Design and Analysis of Dual-Band EBG Resonator Antennas Using Millimetre-Wave EBG Structures for Improved Directivity and Radiation Bandwidth

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Abstract

The design of a dual-band Electromagnetic Band Gap (EBG) resonator antenna using the defect-mode characteristics of a millimetre wave EBG superstrate is presented. The technique of multiple source excitations is used to increase the antenna directivity and 3-dB radiation bandwidth in two frequency bands. Computed radiation patterns confirm the dual-band directivity enhancement with a wider radiation bandwidth. By properly spacing the array feed elements, high directivity and low side-lobe levels are achieved without the appearance of grating lobes.

1. Introduction

The use of Electromagnetic Band Gap (EBG) structures as antenna superstrates is a promising solution for enhancing the directivity of various antennas. One class of such antennas, also known as EBG resonator antennas or Fabry-Perot Resonator antennas, has the main advantages of design simplicity and low complexity as compared to the conventional planar antenna arrays. Various configurations of such EBG resonator antennas have been developed for use in single and multiple frequency bands using single feed source [1-2]. The defect modes in these antennas have inherent narrow bandwidth that can be increased using dual EBG resonators in combination with multiple-feed sources which results in improved directivity [3]. In this work, the design of a dual-band EBG superstrate is presented to increase the antenna directivity and radiation bandwidth using an array of sources. The antenna is designed to operate in two frequency bands around 28 GHz and 38 GHz for point-to-point communication links. CST Microwave Studio commercial software has been used for the design and analysis.

2. Dual-Band EBG Superstrate: Unit-Cell Design

The proposed antenna configuration is shown in Fig. 1. When the antenna ground plane is replaced by the image of the antenna, the corresponding unit-cell geometry is as shown in Fig. 2. It consists of two-dielectric slabs ($\varepsilon_r = 10.2$) and a defect dielectric rod ($\varepsilon_r = 2.2$) placed in the air gap, quarter–free-space-wavelengths above the first slab. The model is excited by normally incident plane waves at port 1 and 2 with periodic boundary conditions on the four-walls, to observe the transmission through the structure. As seen from Fig. 2, the EBG structure exhibits two defect modes within a very wide band-gap. The first mode with a wide bandwidth (low Q) is due to the insertion of defect dielectric rods, while the second mode with a narrow bandwidth (high Q) is due to the cavity between the inner slabs. By controlling the thickness, periodicity of the square-shaped defect rod, and the location of dielectric slabs, defect frequencies have been tuned to 28.5 GHz and 38.9 GHz. The two defect-modes satisfy the necessary condition of directivity enhancement, i.e., they have vanishing tangential electrical fields at the structure's symmetry plane, where a conducting ground plane will be positioned, and hence are useful to implement a dual-band EBG resonator antenna.

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3. Dual-Band EBG Resonator Antenna

The EBG resonator antenna configuration, shown in Fig. 1, has overall dimensions of 60×60×10 mm^3. The parameters h and h_1 describe the location of two defects, and are equal to half-free-space-wavelength at 38 GHz and 28 GHz, respectively. In simulations, the antenna is excited by a horizontal electric dipole (HED), which is a broadband feed, located 0.5 *mm* above the ground plane. The computed *E*-plane radiation patterns for the dual-band antenna with a single HED source are presented in Fig. 1. Maximum directivities of 17.5 dBi and 25 dBi and 3-dB radiation bandwidths of 5% and 1.7% are predicted at 28.5 GHz and 38.9 GHz, respectively.

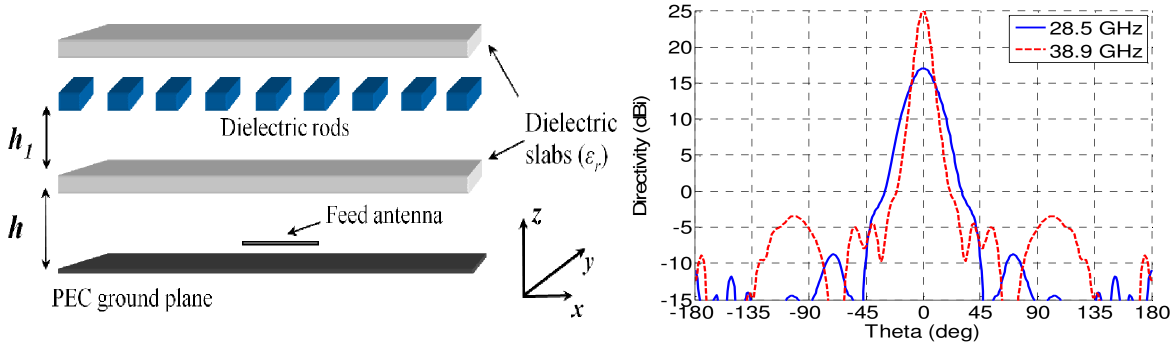

Fig. 1: Dual-band EBG resonator antenna configuration and peak directivities.

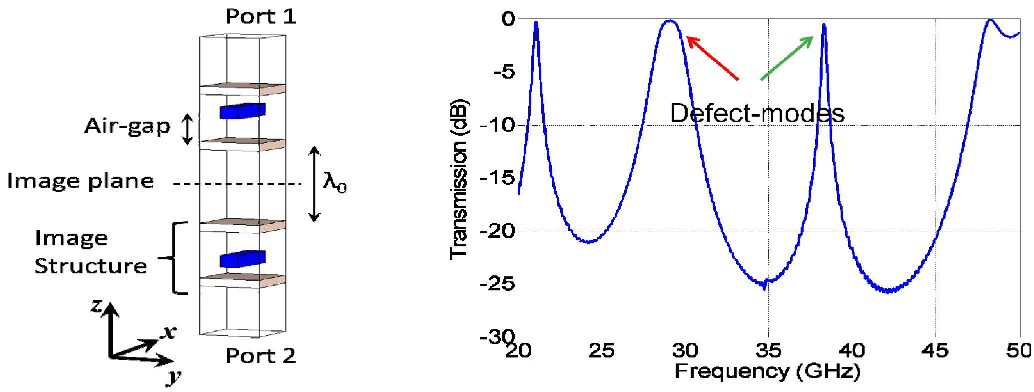

Fig. 2: Unit-cell model and its transmission factor for normal incidence.

The EBG antenna is then excited with multiple HED sources, arranged in a two-dimensional array centred above the ground plane, with λ_0 spacing at 28.5 GHz (to compensate for low Q-factor). By doing so, the electric field distribution on the EBG structure becomes more uniform and the effective radiating aperture increases which contributes to increased directivity and radiation bandwidth in both bands. As shown in Fig. 3, maximum directivities of 25.7 dBi and 30.2 dBi and 3-dB radiation bandwidth of 7.8% and 2.9% are predicted at 28.5 GHz and 38.9 GHz, respectively, with 25 HED sources. The side lobe levels in the *E*-plane at both frequencies remain below -18 dB.

The effect of the inter-element spacing and number of HED sources on the side lobe level (SLL) is also studied. Fig. 4 shows that for fixed number of sources (25 in this case), directivity can be increased in both bands by spacing HED elements greater than λ_0, with very little effect on SLL. Grating lobes are completely suppressed in both bands as compared to traditional arrays (with inter-element spacing $\geq \lambda_0$) without EBG superstrate. This occurs due to the reflection and wave spreading behaviour of the EBG superstrate layer, which does not contribute towards the constructive interference.

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4. Conclusions

Multiple defects can be incorporated in the EBG structure to achieve multi-frequency operation. Directivity enhancement is related to the defect-mode transmission bandwidth and its quality factor. The directivity level and 3-dB radiation bandwidth can further be enhanced by increasing the number of internal sources feeding the cavity, spreading the field more uniformly and hence effectively increasing the antenna aperture efficiency. Computed radiation bandwidth of 7.8% and 2.9% has been achieved with peak directivities of 25.7 dBi and 30.2 dBi. The dual-band EBG structure suppresses the grating lobes effectively when excited by array-feed, with inter-element spacing greater than $\geq \lambda_0$.

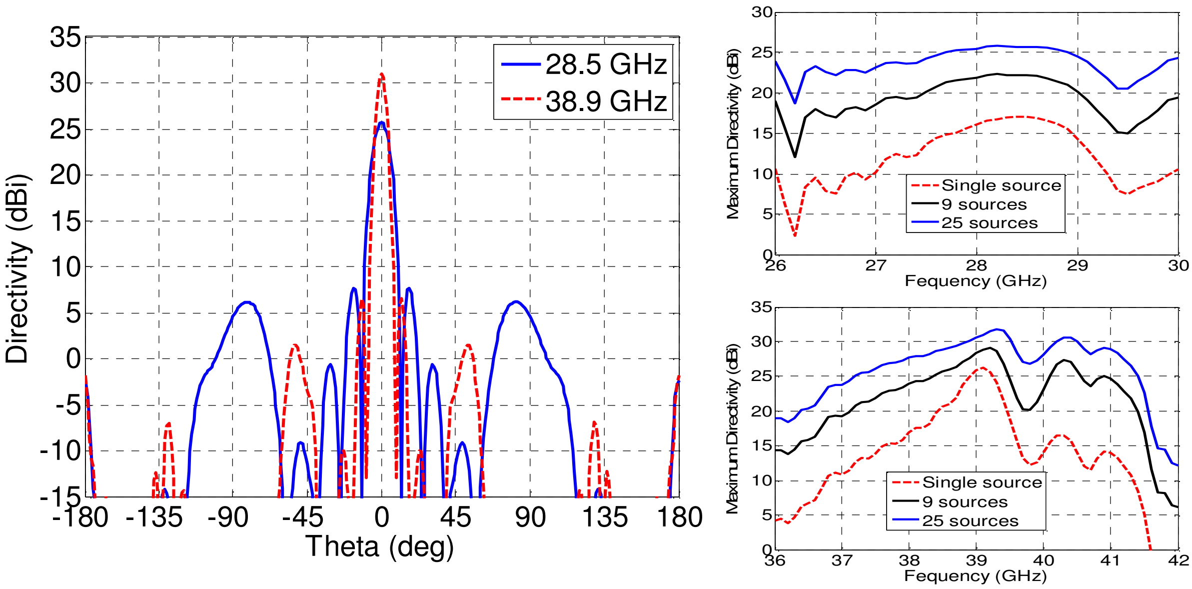

Fig. 3: Computed *E*-plane radiation patterns and radiation bandwidth with 25 HED sources.

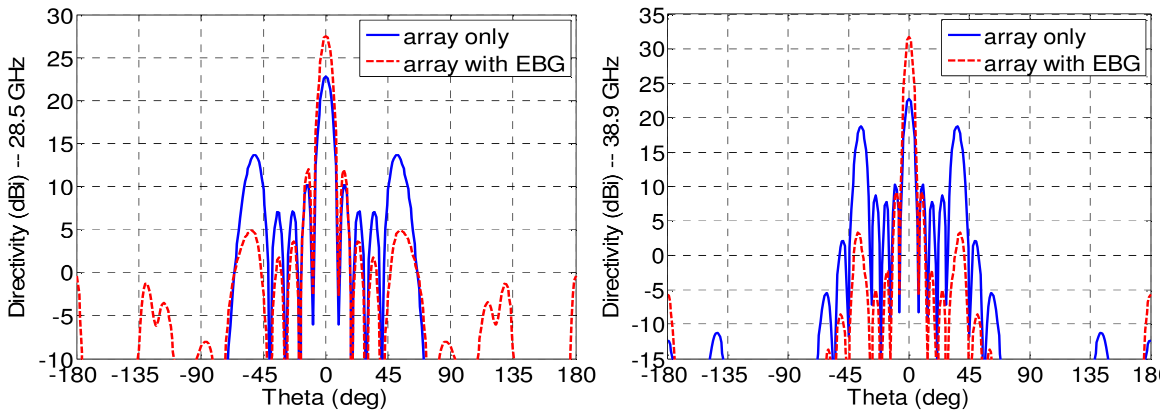

Fig. 4: Grating lobe suppression in EBG resonator antenna excited with an array feed.

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