Improvement of Simultaneous Switching Noise Suppression of Power Plane using Localized Spiral-Shaped EBG Structure and λ/4 Open Stubs

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Abstract— **In this paper, we propose a localized spiral-shaped EBG structure which can effectively suppress simultaneous switching noise (SSN) when the power plane drives high-speed ICs on a small area. Also we present a new technique to greatly improve resonance notch in a stopband by utilizing λ/4 open stubs in a conventional periodic EBG power plane. Numerical simulations are performed using commercially available 3D electromagnetic field simulator for both proposed structures. The results show they have better performance for SSN suppression, compared to conventional periodic EBG structures.**

Keywords-component; simultaneous switching noise (SSN), Electromagnetic Bandgap (EBG), spiral-shaped EBG structure, resonance notch suppression

I. INTRODUCTION

Today, as the demand for the digital system with higher speed and wider bandwidth grows, the clock frequency becomes increasing with a fast edge rate. Therefore simultaneous switching noise (SSN) or ground bounce noise (GBN) that are caused by rapid time-varying currents on a package or multilayer PCB become an important issue in a high-speed digital system. The SSN affects signals passing through peripheral via holes and causes electro-magnetic interference (EMI). A typical method for mitigation of the SSN is to use a decoupling capacitor between power plane and ground plane. However, the decoupling capacitor is not effective in the frequency region higher than 600 MHz because of parasitic inductance in itself [1],[2].

As an approach in GHz region, the power/ground plane design using electromagnetic bandgap (EBG) or photonic bandgap (PBG) structures has been extensively studied recently. The EBG structure is the high impedance surface that has a perfect magnetic conductor (PMC) at a specific frequency band and blocks surface currents [3]. First, a mushroom type EBG structure which consists of metal pads connecting to the ground plane through via holes was proposed. But it is so complicated to manufacture and is not cost-effective because of the multilayer structure [4],[5].

Then the power plane that utilizes a low period EBG structure with keeping the ground plane solid was proposed [6]-[10]. Fig. 1 shows conventional EBG unit cells for the power plane design [6],[10]. They are rectangular or hexagonal structures and the unit cell size is 30 mm×30 mm in most cases. The EBG unit cells are periodically and uniformly distributed on a whole power plane, which results in many surfaces of discontinuity. The surfaces of discontinuity have a bad effect on signal return currents following the reference plane, therefore it can cause a signal integrity (SI) problem. In addition, the performance of these EBG structures is dependent on the port location, so it is not easy to use them widely in a realistic situation [11]. If the digital system requires few driver ICs, we do not need to use the periodic EBG structures which may lead to degradation of signal integrity sometimes due to the surface discontinuity.

In section Ⅱ, we propose a spiral-shaped EBG structure which locates itself only around the via holes generating the SSN when the power plane supplies power to the driver ICs. To verify its performance, 3-dimensional electromagnetic field simulation is performed using the commercial software of Microwave Studio [12]. And also in section Ⅲ, we present a technique to eliminate resonance notches of the conventional EBG structures in the stopband by inserting λ/4 open stubs. The proposed approaches are numerically simulated and compared with the conventional EBG methods. The measured results of both proposed structures are presented and compared with the simulation results. Finally, both proposed structures are validated and summarized.

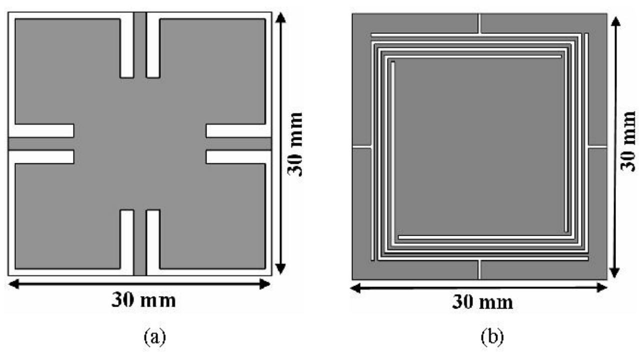

Figure 1. Conventional EBG unit cells. (a) Basic rectangular cell [6] (b) Hybrid-cell [10]

II. LOCALIZED SPIRAL-SHAPED EBG STRUCTURE

To compare their performances when the typical EBG unit cells are used locally, we simulate and measure the localized EBG structure and periodic EBG structures in Fig. 2 while

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maintaining the same unit cell size as the unit cell in Fig. 1. The periodic EBG structure consists of 9 unit cells (3×3). In the localized EBG structure, the power plane is kept a solid plane except around the ports as shown in the Fig. 2(c) and Fig. 2(d). The substrate conditions are as follows. The relative dielectric constant and thickness of the substrate are 4.1 and 0.4 mm, respectively. Total substrate size is 90 mm×90 mm.

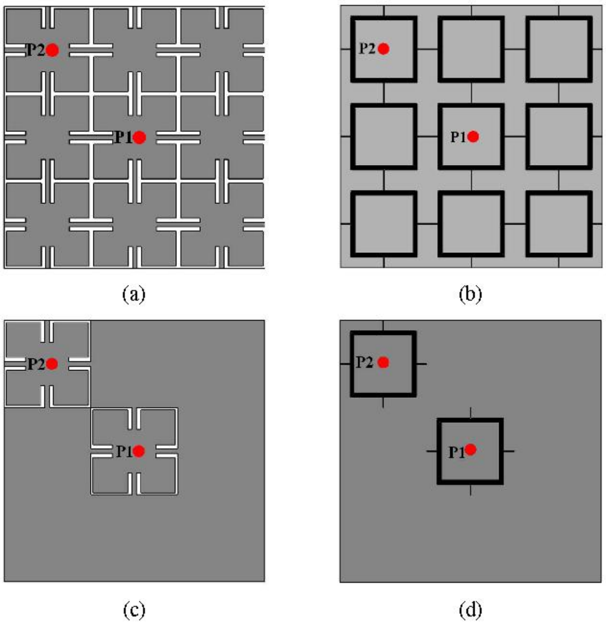


Figure 2. Periodic and localized EBG structures. (a) Periodic EBG structure of the basic rectangular cells [6] (b) Periodic EBG structure of the hybrid-cells [10] (c) Localized EBG structure of the basic rectangular cells (d) Localized EBG structure of the hybrid-cells

Fig. 3 shows the measured results of the EBG structures in Fig. 2. They show that the localized EBG structure has very similar performance to the conventional periodic structure if the unit cell size is maintained to be same (30 mm×30 mm). But as shown in Fig. 3, if the unit cell size reduces to 15 mm×15 mm, the performance of the localized EBG structure can be greatly deteriorated and cannot suppress the SSN well.

To achieve good SSN suppression with small EBG cells, we propose the spiral-shaped EBG structure. The proposed EBG cell and its numerical simulation and measured results are presented in Fig. 4. The structure has a hexagonal spiral shape and extends a thin line around the hexagonal shape to increase its inductance for efficient noise suppression at low and high frequency regions. As shown in Fig. 4(a), the proposed unit cell has an inner hexagon with a diagonal line of 12 mm and three turns of the metal line that connects the power plane. The width and the gap of the metal line around the hexagonal pad are 0.2 mm, respectively. The substrate conditions are same as them in Fig. 3. The ports on the PCB are located at the same positions as in Fig. 2(c) and Fig. 2(d). The SSN suppression characteristics of the proposed structure are presented in Fig. 4(c). As shown in the figure, the measured results are similar to the simulated ones.

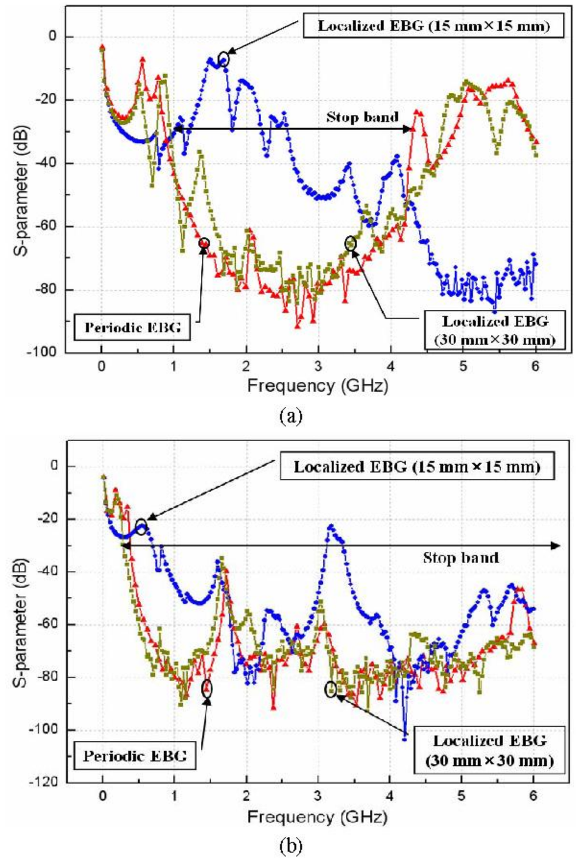


Figure 3. Measured results of periodic and localized EBG structures. (a) S_{21} of the basic rectangular cell (b) S_{21} of the hybrid-cell structure

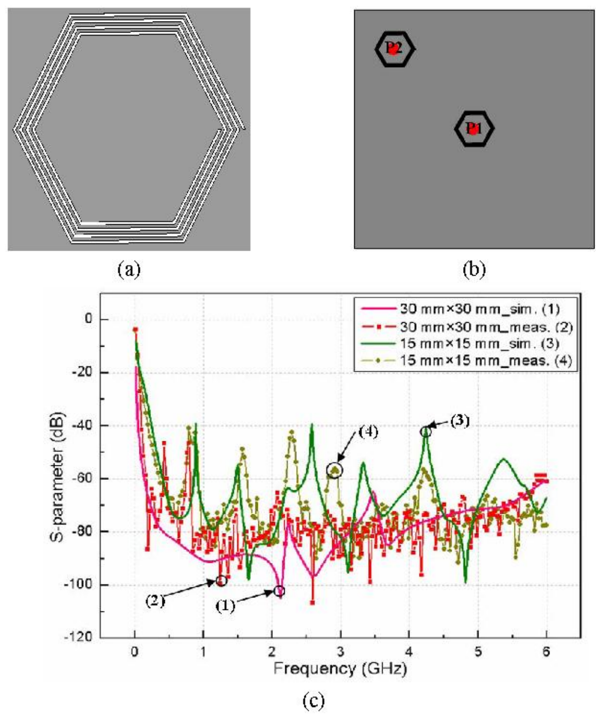
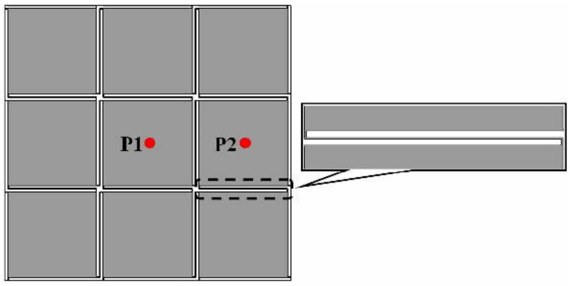
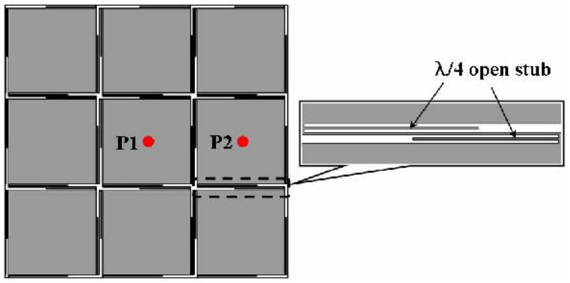


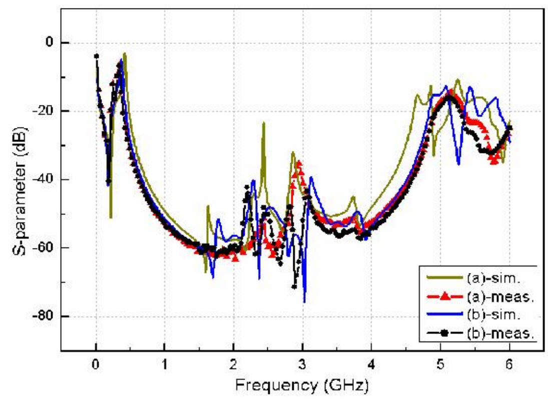
Figure 4. The spiral-shaped EBG structure and its simulated/measured results. (a) The proposed unit cell (b) The localized EBG structure (c) The simulated and measured results of the proposed localized EBG structure



(a)



(b)



(c)

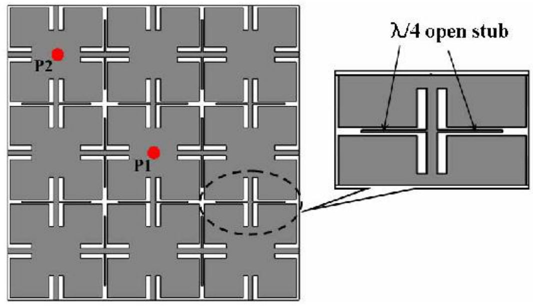
Figure 5. Conventional and modified L-bridge EBG structures. (a) Conventional EBG structure [8] (b) Modified EBG structure with λ/4 open stubs (c) Simulated and measured results

Based on the -30 dB suppression level, the proposed structure has a wide stopband from 0.1 GHz to more than 6 GHz. And the noise suppression is very stable because it appears below -40 dB in the stopband. The suppression characteristics of the proposed EBG unit cell are better than them of the previous conventional EBG cells when it is locally used with the same cell size as well as reduced cell size.

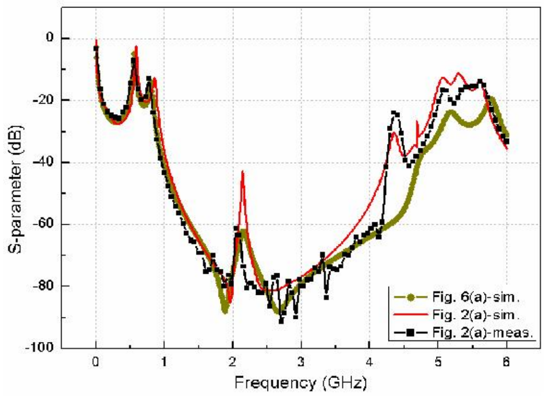
Although there still remains the optimization process for minimizing power plane impedance at the low frequency, the proposed structure provides a possibility to efficiently confine the SSN to the ports in the cases that the driver ICs are densely integrated on a small area.

III. Modified EBG Structure for Resonance Notch Suppression by Open Stubs

We can see some resonance notches in the simulated and measured S-parameter results of the conventional EBG structures in the stopband region. These notches may cause unpredictable resonance to degrade signal integrity and to radiate the interfered signal outside. For more stable SSN suppression, we propose a technique to selectively eliminate the notch at a specific frequency by introducing λ/4 open stub into the EBG structure. The added λ/4 open stub makes an electrical short at that frequency and suppresses the noise signal.



(a)



(b)

Figure 6. Modified EBG structure (a) Modified EBG structure with λ/4 open stubs (b) Simulated and measured results

Fig. 5(a) and Fig. 5(b) show the conventional and modified L-bridge EBG structures, and the simulated and measured results are also displayed in Fig. 5(c). The simulation shows that the conventional EBG structure has resonance notches at about 2.4 GHz and 2.86 GHz [8]. We tried to suppress 2.4 GHz and 2.86 GHz notches using the modified L-bridge with two open stubs. The widths of L-bridge and the open stub between the unit cells are 0.2 mm. The lengths of two open stubs are 18.86 mm and 15.82 mm respectively. They may be calculated from ADS LineCalc. The two stubs are attached at both sides of the bridge between the EBG cells as shown in Fig. 5(b). The same substrate data are used for the S-parameter simulation as in the previous simulation. According to the simulated results of Fig. 5(c), the open stubs improve the suppression to the level lower than -50 dB at target frequencies, which is a greatly improved result. And the measured results are also presented in Fig. 5(c). Although the measured data of the conventional structure has no serious notch at 2.4 GHz, they are very similar to the simulation and show the S-parameter characteristics below -40 dB on the whole by $\lambda/4$ open stubs.

To validate the SSN suppression effect of the open stubs, we also apply the same technique to another conventional EBG structure of Fig. 2(a). In this structure, to improve 4.4 GHz notch characteristic in the measured result, $\lambda/4$ open stubs with the length of 9.91 mm and the width of 0.5 mm are attached at both sides of the bridge between the EBG cells as shown in Fig. 6(a). The simulated results are given in Fig. 6(b). They show that the notch suppression is achieved below -60 dB at 4.4 GHz, which is greatly improved result. By suppressing the notch at the edge of the stopband, a wider bandwidth can be achieved through the modified EBG structure with $\lambda/4$ open stubs. Therefore, the modified EBG structure provides not only the more stable SSN suppression characteristic but also the wider stopband than the conventional EBG structures.

IV. Conclusion

In this paper, we proposed the spiral-shaped EBG cell to effectively suppress the SSN around the ports and provided its simulated and measured results. The proposed structure can be widely used in the cases that few driver ICs are used or driver ICs are densely located on a small area in the high-speed digital system. And we also proposed the new technique to suppress the notch at the specified frequency by using $\lambda/4$ open stubs. This technique provided the more stable SSN suppression than the conventional EBG structures. To verify the performance of our proposed structures, extensive 3D EM simulations were performed using commercially available software and the results were presented. And the experimental results supporting the simulation data were also presented.

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