The design of miniature Electromagnetic Band Gap (EBG) ground plane

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1. Introduction

Electromagnetic Band Gap (EBG) is originated from Photonic Band Gap (PBG) structure. They both are periodic structure for forbidding the transmission of certain frequency bands of electromagnetic wave. However, the design of early PBG structures was too large to apply in practical usage. In 1999, Dr. Sievenpiper from UCLA modified corrugated metal stub surface [1-2] and small metal bumps surface [3] to build the mushroom EBG ground plane [4]. Dr. Sievenpiper etched periodic hexagonal patches on top of FR4 substrate and drilled holes to connect the hexagonal patches with the ground plane on the bottom of the substrate. The electric field between the patches creates capacitance effects; the current through the vias of the top and bottom substrate creates inductance effects. The equivalent inductance and capacitance of EBG plane can be represented as LC parallel circuit. The frequency of electromagnetic wave within the resonate frequency of the LC parallel circuit can not propagate through the EBG ground plane.

Due to the advantages of small size, low cost and ease fabrication, many research institutes have focused on the applications of EBG ground plane, such as, microstrip antenna [5], band stop filter [6], and RFID [7]. However, the dimensions of EBG ground plane are proportional to the wavelength of electromagnetic wave; therefore, the size of EBG is too large to be used at low frequency bands. This paper proposes two methods to minimize the EBG ground plane. The first method uses meander path to increase the current path for increasing the inductance effects and interdigital structure at the edge of patches to increase the capacitance effects. The second method removes the connecting wire and implements chip inductor within the through hole between top and bottom substrate. From the experimental results, both methods successfully decrease the band gap frequency under the same unit cell size.

2. Design of the basic EBG ground plane

The EBG plane is fabricated on FR4 substrate with thickness (P) of 1.6 mm and relative permittivity of 4.4. In the center of the patches, through holes (H) with diameter of 1 mm is used to connect the top and bottom sides of substrate. Fig. 1(b) is the side view of the basic EBG ground plane. Connected wires between the top and bottom layers can be seen. A 50-Ω microstrip line placed above the EBG plane is used to measure the band gap frequency. Fig. 2(a) shows the illustration of EBG measuring

Fig. 3(a) shows the measured results of S11 and S21 with 5 mm period. The 10 dB band gap frequency from 5 to 8 GHz can be seen. For reducing the band gap frequency, the period of cell is increased to 10 mm. Fig. 3(b) shows the measured results of S11 and S21 with 10 mm period. The 10 dB band gap frequency from 2.5 to 3.9 GHz is lower than that of Fig. 3(a).

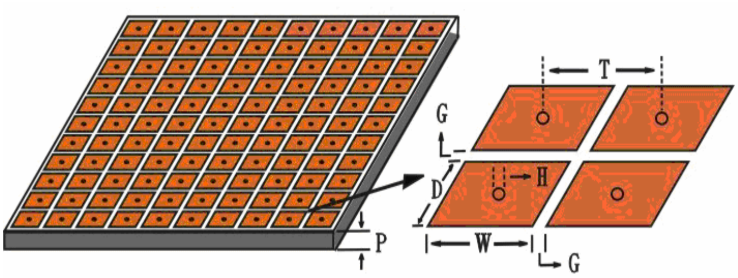


Figure 1(a): The structure and dimensions of the basic EBG ground plane

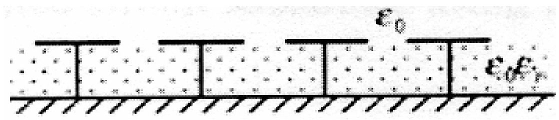
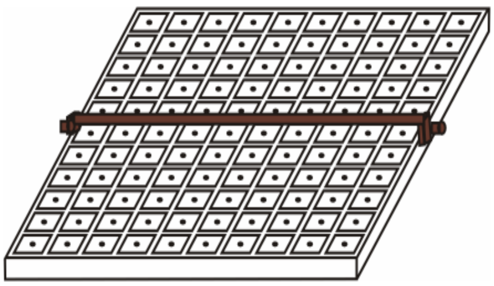
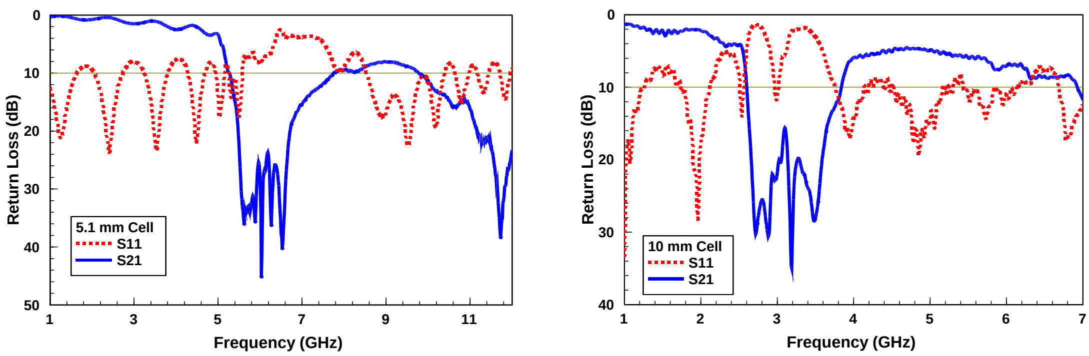


Figure 1(b): The side view of the basic EBG ground plane



2(a)

Figure 2(a): The illustration of measuring EBG plane

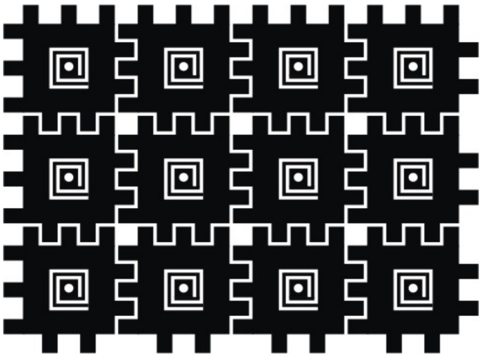


3(a) 3(b)

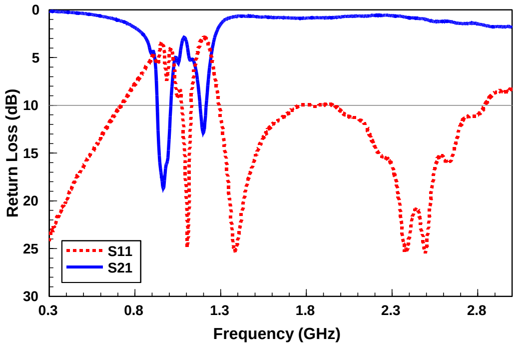
Figure 3: The measured results of S11 and S21 of the basic EBG plane with (a) 5 mm, (b) 10 mm

3. Miniaturization of EBG ground plane

Another problem occurred when the size of EBG plane becomes too large for low frequency applications. To decrease the band gap frequency without increasing the EBG size, the meander path in the center of cells and interdigital structure between the cells are used to increase the LC equivalent values. Fig. 4(a) shows the meander path and interdigital structure EBG plane with 10 mm period. Fig. 4(b) shows the measured results of S11 and S21. Two frequency band gaps centered at 0.95 and 1.2 GHz are much lower than that of basic EBG structure.



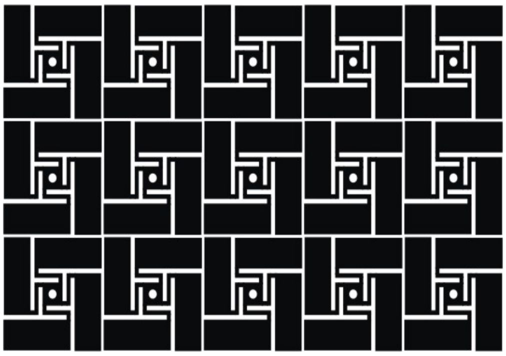
4 (a)



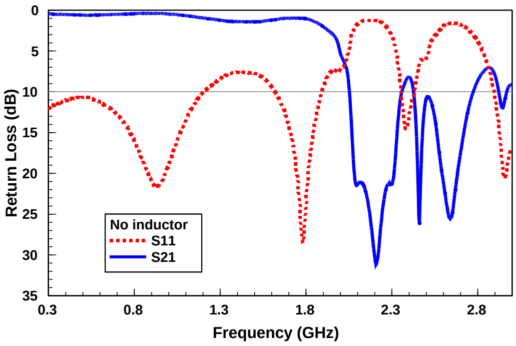
4(b)

Figure 4(a): The structure of meander path and interdigital EBG plane with 10 mm period, 4(b) the measured results of S11 and S21.

Fig. 5(a) shows the four-section EBG ground plane structure. The period of cell is still 10 mm, and the cell is divided into four sections with meander path at the center of cells. The four meander paths in one cell result in four parallel inductances, which reduce the equivalent inductance. Fig. 5(b) shows the measured results of S11 and S21. From the result of S21, the band gap frequency from 2 to 2.8 GHz is a little lower than that of basic EBG structure with 10 mm period.



5 (a)



5(b)

Figure 5(a): The four-section EBG plane structure, 5(b) the measured results of S11 and S21

The other method for minimizing EBG plane is to implement chip inductor into the through hole of EBG ground plane. Figure 6 shows the measured results of S21 with different values of chip inductors. When the value of chip inductor gets larger, the band gap frequency moves to lower frequency range.

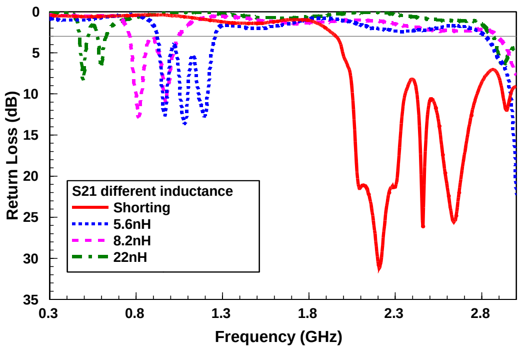


Figure 6: The measured results of S21 with different values of chip inductors

4. Conclusions

The compact EBG ground plane is proposed and investigated in the paper. To decrease the band gap frequency, the size of EBG cell has to be increased; however, larger EBG cell prohibits its applications. Using meander path and interdigital structure success decrease the band gap frequency within the same size of EBG cell. Another method to decrease the band gap frequency is to implement chip inductor into the through hole of EBG ground plane. The experiment results show the band gap frequency moves to lower frequency range while the chip inductor has larger value.

Acknowledgement

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