(Sub)mm-Wave Components and Subsystems based on EBG Technology

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Abstract – **This paper highlights some application areas of Electromagnetic BandGap (EBG) technology at (sub)millimetre wave frequencies. Configurations include a radiating sub-system consisting of a dipole on top of a woodpile structure, an EBG waveguide including transitions from rectangular metallic waveguide and a mixer using EBG technology. Artificial magnetic conductors (AMC) have attracted a lot of attention at micro-wave frequencies. A version, suitable for sub-millimeter wave applications, is discussed.**

1 INTRODUCTION

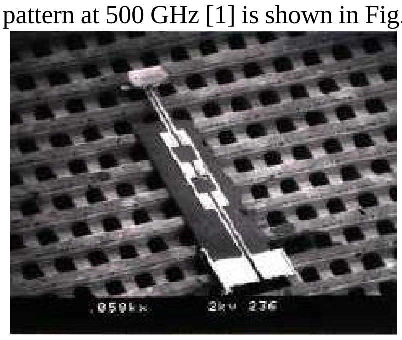
Electromagnetic Bandgap (EBG) materials, also known as Photonic Crystals or Photonic Bandgap materials (PBGs) are periodic structures that for a range of frequencies can be impenetrable to electromagnetic waves, thus giving rise to the so-called bandgap. Since their discovery and first demonstration in the late 1980's, interest in photonic crystals has grown explosively. In the (sub) millimeter wave range some applications have attracted much attention, e.g. imaging arrays which are of great interest for space astronomy, atmospheric research or security systems. The use of EBGs for these applications can have advantages with respect to the standard solutions. As an example, conventional planar antennas present surface mode excitation problems, which can be overcome using EBG substrates. Also, systems based on EBGs may involve less processing steps in their fabrication while preserving system performance. It is also foreseen that using this technology it should be possible to make fully 3-dimensional circuitry allowing the construction of more complex systems. Further, by introducing perturbations within the crystal structure it is possible to realize compact integrated waveguides, bends and splitters.

In this paper some components based on EBG technology are presented. These include a dipole placed on top of the woodpile. Its measured performance is also shown. An EBG waveguide and a mixer combining EBG and conventional technologies are discussed afterwards. The mixer represents the first step towards a fully integrated system based on EBG technology. Finally, a sub-millimeter wave version of an Artificial magnetic conductor is discussed and its predicted performance shown.

2 EBG ANTENNAS

Because of their ability to suppress unwanted radiation in 3-dimensions, 3D EBGs have attracted much interest as antenna substrates. Their use prevents the excitation of substrate modes, which represent both a loss and an undesired inter-antenna coupling mechanism in planar antennas.

An integrated antenna system consisting of a dipole antenna placed on top of a woodpile structure was built. The radiation patterns were measured at the SRON facilities, Groningen, The Netherlands, using a positioning system in which the antenna could be rotated around two axes. A carcinotron working at 500 GHz was used as the RF source. The measured radiation pattern at 500 GHz [1] is shown in Fig. 1b.



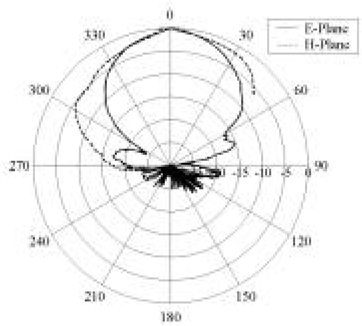


Figure 1: Dipole antenna on top of woodpile structure (top). Measured radiation pattern at 500GHz (bottom).

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The back radiation has been significantly reduced due to the presence of the EBG. The H-Plane was could not be completely measured due to the disturbance caused by the connector used to have access to the detected signal. It should also be noted that the obtained E-plane beamwidth is ˜44º while it is ˜64º for the H-plane (taking into account only that half of the pattern that was not disturbed). This values are much smaller than that of an isolated dipole.

The radiation is also significantly reduced in the end-fire direction, showing that this configuration also diminishes the mutual coupling between antennas. Since parasitic cross-coupling has limited severely the application of planar antennas in imaging arrays, the use of EBGs presents a possible way of alleviating this problem.

3 EBG WAVEGUIDES

In order to fully exploit EBG technology, a fully integrated EBG system should be designed, thereby avoiding the transitions between different technologies. To achieve this objective, the individual components that constitute a RF system first need to be realized in EBG technology.

Waveguides are one of the most basic components in any RF system. In the case of a woodpile or layer-by-layer structure a waveguide can be created by removing one of its bars [2]. Since the output of sources available in this frequency range still use conventional technology, i.e. metallic rectangular waveguide, a transition from this waveguide to EBG waveguide was required. An external view of the manufactured silicon EBG waveguide, together with the silicon transitions to metallic waveguide, is shown in Fig. 2. They were fabricated using deep reactive ion etching, a method which allows the accurate manufacture of structures that are not restricted to any particular crystal orientation.

Preliminary transmission results are shown in Fig. 2b. A transmission band centred around 250 GHz is clearly seen. The measurement range starts at 244 GHz, as this is the cut-off frequency of the matching section used in the adapters. We thus are unable to determine the transmission at lower frequencies. Our theoretical modelling indicates a transmission band centred at 253 GHz with 10 dB frequencies of 247 GHz and 258 GHz. Within the limitations of our experiment, the agreement in frequency between theory and experiment is good.

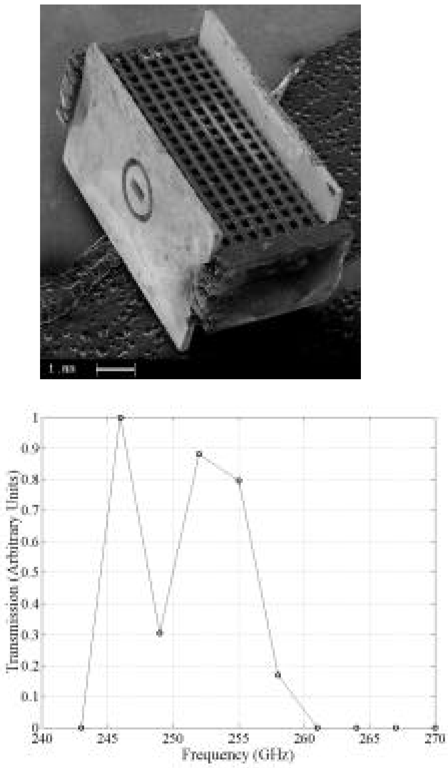

Figure 2: Back to back transition from rectangular waveguide to EBG waveguide (top). EBG waveguide transmission measurements (bottom).

4 EBG MIXER

A heterodyne mixer with integrated EBG technology has been fabricated and measured [2.3]. This design utilises a subharmonic mixer with a RF centre frequency of 250 GHz. To collect the radiation at this frequency the mixer uses a configuration similar to that described in section 2, i.e. a dipole antenna placed on top of a woodpile structure. The LO power (at around 125 GHz) is introduced via a rectangular metallic waveguide and is coupled to the coplanar stripline, where the diodes are placed, using a quasi-Yagi transition (Fig. 3). A RF filter and a low pass filter are included in order to get the required isolation between ports and to achieve a good impedance match to the diodes.

The EBG mixer noise performance was characterised at the Rutherford Appleton Laboratory facilities. A BWO, tuneable from 100 GHz to 130 GHz, was used as the LO source. A directional coupler together with a power meter were used to determine the LO power. The mixer IF output was connected to a low noise amplifying chain operating at a centre frequency of 4 GHz.

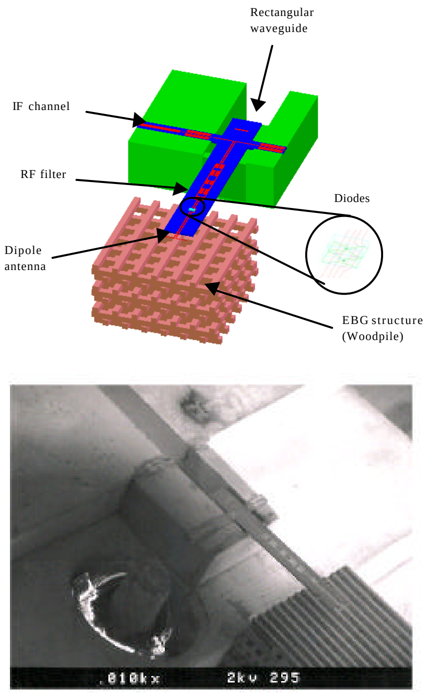

Figure 3: Schematic showing the EBG mixer design (top). Photograph of the manufactured mixer (bottom).

The performance of the mixer was measured with the Y-factor technique, using a liquid nitrogen cooled blackbody as the cold source. The receiver noise temperature is quite constant at about 7000 K over a broad frequency range: we measured a best double sideband noise temperature of 3500 K at a frequency of 232 GHz (see [3])

5 ARTIFICIAL MAGNETIC CONDUCTORS

Artificial magnetic conductors have attracted a lot of attention recently as they seem to do double action. They suppress surface waves, and they introduce in-phase image currents. In general, the structure consists of a two-dimensional pattern of capacitive and inductive elements facilitating compact EBG's that operate at relatively low microwave frequencies.

The "Reflection Phase Diagram" of AMC structures gives information about how the structure reacts to a wave impinging on it. A characteristic feature of AMCs is the existence of a frequency range over which an incident electromagnetic wave does not experience any ð phase reversal upon reflection. In this range the structure behaves as a Perfect Magnetic Conductor. The frequencies range, which has the above-described properties, is

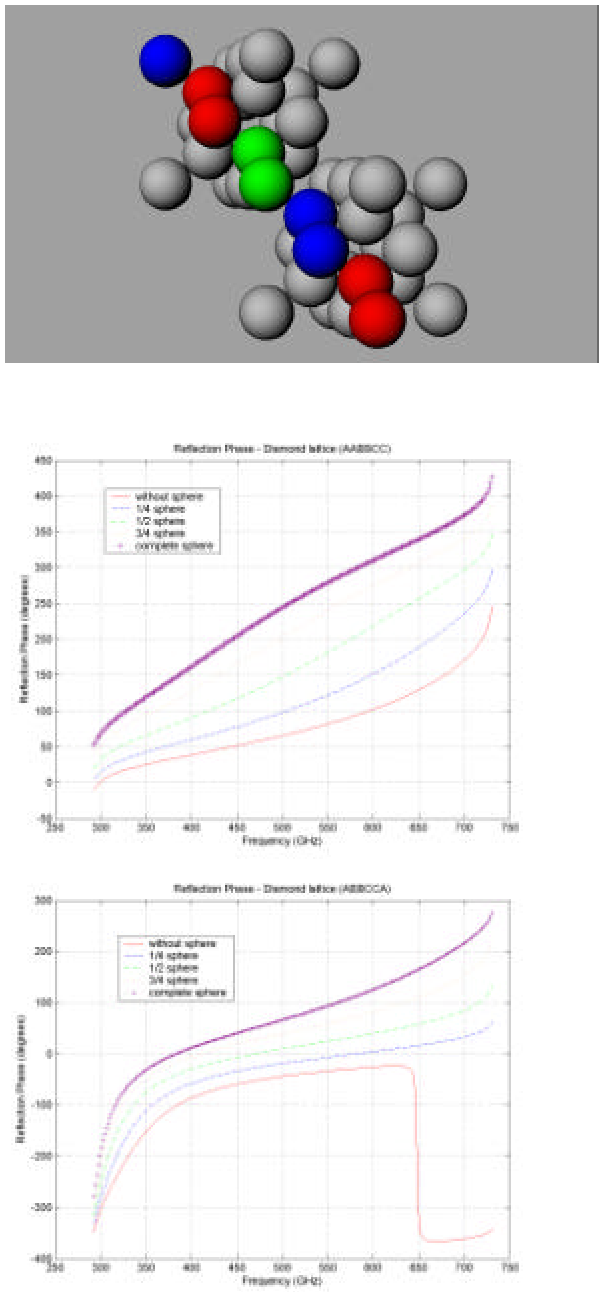

Figure 4: Diamond lattice showing the AABBCC stacking along the body diagonal (top). Computed phase reflection for the AABBCC stacking (middle) and ABBCCA stacking (bottom).

generally rather narrow. In order to overcome this rapid deterioration of the zero-phase-change-under-reflection properties, another structure is proposed.

This structure lends itself for manufacture at sub-millimetre wavelgnths and it is based on a diamond lattice of close-packed metallic spheres embedded in a dielectric host. This structure has been shown to possess the largest known forbidden complete frequency band [4] (for all incident directions and for both polarizations). The study of reflection properties has been performed by the so-called layer Koringa-Kohn-Rostocker method. In our study, a modified version has been used of the publicly available computer LKKR code and it is assumed that the electromagnetic wave is incident along the body-diagonal of the diamond lattice (the (111) crystal direction). The reason was that the particular stop gap around the gap is the largest. An infinite diamond lattice in the (111) crystal direction can be viewed as AABBCC stacking of identical hexagonal planes of spheres (see figure 4). Obviously, once a diamond crystal is terminated, one can imagine two different surface terminations in the (111) crystal direction, either AABBCC or ABBCCA (or incomplete parts of the upper A sphere). Both cases were considered. Figure 4 shows the predicted phase reflection for the two crystal terminations.

It is clear that the curve is flat for a rather wide frequency band. By varying the termination of the top-most layer, it is possible to vary the absolute phase level of the flat region. This can be used to match to any particular antenna impedance.

5 CONCLUSIONS

Sub-millimetre wave components and sub-systems, designed and fabricated using EBG technology, have been presented. Both radiating EBG components, i.e. dipole antennas on top of woodpile structure, and EBG waveguides have been studied. The results of the first EBG mixer have been described and preliminary results have been given. A broadband sub-millimetre artificial magnetic conductor has been presented. Our findings demonstrate that EBG circuit architecture presents a promising and viable alternative to conventional techniques. We conclude that the types of components studied can potentially benefit from the use of EBG technology.

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