Study of EBG Structures using Metamaterial Technology

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In the field of electromagnetic wave engineering, the recent interest is on metamaterial technology, and application of EBG (Electromagnetic Band Gap) structure utilizing this technology to noise suppression and interference control is under consideration. The point to be noted here is that EBG structure can be fabricated using conventional printed circuit board (PCB) materials and manufacturing techniques, thus has the possibility of use in variety of applications.

Oki Printed Circuits has been working on a prototype of a compact via-less EBG structure with a stopband in the vicinity of 2GHz to evaluate the effectiveness of the PCB-based EBG structure[1].

This article will describe the design method and evaluation results of the compact via-less EBG structure under development.

Metamaterial

Metamaterial is defined as an artificial material or synthetic structure with properties not normally present in nature[2]. In particular, a structure configured by arranging units of material pieces smaller than a wavelength side-by-side and given electrical properties is referred to as electromagnetic metamaterial. Formation of such a structure enables free control of electromagnetic permeability and permittivity. A negative refractive index medium in which permeability and permittivity simultaneously becomes negative is an example. An electromagnetic wave in negative refractive index medium tends to have a phase velocity direction that is opposite from the group velocity direction. In recent years, there have been various metamaterial proposals that make use of these unique properties[3].

Metamaterials using PCBs

Variety of metamaterials have been studied thus far, but many of the flat-sheet structured metamaterials can be achieved with PCBs. Implementing metamaterials with PCBs has the following advantages;

1) Fabrication is possible using conventional materials and manufacturing techniques, and existing design and evaluation environment can be utilized.
2) Thickness is virtually zero.
3) Since properties depend on the high manufacturing precision of the PCBs, variations are very small.
4) Actual measured values are highly consistent with simulation values, and properties can be easily determined at the design stage enabling reduction in the number of prototypes.

Characteristics and Issues of EBG Structure

(1) Characteristics of EBG Structure

EBG structure is one of the metamaterials with the property to suppress electromagnetic wave propagation (stopband) in a particular frequency band. It is formed from unit cells composed of conductors and dielectrics arranged periodically in either a single row or columns of multiple cells.

On a PCB, EGB structure can be obtained by forming a periodic pattern. The board material and pattern shape determine the electrical properties of the structure.

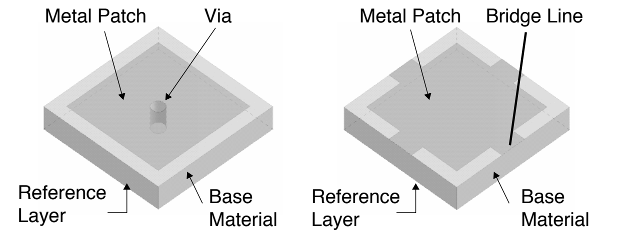
The characteristic of the EBG structure to block electromagnetic waves in a particular frequency band can be used in a variety of suppression needs such as mutual coupling between antennas, interference between circuit blocks and noise of a certain frequency.

(2) Common EBG Structures

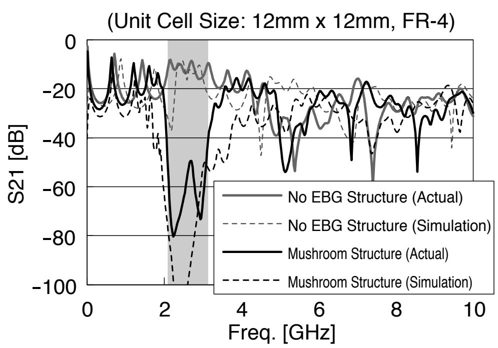
1) Mushroom EBG Structure

Mushroom EBG structure is configured from via-mediated metal patches arranged periodically on the reference layer (**Figure 1 (a)**). An example of the structure's transmission properties is shown in **Figure 1 (c)**. Mushroom EBG structure configured in this way is known as a composite right/left-handed transmission line, and between the right-handed and left-handed frequency bands is the stopband[4].

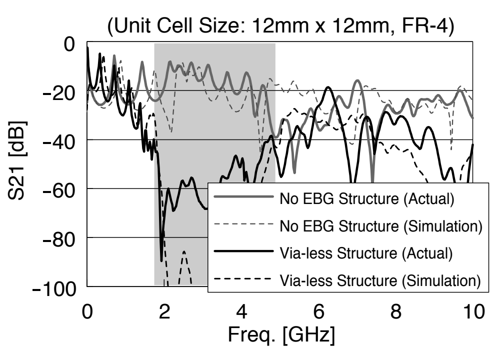
Due to the addition of the metal patch layer and the need for a connection via such as IVH (Interstitial Via Hole), mushroom EBG structure increases manufacturing cost. On the other hand, since the reference layer itself is left as is and mushroom structures are added to applicable places, the structure is considered effective for applications requiring high currents.



(a) Mushroom EBG Structure (b) Via-less EBG Structure



(c) Example Transmission Properties of Mushroom EBG Structure



(d) Example Transmission Properties of Via-less EBG Structure

Figure 1. EBG Structures

2) Via-less EBG Structure

In a via-less EBG structure, unit cells composed of metal patches and bridge lines to connect them are periodically arranged on a layer that opposes the reference layer (**Figure 1 (b)**).

Via-less EBG structure configured in this way can be viewed as periodically-arranged parallel circuits of inductors and capacitors with a stopband attributed to their resonance (**Figure 1 (d)**). Additionally, if the structure is considered in conjunction with the capacitive component formed between the opposing layers, it is possible to give the structure a stopband of the composite right/left-handed transmission line.

Via-less EBG structure does not require via or new layers, and it can be formed only with the patterning of the applicable layer.

(3) Issues with EBG Structures

Properties of the EBG structure are determined by the PCB material and pattern shape. Therefore, the size of the unit cells that form the periodic structure significantly affects the stopband frequency. **Figure 2** shows the relationship between the frequency at which the stopband appears and unit cell size. It can be seen that the two are in a trade-off relation. For instance, when suppressing noise in general electronic equipment, if the target frequency is low, the unit cell size must be large. However, if the unit cell size is made small for easier implementation into the electronic equipment, the stopband frequency becomes high. The unit cell must be compact for utilization in general electronic equipment, but simple compactness is difficult.

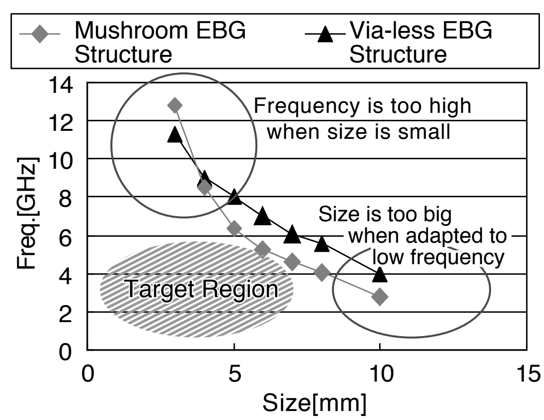


Figure 2. Stopband and Unit Cell Size

Study to Compact EBG Structure

In this study, via-less EBG structure with its low cost and high degree of design freedom was investigated utilizing the existing manufacturing process. The target frequency was the familiar 2.4GHz band used for wireless LANs. Passive components for that frequency band are typically expensive, and use of those components increases cost. However, if the functions of those electronic components can be applied using via-less EBG structure consisting only of patterns, it would lead to cost reduction. Therefore, a study was performed to obtain a compact EBG structure with a stopband in the vicinity of the target frequency.

(1) Equivalent Circuit

The equivalent circuit of via-less EBG structure is shown in **Figure 3**. The structure can be represented as a circuit in which the metal patch L_1 and capacitance C_1, between the metal patch and reference layer, is connected by bridge line L_2 and inter-cell capacitance C_2.

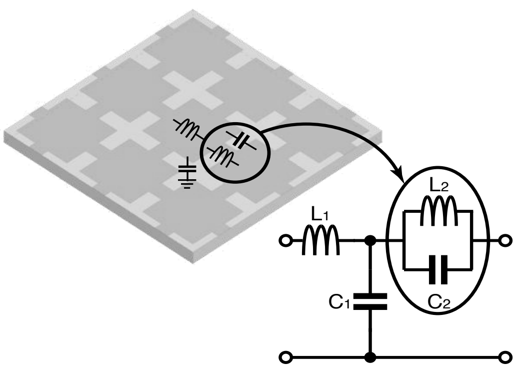


Figure 3. Equivalent Circuit of Via-less EBG Structure

Resonant frequency of the LC resonant circuit due to L_2 and C_2 is:

$$f = \frac{1}{2\pi\sqrt{L_2C_2}}$$

This resonance suppresses propagation and gives the structure a stopband. In order to obtain a stopband in the low frequency band, it is necessary to increase L_2 and C_2.

(2) Design of Compact Via-less EBG Structure

Since cell size needs to be small, large capacitance between cells is difficult to achieve. Therefore, in order to obtain the required stopband in the low-frequency region, a pattern that increases the inductance of the bridge line must be designed. This means making the line thin and long as much as possible to be effective for compact, low-frequency use. To achieve such a via-less EBG structure, a thin bridge line was routed through the cell with 1) a bending pattern at a given location, 2) a meandering pattern and 3) a spiraling pattern as shown by the arrows in **Figure 4** to extend length hence increase inductance. Stopband performance from 2GHz was confirmed by simulation and actual measurements of a compact via-

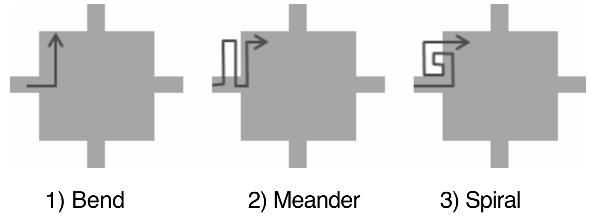
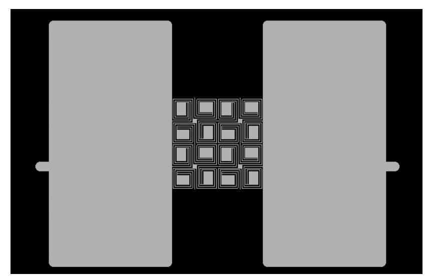


Figure 4. Bridge Line Design Methods

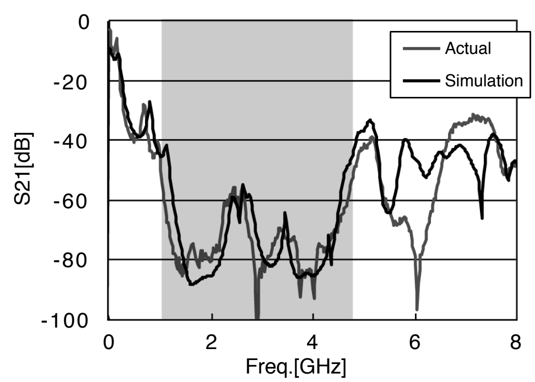
less EBG structure designed using a 5mm x 5mm unit cell and patterns 1) ~ 3).

The example pattern design and transmission properties are shown in **Figures 5 (a)** and 5 **(b)**, respectively. A stopband around the 2GHz range using conventional structures would most often require unit cell size of 10mm x 10mm or greater. However, with proper design of the bridge line, stopband below 2GHz is possible in a unit cell size of about 5mm x 5mm.



2 x 2 Arrangement of Unit Cells (5mm x 5mm)

(a) Pattern Example



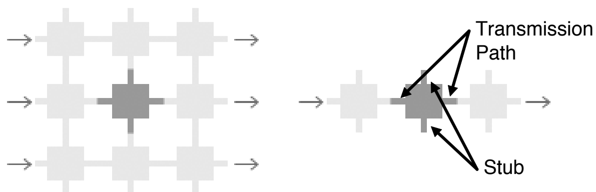
(b) Transmission Properties

Figure 5 . Example of Compact Via-less EBG Design

(3) Design of Single Row Compact Via-less EBG Structure

Assuming the actual implementation of the examined EBG structure into electronic equipment, it is likely further compactness will be required. Therefore, a study was conducted to further compact the via-less EBG structure for integration into Wi-Fi and other electronic equipment that operate in the 2.4GHz band.

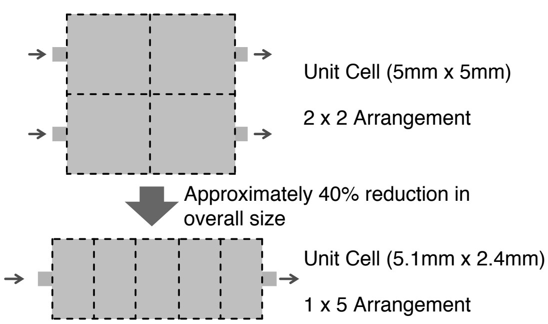
Arrangement of the unit cells was changed from two dimensions to a single row (**Figure 6**). Due to the single row arrangement, some of the bridge lines for connecting adjacent unit cells become unnecessary. These bridge lines were eliminated, and by reworking the routing of the remaining bridge lines, further compactness can be expected.



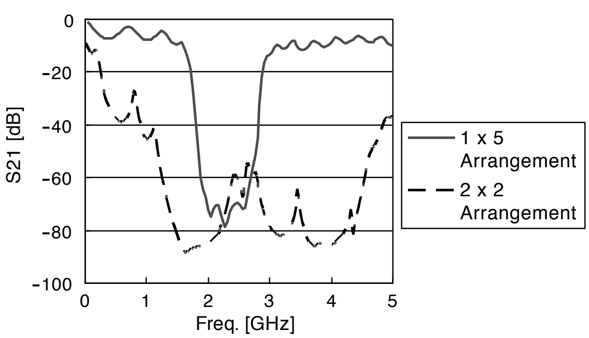
(a) Two Dimensional Arrangement (b) Single Row Arrangement

Figure 6. Unit Cell Arrangements

More specifically, as shown in **Figure 7**, five 5.1mm × 2.4mm unit cells were arranged in a single row and designed to have a stopband with a center frequency of 2.4GHz. Simulation confirmed this arrangement has a stopband about 1GHz wide in the vicinity of 2.4GHz. Although the stopband width is narrower than the other via-less EBG structures that were studied, the unit cell size is approximately half, and overall size has been reduced 40%. In addition, the stopband can be controlled with the optimization of the pattern that forms the unit cell.



(a) Images of Unit Cell Arrangements



(b) Example of Transmission Properties

Figure 7. Example Design of a Single Row Compact Via-less EBG Structure

Summary

As an application of metamaterial technology, a compact via-less EBG structures were created using PCBs and shown that further reduction in size is possible. These EBG structures can be fabricated using conventional PCB manufacturing techniques. This enables electronic circuit functions of certain passive elements to be achieved with PCB patterns, and deployment in a variety of applications can be expected. ◆◆

■ References

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Note: Titles and organizations are current as of March 2012

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