) and is defined by the lattice constant (or periodicity), a, the rod width w, and rod height h. For our alumina prototype these values were a=11.2mm, and w=h=3.2mm, which gives an EBG that extends from 11.33GHz to 12.83GHz representing the band of frequencies where no propagating modes exist in the EBG material. This EBG has been confirmed using a band diagram [7]. For the EBG material shown in Fig. 3(a) there are four layers of alumina rods in total. The woodpile EBG material is placed above a double slot antenna in an aluminium ground plane, which is fed from below by a waveguide with a square cross-section. The separation between the ground plane and EBG material is 11.6mm and corresponds to approximately half a wavelength at the design frequency of 12.5GHz. For waves normally incident on the EBG material there is 100% transmission from the resonator to free space, whereas obliquely incident waves undergo angle-dependent attenuation, creating a highly directional radiation pattern. The computed LP radiation patterns for the two principal planes of the antenna at 12.565GHz are shown in Fig. 3(b). The computed directivity at 12.565GHz is 21.8dBi. The advantages and applications of this antenna are similar to those described for the 1D EBG resonator antenna.



(a) (b)

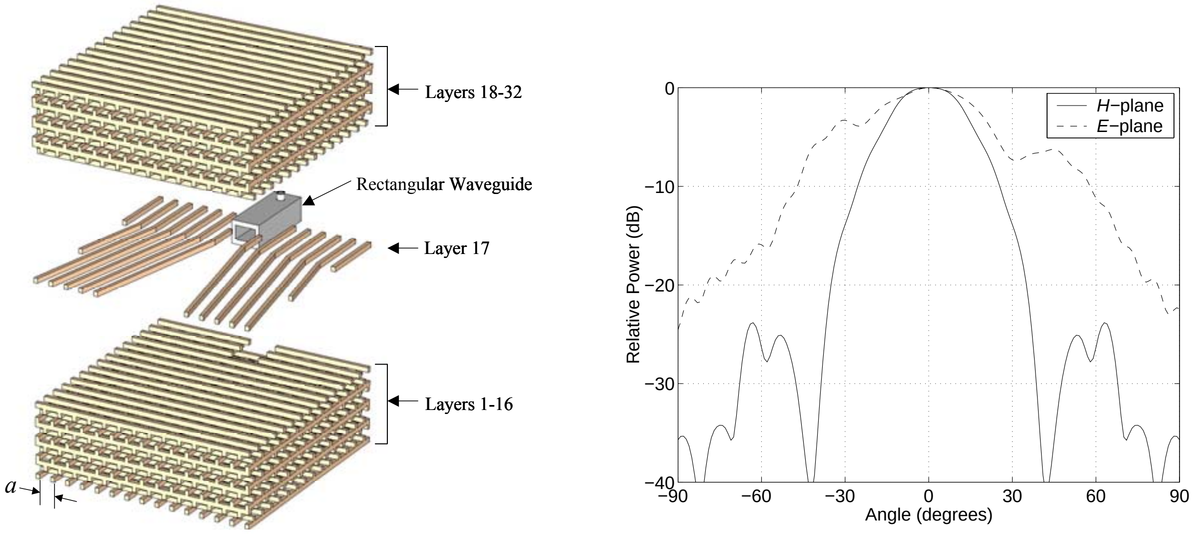
Fig. 3. (a) Cutaway drawing of a resonator antenna using a three dimensional EBG material known as the woodpile. The antenna uses a double slot feed. (b) Computed linearly polarized radiation pattern for the antenna at 12.565GHz.

WOODPILE EBG MATERIAL SECTORAL HORN ANTENNA

It is possible to create a "defect" waveguide within the woodpile EBG material by removing a single rod from a complete lattice. For frequencies that lie within the EBG of the material energy will be guided along the void created by the absent rod. This waveguide may then be further modified to create a sectoral horn antenna, as shown in the exploded diagram of Fig. 4(a). On layer 17 of the woodpile structure, a single rod is removed to create a waveguide, and the rods are splayed apart to form the walls of a sectoral horn antenna. A metallic rectangular waveguide is used to deliver energy to the horn antenna, which is in turn connected to a rectangular waveguide to coaxial waveguide transition. Alumina rods (ε_r=9.3, tan δ=0.0002) are used to implement the woodpile EBG material, which has a lattice constant, a=10.6mm, w=0.25a, and h=0.3a. These parameters create an EBG that extends from 11.7 to 13.5GHz; over this bandwidth no modes propagate through the EBG material. The computed –10dB reflection coefficient bandwidth for the EBG horn antenna is from 12.3GHz to 13.1GHz (ie about 6.6%). The directive radiation pattern for the sectoral horn antenna may be confirmed by examining the computed LP radiation patterns at 12.7GHz for the principal planes shown in Fig. 4(b). The computed directivity at this frequency is 13.2dBi. Since the horn antenna is made entirely from dielectric it could prove useful at millimeter and sub-millimeter frequencies where the losses from metallic walls of traditional horn antennas can be significant. It also has the advantage of being easily integrated with other woodpile EBG components such as power dividers and waveguide bends, to form compact communications subsystems. One suggested application for the antenna is in the field of terahertz imaging [13], where the EBG horn antenna could form part of a single pixel in an imaging system [14].

CONCLUSION

Four different antennas that exploit on the properties of 1D and 3D EBG materials have been described. The first three structures are resonator antennas that exploit the angle-dependent attenuation properties on an EBG resonator to create highly directive radiation patterns. Both CP and LP resonator antennas have been realized using 1D EBG materials and an LP resonator antenna created using a 3D woodpile EBG material. The computed directivity of each of the resonator antennas was in excess of 21dBi. A sectoral horn antenna realized using the woodpile EBG material was also described. This device uses the EBG of the material to confine and direct electromagnetic radiation, creating an efficient transition from an EBG defect waveguide to free space.



(a) (b)

Fig. 4. (a) Exploded view of the woodpile EBG sectoral horn antenna. (b) Computed linearly polarized radiation pattern for the antenna at 12.7GHz.

ACKNOWLEDGMENT

This work was supported by an ARC Linkage Postdoctoral Fellowship (CSIRO). B. C. Sanders acknowledges financial support from the Alberta informatics Circle of Research Excellence (iCORE) fund. The authors would like to thank the Australian Centre for Advanced Computing and Communications (AC3) for providing access to supercomputing facilities.

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