Progress In Electromagnetics Research Letters, Vol. 15, 69–77, 2010

NEW STRUCTURE OF COMPOSITE POWER PLANE USING SPIRAL EBG AND EXTERNAL MAGNETIC MATERIAL FOR SSN SUPPRESSION

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Abstract—A new structure of composite power plane with a spiral electromagnetic bandgap (EBG) and an external magnetic material is proposed for the suppression of simultaneous switching noise (SSN) in the mixed-signal systems. The new structure proposed in the present research is designed with an external magnetic material and the spiral EBG structure. The new structure is relatively simple to fabricate and cost effective because the external magnetic material is partially placed on the top of perforated spiral-bridged EBG plane. The EBG bandgap is shifted to lower frequencies by the real part of the permeability (μ_r'), and the power plane Q-factor is also decreased by the imaginary part of the permeability (μ_r'') associated with the magnetic loss. It is expected the reduction of a circuit size and an improvement of the power integrity with the mixed-signal systems in the given new structure.

1. INTRODUCTION

Mixed-signal systems incorporating both of analog and digital circuits require high clock frequencies, fast edge rates, and low voltage levels. The simultaneous switching noise (SSN), also known as the delta-i noise or the ground bounce noise (GBN), has been dealt with one of the major concerns in the mixed-signal systems. Resonant modes of the parallel plate waveguide severely affect both of the signal integrity (SI) and the power integrity (PI), when the SSN is excited between power and ground planes. Moreover, the SSN causes various electromagnetic interference (EMI) problems such as the radiated emission [1, 2].

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Several researchers have been investigated for the blocking of the SSN propagation in the power systems [3–11]. Conventional methods are to use decoupling capacitors or embedded capacitors, which is placed between power and ground planes [3, 4]. However, the decoupling capacitors operate in the range of a few hundred megahertz by their parasitic inductance, and the embedded capacitors having less inductance still have the frequency limitation of 1 GHz with the manufacturing difficulty.

Recently, the electromagnetic bandgap (EBG) structures are proposed for the SSN suppression in the frequency range above 1 GHz [5–11]. The EBG structures have a forbidden bandgap in the form of distributed LC networks realized by capacitive metal cells connected by narrow inductive lines [5]. Because of their geometrical dependence of the resonant frequencies, the sizes of conventional EBG structures are very large for most of modern high density PCB systems. Several EBG structures [6–11] have been attempted for the reduction of the resonant frequency and its size. An S-bridged EBG structure [8] is to increase the effective inductance by extending the inductive path between the unit-cells. A material approach inserting a magnetic material between the power and the ground planes [11] has been firstly proposed for a miniaturization of structure and power integrity. However, it is expected that the manufacturing process will be difficult because the magnetic material is placed between EBG patterned plane and solid plane shown in the reference paper [11].

In the present research, a new structure of composite EBG power plane having a magnetic material outside the power plane is introduced for the suppression of SSN. A good thermal reliability and easy fabrication effects are obtained from the new structure of composite power plane. Also, the reduction of size with the power integrity is successfully achieved with use of the magnetic material and the spiral-shaped EBG structure.

2. NEW STRUCTURE AND MAGNETIC MATERIAL

Figure 1 shows design of the new structure proposed in the present research, where an external EMI suppression sheet (Jahwa electronics) is partially placed on the spiral inductors. Three coaxial ports are built at the centers of the unit cells for the SSN measurements. The proposed structure with 3 × 3 unit cells, was fabricated using a double-sided FR-4 substrate ($\varepsilon_r = 4.4$) with the dimension of $49.8\,\mathrm{mm} \times 49.8\,\mathrm{mm} \times 0.4\,\mathrm{mm}$. The unit cell and its geometry shape of the new structure is shown in Figure 2. The rectangular power islands are connected to the rectangular mesh of the power plane through the

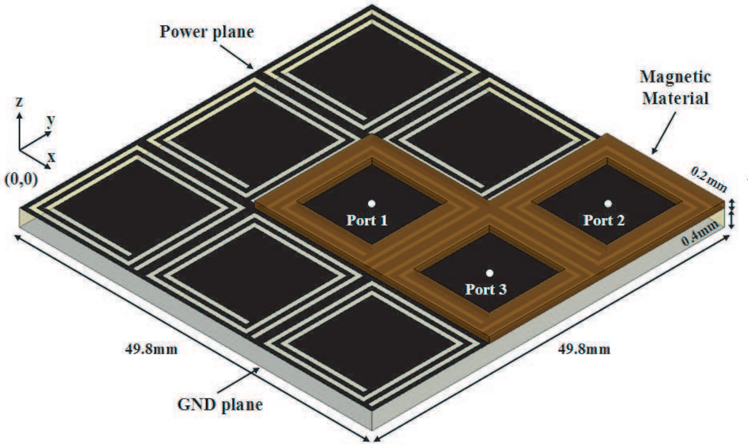
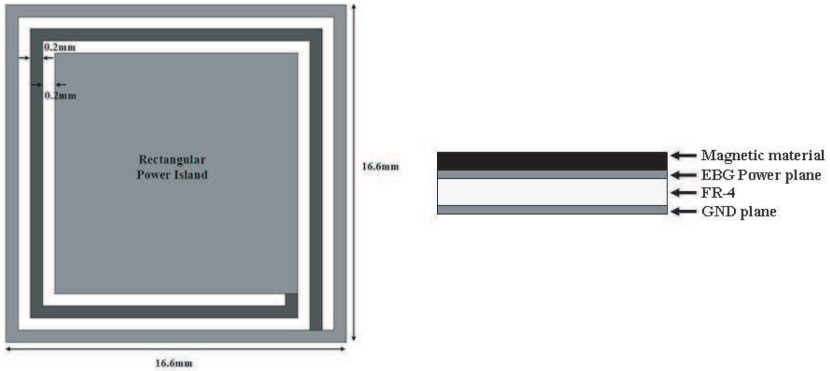


Figure 1. Design of the proposed new structure.



(a) (b)

Figure 2. Unit cell and geometry shape. (a) Top View. (b) Cross-section View.

spiral-shaped inductor bridges. As shown in Figure 2, the magnetic material is externally installed on the top surface of the new structure, which is different with that shown in reference [11].

Figure 3 shows complex permeability (real permeability: μ_r', imaginary permeability: μ_r'') of the EMI suppression sheet, and this material is used in the new structure. Below 20 MHz, the high real permeability (μ_r') enhances the inductance of the power plane and decreases the associated lower bandgap frequency of the EBG. Above

20 MHz, the imaginary permeability (μ_r'') behaves for the absorption of the external SSN field, instead of the reduced real permeability.

The new structure was simulated using a finite element method tool (HFSS v.11.1). S-parameter was measured by using a 2-port vector network analyzer (Agilent N5230A) for different 2-port combinations. Figure 4 shows configuration for the time domain measurement where a 0.2 GHz clock buffer (CDCVF2310, Texas Instruments) induces an SSN to the proposed power plane through a direct connection. At port 1, the propagated SSN was measured by using an oscilloscope (Agilent DSO90254A).

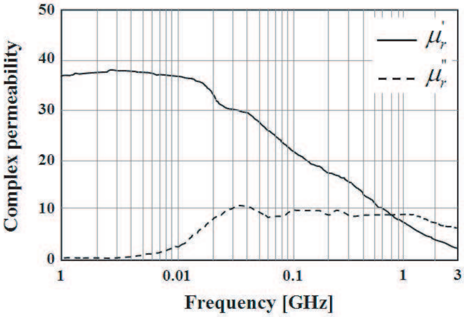
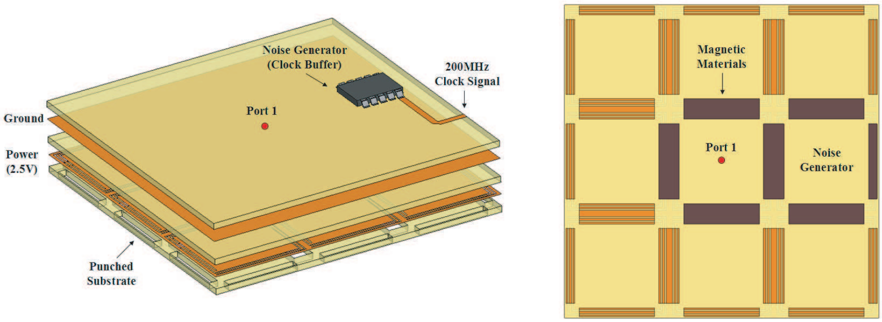


Figure 3. Complex permeability of EMI suppression sheet (source: Jawha electronics).



(a) (b)

Figure 4. Configuration of the new structure of EBG power plane for time domain measurements. (a) 3-D view and (b) bottom view.

3. SIMULATED AND MEASURED RESULTS

Figure 5 shows the comparison of the propagation loss between the S-bridged EBG power plane [8] and the new structure with/without the external magnetic material. As shown in Figure 5, 30 dB suppressions of S-bridged EBG S_{31} measured and proposed EBG without magnetic material S_{31} measured are started at 0.8 GHz and 0.53 GHz, respectively. The significant improvements of the SSN propagation with the proposed EBG without the magnetic material S_{31} measured is observed in the frequency range from 0.53 to 1 GHz. It is believed that this phenomenon is caused by the following reason; the effective inductance of the proposed EBG without the magnetic material is larger than that of the S-bridged EBG plane. For the measurement result of the proposed EBG with the magnetic material S_{31} in Figure 5, the lower stopband frequency is shifted to 0.19 GHz by the complex permeability of external magnetic material. As shown in Figure 1, the physical distance between ports 1 and 2 is longer than that between ports 1 and 3. Therefore, it is observed that the measured S_{21} of proposed EBG with the magnetic material is lower than measured S_{31} by the increased propagation distance. For the proposed EBG with the magnetic material, there is a reasonable agreement between the simulated and measured S_{31}.

Figure 6 shows the measured voltage fluctuations at port 1. The measured voltage fluctuations of S-bridged power plane in Figure 6(a)

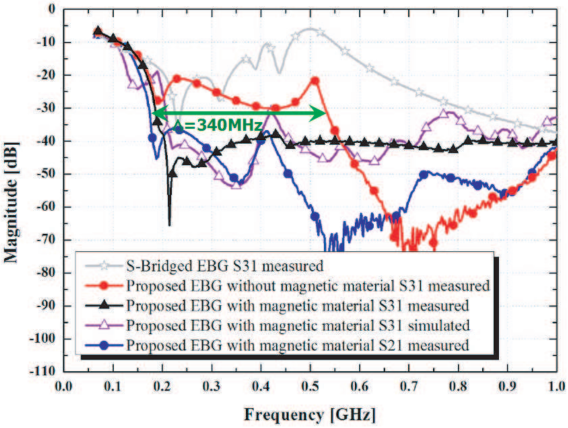
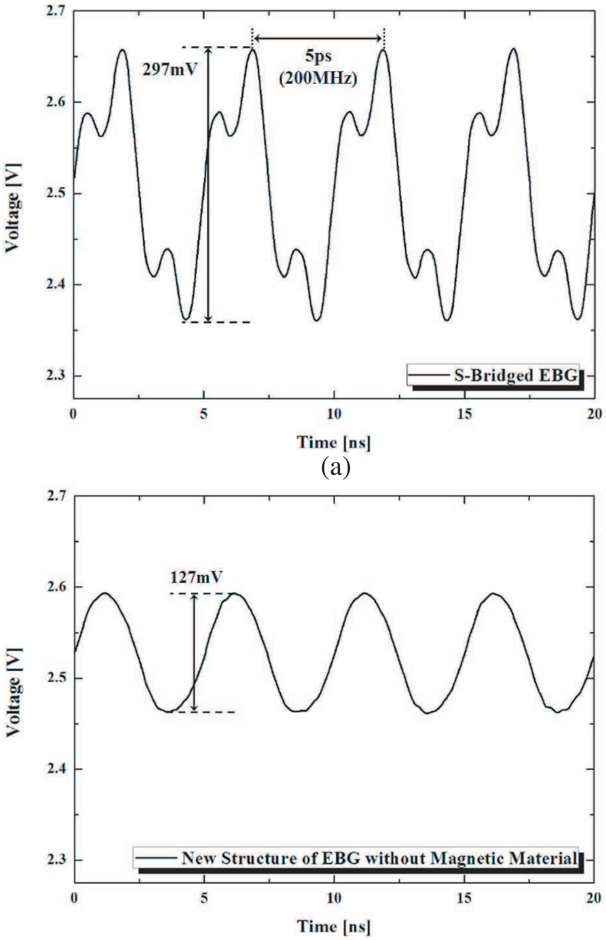


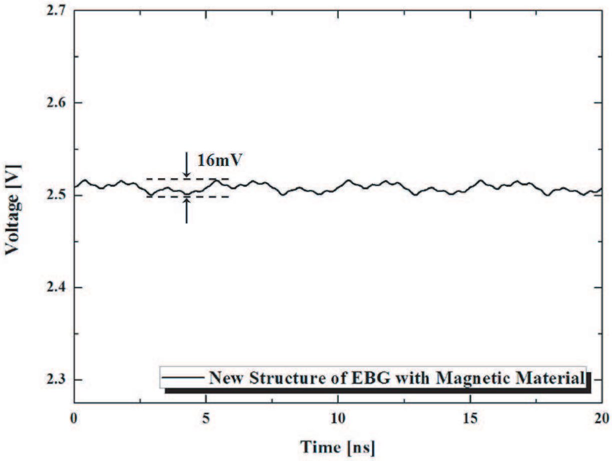
Figure 5. Comparison of the SSN propagation loss between the S-bridged EBG plane and the new structure of EBG planes with/without external magnetic material.

and the new structure without the magnetic material in Figure 6(b) were 297 mV and 127 mV, respectively. This effect is induced by the high value of SSN propagation loss of the new structure without the magnetic material than the S-bridged power plane at around 0.2 GHz. Especially, it is clearly observed that the proposed new structure with the magnetic materials retains a negligible amount of the SSN fluctuation with 16 mV as shown in Figure 6(c). In conclusion, the measured voltage fluctuation of proposed new structure with the magnetic material is smallest than other structures, it is believed that this phenomenon is strongly caused by the lower bandgap frequencies of that than other structures as shown in Figure 5. Also, this lower



(a)

(b)



(c)

Figure 6. Measured SSN at Port 1 for 200 MHz clock noise. (a) The S-bridged EBG plane [8]. (b) The new structure of EBG plane without the magnetic material. (c) The new structure of EBG plane with the magnetic material.

bandgap frequency of the proposed new structure with the magnetic material is mainly caused by the higher effective inductance of that. Therefore, the dimension of the power plane could be effectively reduced using the proposed structure, and the proposed new structure shows good power integrity in frequency and time domain.

The SSN suppression level of the new structure with external magnetic material shows almost same property as compared with EBG structure having internal magnetic material [11]. However, it is expected that the new structure with external magnetic material has easy fabrication process from the structural point of view, because the magnetic material is externally placed on the new structure proposed in the present research. In a view point of thermal management, the present structure will be better than that introduced in the reference [11] because the magnetic material of the new structure is located on its top surface. In the near future, the reliability for the new structure of EBG plane with the magnetic material should be seriously characterized for its commercialization.

4. CONCLUSION

In the present research, a new structure of EBG power plane with an external magnetic material is proposed for the suppression of SSN in the mixed-signal systems. The bandgap frequency is shifted to lower frequency range by the real part of the permeability (μ_r') and the SSN propagation loss is more increased by the imaginary part of the permeability (μ_r''). It is expected that the manufacturing process of the new structure with external magnetic material is easier than that of the EBG power plane having internal magnetic material [11]. Finally, the new structure proposed in the present research will play an important role for the reduction of the circuit size and the improvement of the power integrity of the mixed-signal systems.

ACKNOWLEDGMENT

This work was supported by the National Space Laboratory (NSL) program under the Korea Science and Engineering Foundation funded by the Ministry of Education, Science and Technology (2009-0092128).

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