REDUCED SIZED CELLS FOR ELECTROMAGNETIC BANDGAP STRUCTURES

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Abstract

Electromagnetic band-gap structures of simple squares are compared to convoluted and interleaved elements to reduce band-gap frequency for fixed periodicity. A reduction of 42% in band gap frequency is obtained for one (Hilbert) convolution. This frequency reduction increases to 55% when adjacent elements in the structure are interleaved.

Introduction

This paper outlines a study incorporating convoluted elements to High Impedance Planes (HIPs) which are formed by Electromagnetic Band Gap (EBG) structures. The aim of the work is to achieve a reduction in structure resonant frequency for a given EBG lattice geometry without requiring the extra complexity of additional capacitive layers.

Electromagnetic Band-Gap (EBG) or Photonic Band- Gap structures are a microwave analogy to optical photonic band gap structures where all mode propagation within the structure is prevented within a certain frequency band, [1]. Radiating elements can be mounted above planar EBGs to form High Impedance Planes (HIPs), [2]. In this configuration the parallel resonance of the band-gap presents an open circuit with a reflection coefficient in phase with the incident electromagnetic fields [2]. The resonant frequency ω_0 of a HIP can be approximated by the surface equivalent capacitance C and inductance L and is given by the expression:

$$\omega_0 = (LC)^{-0.5} \qquad (1)$$

Equation (1) offers a first order calculation of the band-gap frequency while the 'dynamic model', recently proposed in [3], takes into account the field interaction between adjacent cells and shows closer agreement with experimental results.

It is well known that a radiating element placed parallel and close to a conducting plane will suffer a dramatic reduction in radiation resistance due to cancellation from image currents. This can be addressed by replacing the conducting plane with a HIP as radiation efficiency reduction due to image current cancellation will not occur.

The lattice geometries used to create HIPs are straightforward, usually consisting of simple square, ring or hexagonal elements. Figure 1 shows an array of square elements arranged in a square lattice. The elements are shorted to a continuous ground plane with via pins. An equivalent surface capacitance C is formed due to inter-element coupling on the upper surface, while an equivalent surface inductance L arises due to the current path through the via pins and bottom continuous ground plane. The constraint that surface elements must fit within the lattice period p means that low frequency designs will be of large size, and this could cause difficulties when space is limited or curved surfaces must be conformed to without element distortion. It is therefore beneficial to minimise the size of the individual elements for a given resonant frequency. This has been achieved by increasing the surface capacitance C with the introduction of an additional element layer which overlaps the original elements [2]. This technique successfully brings down the operating frequency, but at the expense of extra structural complexity and reduced bandwidth as the relative bandwidth $\Delta\omega/\omega$ is proportional to $\sqrt{L/C}$. In this paper we will present an alternative approach where HIPs with convoluted elements reduce the high impedance frequency without the need for extra surface layers.

Convoluted Element HIPs

Four different element types will be compared in this study. The first provides a reference and consists of simple squares, Fig.1. Designs 2 and 3 use the square lattice of Fig.1 and have two and three orders respectively of a convolution technique devised by Hilbert which has been applied to periodic structures in [4]. The final design is a modified version of design 2 where adjacent elements are interleaved. This has been done to introduce an extra end capacitance [5]. Element designs of 4 cells are included in Table 1. In all designs the elements were shorted at their centres to a continuous ground plane by 0.45mm diameter vias. Each surface consisted of a 12 by 12 element array with a lattice period of 8.25mm. All surfaces were mounted on a substrate with height h equal to 2.0 mm and a relative permittivity of 3.5.

Each surface was simulated using Ansoft HFSS and the band gap frequencies were verified using a TE and TM mode transmission measurement technique reported by Sievenpiper in [2]. TM surface waves are cut off by the lower edge of the band gap while the upper edge is defined by TE mode transmission. The results were compared to those for a simple conducting sheet with the same overall dimensions as the HIPs. The band gap was defined as the frequencies at which the TM and TE mode S21 magnitudes were more than 5 dB below those of the reference conducting plane. The measured band gap centre frequency and width is given in table 1 for each design.

Measurements for the solid square patches of design 1 show the band-gap to be centred on 4.06GHz. An improved use of the square cell shape is made by the space filling Hilbert curves of designs 2 and 3. In these designs the area around the cell diagonals is efficiently filled, while path length is kept large by using only orthogonal conductor components. Design 6 consists of a modified 2 cycle Hilbert curve where adjacent elements interleave. Comparing measurements for designs 2 and 3 to the square elements of design 1 clearly shows that there is a reduction in band gap frequency for convoluted elements and this effect is most marked when the order of convolution is increased. Table 1 shows there is a substantial fall in band gap frequency of 42% for a 3 cycle Hilbert convolution (design 3). Furthermore, measurements for design 4 indicate that band-gap frequency is reduced by 55% compared to design 1 when the convolution is interleaved. In this case the element size is larger than the lattice periodicity. Measured normalised transmission curves are shown in Fig.2 where the curves have been referenced to an identical size conducting ground plane. The band gap has remained almost constant for all 3 Hilbert designs. Hilbert elements are regarded as narrow band Frequency Selective Surface (FSS) elements and it is anticipated that the band gap width could be enhanced for these curves by widening the element tracks. This is difficult to achieve in practice at these frequencies due to etching problems as adjacent lines would become very close. It is also possible to improve the band-gap width by increasing the substrate height.

Published results for half wave dipoles placed immediately adjacent to convoluted element HIPs show the antennas to remained matched and demonstrate a bore-sight gain increase of 6dB, [5]. This confirmed that the surface does present the expected reflection coefficient of +1.

Conclusions

Use of convoluted elements in High Impedance Ground Planes has resulted in a significant fall in the frequency of the structure band-gap. Measurements reported in [5] have shown that a tangential dipole can be placed in close proximity to the HIP without degradation to the input match and the radiation patterns are enhanced in gain by 6dB at bore-sight over free space values.

It has been shown that Hilbert space filling curves offer a substantial reduction in band gap frequency of 42% for a given lattice periodicity. It has also been demonstrated that interleaving adjacent Hilbert convoluted elements increases the frequency reduction to 55%, though the high surface capacitance makes them narrow band-gap in nature.

References

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List of figures:

Figure 1: High impedance surface, Design 1: Square lattice of square elements, $l/P = 0.91$.

Figure 2: Surface wave transmission.

_________ TM mode

-□-□-□- TE mode

Table 1: Band-gap measurements of high impedance designs.

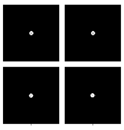
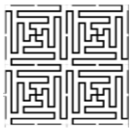
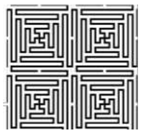
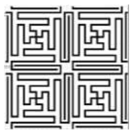
Design	1 	2 	3 	4 
l/p	0.91	1.0	1.0	1.06
Band gap centre frequency f_c (GHz)	4.06	2.91	2.35	1.81
Reduction in f_c	-	28.3%	42.2%	55.4%
Band gap width (MHz)	445	110	100	95
Band gap as %age of f_c	11.0%	3.8%	4.3%	5.2%

Figure 1

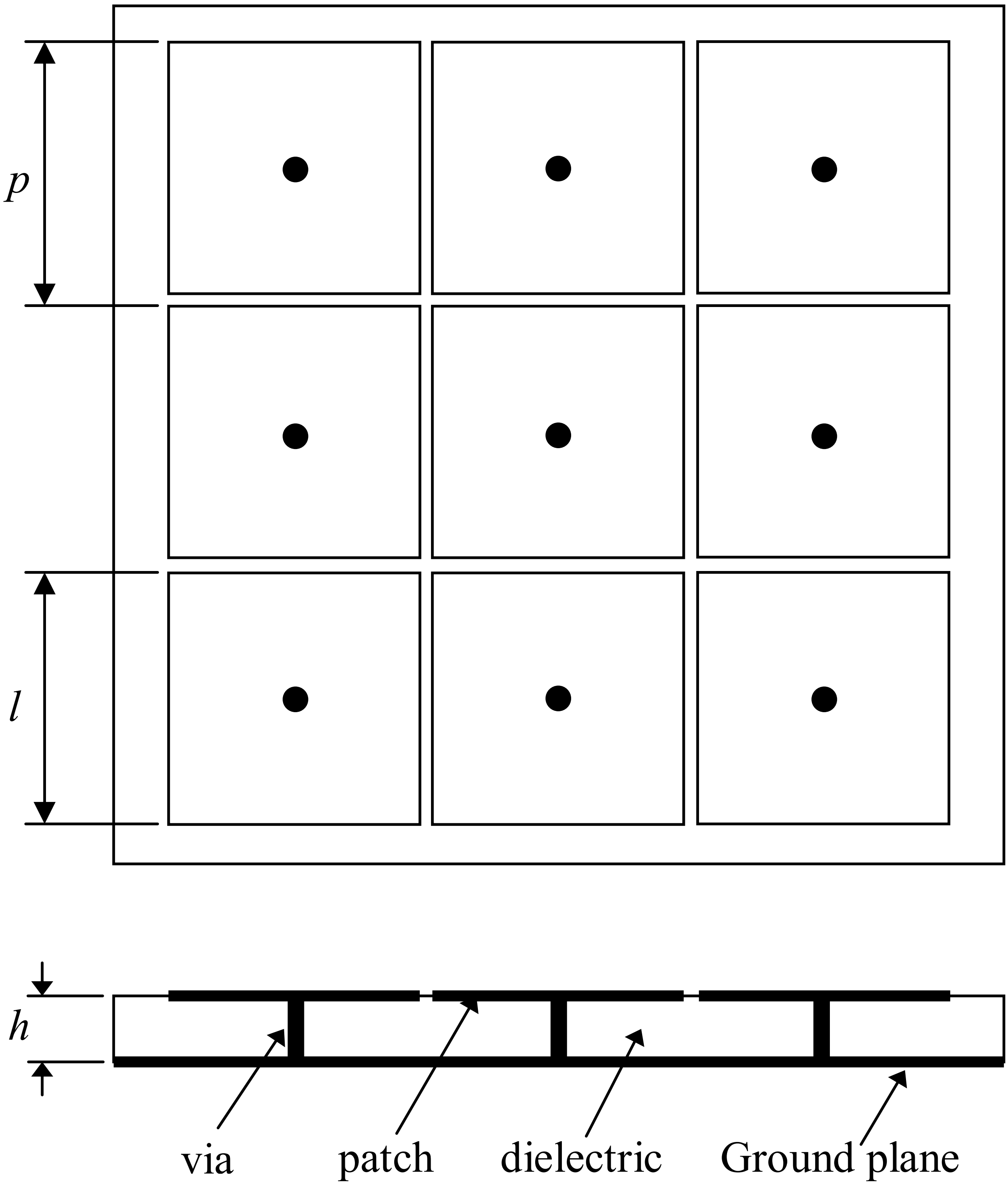
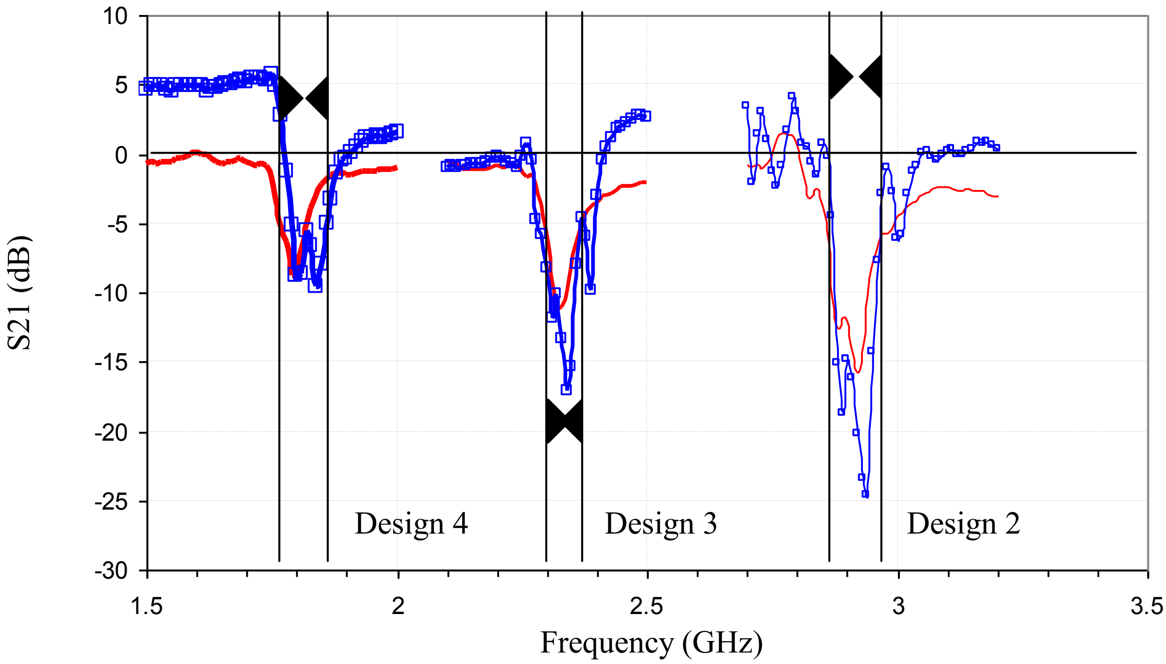


Figure 2


10
5
0
-5
-10
-15
-20
-25
-30
S21 (dB)
Design 4
Design 3
Design 2
1.5
2
2.5
3
3.5
Frequency (GHz)