Microwave Band-gap and Band-pass Structures using Planar Metallodielectric Periodic Arrays

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ABSTRACT – The behaviour of a two dimensional periodic array printed on a substrate ha been analysed. It exhibits a frequency band of 2 GHz where propagation of electromagnetic wave is prohibited in all directions along the planar surface. In the passband, it was found that the periodic array enhances the directivity and the gain of the transmitting antenna by concentrating the fields onto the substrate.

Indexing terms: *photonic band gap, periodic structures, Frequency Selective Surfaces (FSS)*

1 INTRODUCTION

Photonic Bandgap(PBG) crystal is a periodic structure that prohibit propagation of all electromagnetic waves within a particular frequency band. Original PBG research was performed in the optical region [1], but PBG properties are scaleable and applicable to a wide range of frequencies. In recent years, there has been increasing interest in microwave and millimeter-wave applications of PBG structures. [2, 3] Currently, research has also extended to Metallodielectric Photonic crystal (MDPC), which is replacing the photonic crystal with periodic metal elements in low dielectric region.

Frequency Selective Surface (FSS) which has been extensively researched is a planar version of a 2-D metallodielectric PBG crystal. The emergence of the band gap was first investigated by our earlier studies on propagation behavior of periodic arrays as FSS in rectangular waveguides and leaky wave antennas. [4-6] Here we discuss the band gap arising from two-dimensional array of conducting tripole elements printed on a dielectric substrate. In general, the resonant properties of FSS across the reflection band make them prime candidates for yielding a controlled photonic band-gap. Extending from the techniques used in the analysis of FSS by the investigating the propagation constant along the substrate's surface, from the dispersion curves, the properties of the PBG can be examined for a specific array geometry [7].

2 PLANAR 2D TRIPOLE ARRAY DESIGN

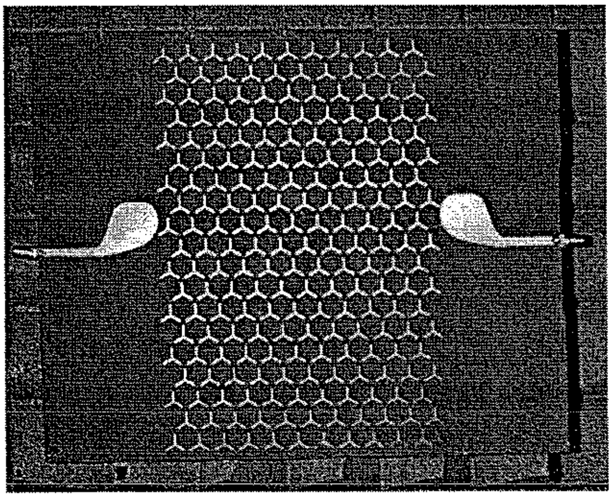

Fig. 1 : Photo of a tripole array with the transmitting and receiving Vivaldi antennas

Figure 1 shows a photo of a tripole array printed on RT-Duriod 5880 (dielectric constant ε_r =2.2, Thickness=1.125mm) with a transmitting and receiving Vivaldi antennas. The tripole array has its element spaced out periodically on 2 axes separated by angle $\alpha = 60°$. The lattice periodicity D = 12mm, tripole's arm length L = 5mm and width W=0.6mm.

The predicted dispersion diagram of the tripole array is shown in Figure 2. Due to the symmetric properties of the reciprocal lattice and the tripole element, the shaded region is determined as the irreducible Brillouin zone. The modeling results show an absolute band gap of 2 GHz, starting from 12.5 GHz. to 14.5 GHz. The TM band gap of 4.2 GHz starts from 12.5 GHz to 16.7 GHz and the TE band gap of 3.8 GHz starts at 10.7 GHz to 14.5 GHz. From the prediction, the TE band gap begins at 10.2 GHz in (Γ - X) direction and increases to 10.7 GHz in (Γ - M) direction. The TM band gap starts around 12.5 GHz for all directions.

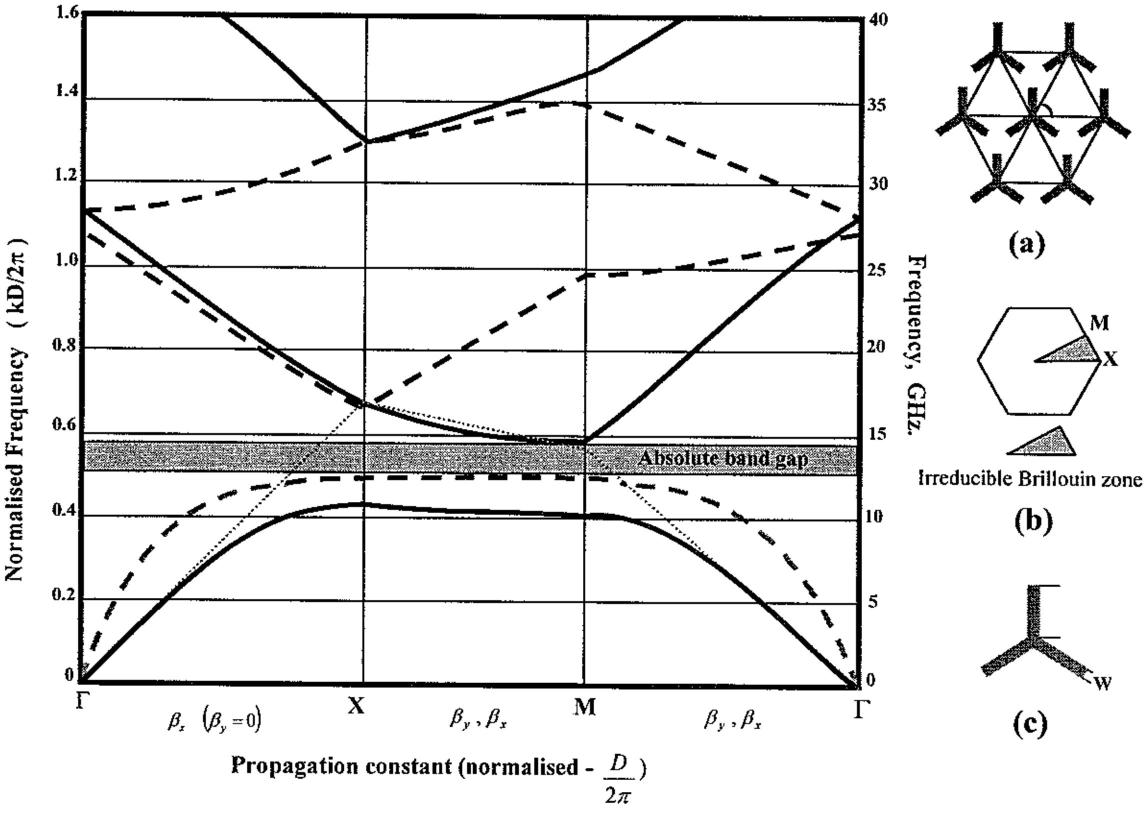

Fig. 2 : TE(line) and TM(dash) modes of a tripole array in a triangle lattice. (a) Direct lattice, (b) Reciprocal lattice and its irreducible Brillouin zone, (c) L = 5mm, W = 0.6mm, periodicity D = 12mm, $\varepsilon_r = 2.2$, Thickness T = 1.125mm, $\alpha = 60°$.

3 MEASUREMENT RESULTS

The Vivaldi antenna in this case is mainly a TE mode slow leaky end-fire travelling wave antenna but the slew angle due by the finite thickness of the slab enable it to pick up the TM mode with low efficiency. The measurement results in Figure 3 are in good agreement with the predictions. The TE bandgap begins at 10.3 GHz in the Γ - M direction and increases to 10.7 GHz in the Γ - X direction. The measured TM bandgap start at 12.2 GHz in (Γ - M) direction and increase to 12.4 GHz in (Γ - X) direction. Notice that the TM_0 mode is measured only after it goes into the slow wave region. (dotted line)

It is discovered that there is a gain of 5-7 dB before the stopband; the tripole array elements have become guiding elements for the transmitting Vivaldi antenna. In the passband frequencies, the fields are concentrates in the direction of the antenna propagating on the dielectric slab, thus increasing its directivity. In fact from the prediction in Figure 2, the surface mode is below the TE_0 surface mode of the dielectric substrate alone. This means the array is slowing the wave propagation down and effectively increasing the overall dielectric constant of the substrate. From the point of view of higher dielectric constant substrate, the fields are naturally bounded to the substrate and therefore increases its directivity and gain.

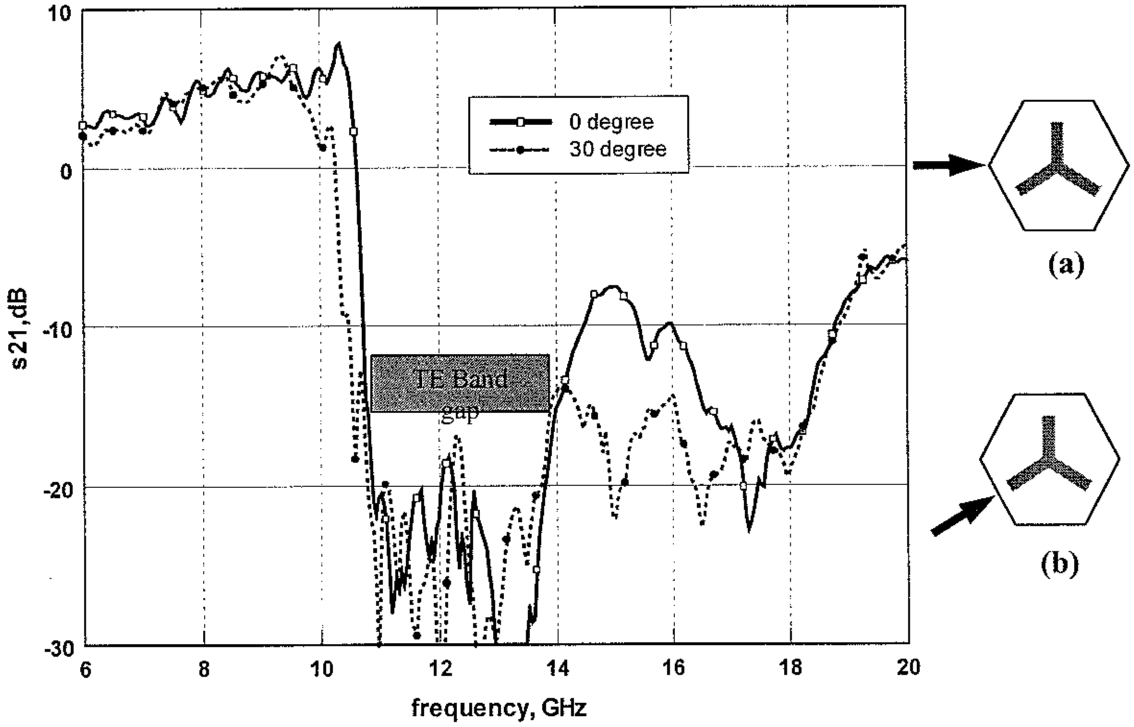

Fig. 3 : Measurement results of the tripole array from Fig. 2,
(a) 0^0 (x direction), (b) 45^0 (xy direction)

The normalised radiation patterns presented for comparison is a Vivaldi antenna with and without a tripole periodic array. The displayed results show the radiation patterns for frequencies before and after the band gap in the E and H planes. The radiation patterns are taken 340° excluding 20° behind the feed.

Figure 4a show normalised radiation pattern before the stop band at 10 GHz. Both the E and H planes of the antenna with the tripole array show the properties of a leaky wave antenna. The antenna with the array has a narrower main beam indicates the power is concentrated towards the direction that the antenna is pointing. This further explains the gain experienced before the band gap.

Figure 4b shows the measurement at 11 GHz, which is in the band gap region. In the H-plane, there is suppression of 20 dB within an angle of +/- 20° in the direction of the antenna. The energy is reflected back towards the sides and back of the antenna. The E-plane measurement is on the same plane as the dielectric slab where the antenna and tripole array are printed. The tripole array which is printed in front of the transmitting antenna suppress the propagation up to an angle of about +/- 90° in the direction of the antenna. From this observation we can see that when the band gap occurs the energy is prohibited in the direction of the tripole array and instead it is reflected and radiated as a leaky wave at an angle away from the dielectric slab.

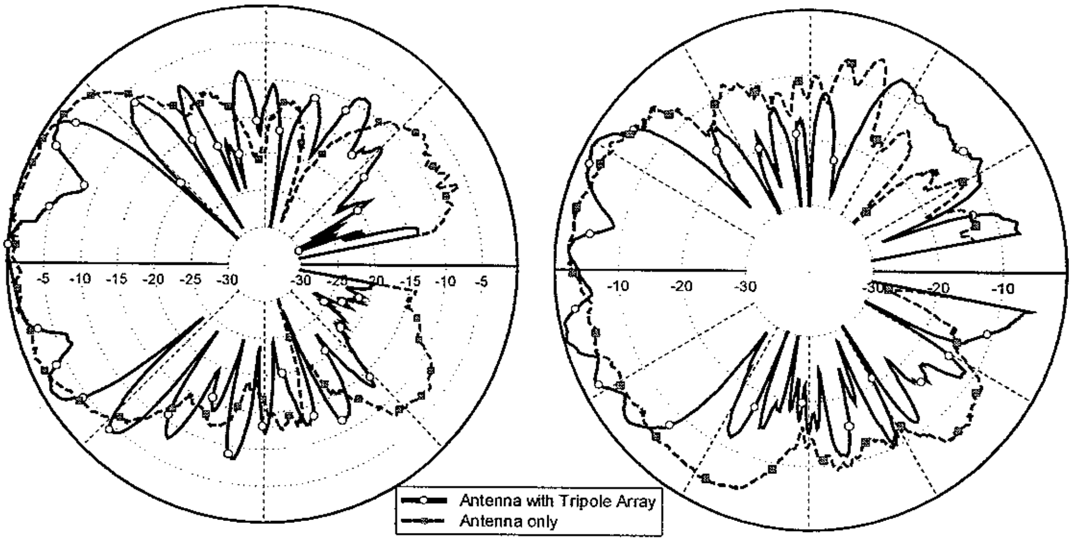

Figure 4a : H and E-plane radiation pattern at 10 GHz

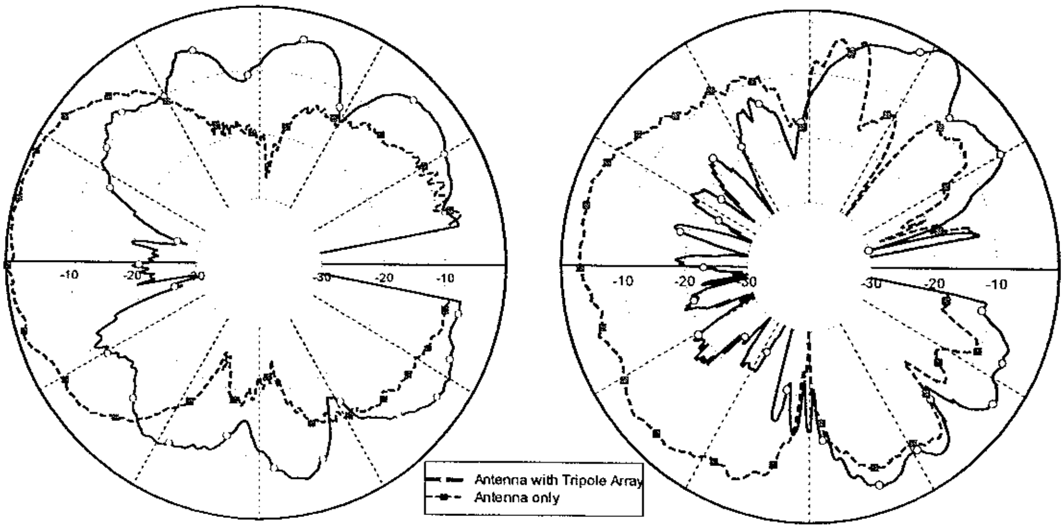

Figure 4b : H and E-plane radiation pattern at 11 GHz

4 CONCLUSION

The band gap and band pass properties for a tripole array on a triangular lattice have been assessed in this paper. The tripole conductor periodic array is shown to produce a large TM and TE band gap. It also possesses overlapping between the TE and TM stopband which is termed as the absolute band gap, whereby the propagation of any electromagnetic wave is prohibited in all directions on the plane. In the passband, the tripole array enhances the gain and directivity of the antenna as it concentrates the fields onto the substrate.

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