Photonic Bandgap Antennas and components for Microwave and (Sub)millimetre wave Applications

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ABSTRACT

This paper discusses some application areas of PBG technology and shows some results of realised antennas and PBG waveguides at microwave and (sub)millimetre wave frequencies. The results are drawn from work on using 2-D PBG crystals as substrates for both single patch and patch array antennas at microwave frequencies and 3-D PBG crystals at submillimeter wave frequencies. In order to get the most of this technology, a fully integrated receiver should be developed in which not only the antennas but also all the other components were designed using PBG technology. Some emphasis is placed on PBG waveguiding. This paper also contributes to the ongoing discussion within the PBG community by briefly mentioning the limiting conditions of the coupled cavity waveguiding mechanism

INTRODUCTION

Periodic electromagnetic materials are presently one of the most rapidly advancing sectors in the electromagnetic arena. Periodic structures such as photonic bandgap crystals allow us to engineer control over the propagation of electromagnetic waves to an extent that was previously not possible. Consequently they have been studied energetically in recent years and the literature reflects the fact that the initial academic studies have now matured. Emphasis is now being placed on finding tangible applications combined with detailed modelling.

Owing to the tremendous potential of photonic bandgap (PBG) structures there is a plethora of applications in which these can be used.

Communications services are one example of an area that is becoming increasingly important. There has been a significant increase in demand for high-speed data services for voice and multimedia applications, particularly for accessing the Internet and the fixed and mobile services. As a result, broadband microwave wireless access has emerged.

Technically, these applications look for new frequency spectrums with higher operational frequencies around 30 GHz, 40 GHz and 60 GHz for point to point, point-to-multipoint and high density fixed services, respectively.

Furthermore, technology in the sub-mm wave region of the electromagnetic spectrum is currently experiencing an explosive growth. The growth is fuelled in part by the need for faster signal processing and communications, high-resolution spectroscopy, atmospheric and astrophysical remote sensing and medical imaging against cancer. The increased atmospheric absorption and specific molecular resonances observed over this range of frequencies gives rise to applications in secure ultra-high bandwidth communication networks.

Novel PBG components and subsystems offer a very promising alternative to overcome the limitations of the current technology (ohmic losses, bandwidth, gain, efficiency). PBG technology can represent a major breakthrough with respect to the current planar approaches, mainly due to their ability to guide and control efficiently electromagnetic waves. In order to get the most of this technology, a fully integrated receiver or emitter system should be developed in which all the components were designed using PBG technology. The first step in order to achieve this goal is the design of the individual components.

This paper discusses the applications areas and shows some results of realised antennas and PBG components at microwave and (sub)millimetre wave frequencies.

Combined research and prototyping at the conventional microwave and the more challenging sub-mm frequency range has guaranteed a broader aptitude, applicability and feasibility of the developed modelling and testing facilities. It ensures an attractive synergy between the applications driven developments at microwave devices, with the technologically more demanding development of sub-mm wave systems. It also simultaneously provides verification of scalability in design and provides essential insight into any possible optical applications of such devices.

MICROWAVE ANTENNAS

A multitude of down to earth PBG applications exist especially within the microwave and low millimetre-wave region. Electronically scanned phased arrays find their use in many applications. For example constellations of satellites can be used for high data-rate transmission for multi-media applications. These applications require scanned multi-beam antennas with relatively wide bandwidth. Each beam is usually working in dual circular polarization. Most of these constellations will work at frequencies up to 30 GHz. The use of active phased array made in microstrip technology is then an attractive solution. However the need for bandwidth and scanning increases the risks caused by surface waves. A very promising way to eradicate the problems created by surface waves, e.g. scan blindness, while at the same time improving performance, is to use a photonic bandgap crystal instead of standard dielectric substrates.
The measured near field pattern [1] of two identical patch antennas that have been placed in an E-Plane array configuration is shown in figure 1.
PBG substrates also provide benefits for single microstrip patch antennas. Such patch antenna designs can have limitations, restricted bandwidth of operation, low gain and a decrease in radiation efficiency due to surface wave loss. While thickening the substrate thickness increases the operational bandwidth, a trade off must be made with the increased excitation of substrate modes. The utilization of a photonic crystal substrate in place of the original bulk substrate has shown to improve the antenna radiation efficiency and reduce the side lobe level [2].
Another microwave application is high precision GPS. High precision GPS surveying can make measurements with sub-centimetre accuracy levels. While software can greatly reduce multipath errors, extra precautions that can shield the antenna from unwanted multipath signals are needed to obtain these accuracies. Choke rings provide excellent electrical performance for GPS antennas, but they are usually very large, heavy and costly. Making use of the fact that Metallo-Dielectric PBG antennas can behave as Artificial Magnetic Conductors, one can design PBG solutions in printed circuit technology [3]. Also, this technology may prove useful in mobile antenna handset designs and enable the radiation (Specific Absorption Rate, SAR) into the operator's hand and head to be reduced. Note that soon all mobile phones will display the SAR value of the handset.

(SUB) MILLIMETER WAVE ANTENNAS

A new generation of scientific space borne instruments, included in both Earth observation and scientific missions, is under consideration at millimetre and sub-millimetre wavelengths. As the frequency increases, a planar structure that integrates the antenna, mixer, local oscillator and all peripheral circuitry onto one single substrate becomes an attractive option. While conceptually simple, in practice it is challenging to develop and test an integrated planar antenna on a semiconductor substrate that has good radiation efficiency and can be easily integrated with the active circuit. One of the problems encountered, is that planar antennas on high dielectric constant substrates couple a significant fraction of the input power into substrate modes. Since these do not contribute to the primary radiation pattern, substrate mode coupling is generally considered as a loss mechanism. By removing the possible existence of substrate modes by using a PBG substrate the problem can be overcome, exemplifying the application of PBG materials. The radiation pattern of an integrated antenna system at 500 GHz [4] is shown in figure 2. The PBG crystal used is the so-called layer-by-layer or woodpile structure [5].

PBG WAVEGUIDING

An ideal PBG crystal is constructed by the infinite repetition of identical structural units in space. Considerable effort in theoretical, experimental and material fabrication research has predicted and demonstrated many of the properties of these ideal crystals. Introducing some disorder by placing a "defect unit" within an otherwise perfect PBG crystal can create localised transmission peaks within the forbidden band gap of the structure. Previous work has suggested PBG crystal channel waveguides that consist of a line defect introduced into an otherwise perfect 2-dimensional crystal. Various bends, couplers and add-drop multiplexers have also been proposed [6,7]. An example of PBG waveguide is shown in Fig. 3. The PBG structure was formed by air holes in a dielectric substrate (ε_r=10.2) with metal plates at the top and bottom (see Fig. 3). A microstrip line was used to excite the PBG waveguide needing a transition between the PBG waveguide width and the 50 Ω microstrip line. Measurement transmission results of a conventional microstrip waveguide including the aforementioned transition and a PBG waveguide are presented in Fig. 3. The microstrip waveguide was fabricated in order to extract information about the losses coming from the connector-microstrip transition and the effect of the stationary wave originated between connectors. In the PBG case, the transmission results show a reflection peak at 13 GHz which coincides with the Distributed Bragg Reflection (DBR) effect. Apart from this, the PBG transmission curve shows equivalent losses as the conventional waveguide demonstrating that the PBG waveguide is a valid alternative to guide the power at millimetre wave frequencies.

Recently an alternative to the linear defect waveguide has attracted considerable attention. This alternative makes use of a periodic chain of localised defects that have been either completely or partially in-filled. The introduction of several localised defects, within coupling distance of each other, opens up a mini-band of allowed transmission [8,9]. Chains or cascades of localised defects form a mechanism for waveguiding, commonly referred to as coupled cavity waveguides, CCW. Experimental verification of 2-dimensional CCW's has been performed in the microwave regime. It has frequently been assumed that bends can be introduced into the waveguide path by taking advantage of the crystal's inherent lattice symmetry without consequential bend reflection loss. However, it can theoretically be shown that the mini pass band created by coupled cavity waveguide bends may only reach 100% transmission for a strict set of criteria [9]. Figure 4 shows some reflections losses that might occur for a CCW-bend in a hexagonal lattice.

CONCLUSION

Currently, there is a need for wide band device functionality, and ideally multifunctional devices. At millimetre wave frequencies, the existence of components for such systems is currently very limited. As long as the market demands these broadband communications, the development of novel communication components and subsystems for mobile equipment and base stations will always be in demand. Ideally, these components and sub-systems would be required to be dynamic, re-configurable and multifunctional. The technological potential of electromagnetic crystals for developing such novel components and subsystems offers a very promising alternative to overcome the limitations of the current technology. PBG technology represents a major breakthrough with respect to the current planar approaches, mainly due to their ability to guide and control efficiently electromagnetic waves.

In order to drive this technology towards the market place we will need to identify component(s) feature(s) of photonic bandgap structures that give added value over and above current approaches. In this paper some examples have been presented.

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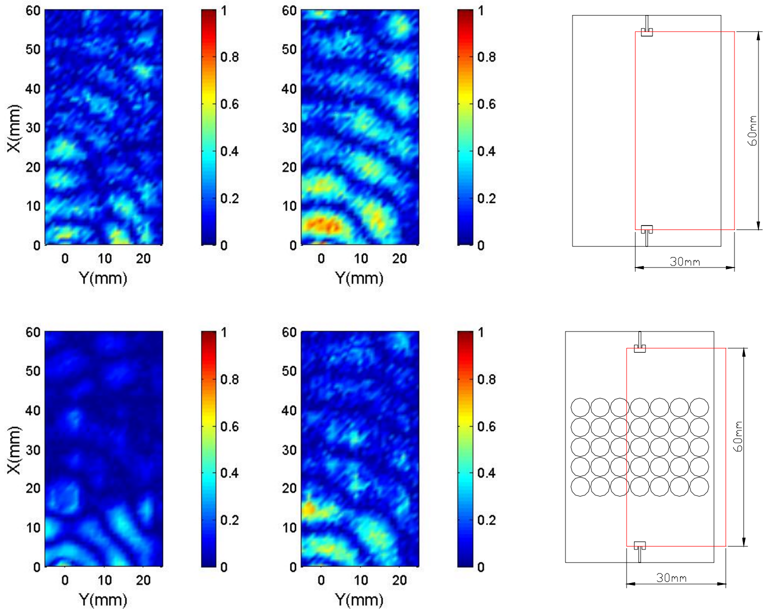


Figure 1: Measured near field pattern. The red rectangles in the right plots are the scanned area. The top and bottom rows correspond to the conventional and the PC substrates. The left and right columns are at 17 GHz (inside the gap) and 14.5 GHz (outside the gap) respectively. Each plot is normalised to its maximum value.

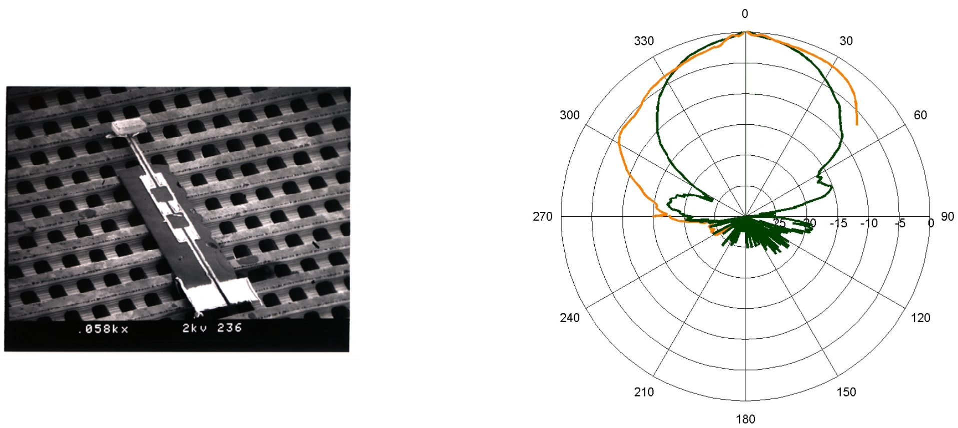
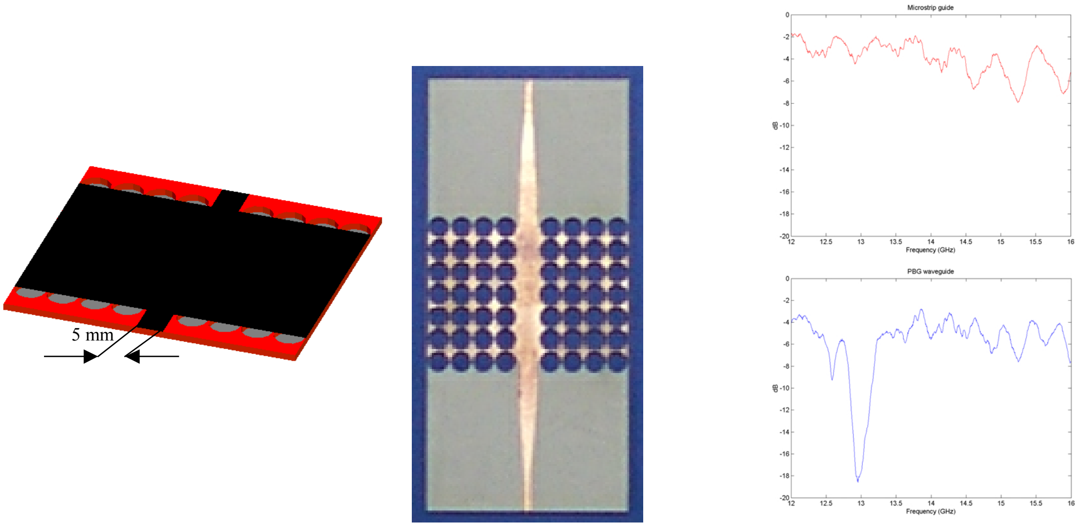
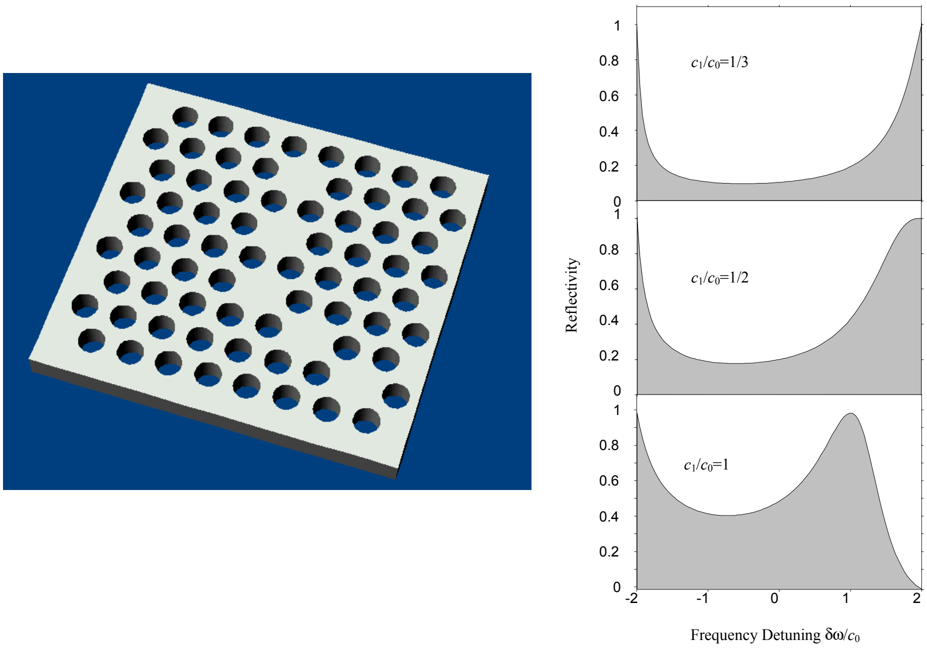


Figure 2: 500 GHz dipole antenna on top of woodpile a) Electron Microscope photograph, b) Measured Radiation pattern for the E- and H-planes (Black line E-plane, Red Line H-plane).



(a) (b) (c)

Figure 3: PBG waveguide based on a linear defect (a) PBG waveguide between metal plates. (b) The inner section of the fabricated PBG waveguide, (c) Transmission measurements of conventional microstrip waveguide (top) and PBG waveguide (bottom)



(a) (b)

Figure 4: Spectral response of a bend in a defect chain in a hexagonal PC lattice; a) Image of a bend in a 1-in-2 defect chain, b) reflection for varying ratio of the next nearest (c_1) to nearest neighbour (c_0) interaction.