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Suppression of Parallel Plate Modes Using Edge-Located EBG Structure in High-Speed Power Bus

Jonghyun Cho[1] and Myunghoi Kim[2*], ***Member, KIICE***

[1]Missouri S&T EMC Laboratory, Missouri University of Science and Technology, MO 65401, USA
[2]Department of Electrical, Electronic, and Control Engineering, Hankyong National University, Anseong 17579, Korea

Abstract

An edge-located electromagnetic bandgap (EL-EBG) structure using a defected ground structure (DGS) is proposed to suppress resonant modes induced by edge excitation in a two-dimensional planar parallel plate waveguide (PPW). The proposed EL-DGS-EBG PPW significantly mitigates multiple transverse-magnetic (TM) modes in a wideband frequency range corresponding to an EBG stopband. To verify the wideband suppression, test vehicles of a conventional PPW, a PPW with a mushroom-type EBG structure, and an EL-DGS-EBG PPW are fabricated using a commercial process involving printed circuit boards (PCBs). Measurements of the input impedances show that multiple resonant modes of the previous PPWs are significantly excited through an input port located at a PPW edge. In contrast, resonant modes in the EL-DGS-EBG PPW are substantially suppressed over the frequency range of 0.5 GHz to 2 GHz. In addition, we have experimentally demonstrated that the EL-DGS-EBG PPW reduces the radiated emission from −24 dB to −44 dB as compared to the conventional PPW.

Index Terms: Electromagnetic bandgap (EBG), Parallel plate waveguide (PPW), Radiated emission

I. INTRODUCTION

In modern microwave and digital electronics, a planar parallel plate waveguide (PPW) is exploited to deliver a signal and power to circuits and devices. For instance, high-speed circuit and mixed-signal systems employ a PPW as a power distribution network (PDN) connecting between circuits and a power source. A PPW-based PDN has the advantages of easy power sharing, simple design, low cost, and high design flexibility. However, various electrical noises induced by PPW modes are problematic [1, 2]. At the frequencies corresponding to the PPW modes, a simultaneous switching noise and radiated emissions are significantly generated, which causes electromagnetic interference and severely degrades the system performance [3-6]. In particularly, a PPW-based PDN is vulnerable to noise excitation at an edge of a PPW because multiple resonant modes can be easily produced by edge excitations [7].

To mitigate edge radiations, an asymmetric pair of power and ground planes is presented in [8]. This method is sufficiently simple to be applied to printed circuit board (PCB) applications. However, the suppression of the radiated emission is not significant. In [9], a shorting via wall is presented and its effects on resonant modes and radiated emissions are investigated. Although it suppresses the resonant modes and reduces the radiated emissions, a shorting via scheme is difficult to be applied to typical PDN structures consisting of power and ground planes that are

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***Corresponding Author** Myunghoi Kim (E-mail: mhkim80@hknu.ac.kr, Tel: +82-31-670-5295)
Department of Electrical, Electronic, and Control Engineering, Hankyong National University, 327 Jungang-ro, Anseong 17579, Korea.

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not required to be directly connected through conductors. In [10, 11], a mushroom-type electromagnetic bandgap (MT-EBG) structure is presented to suppress the PPW modes. The MT-EBG structure suppresses the resonant modes over the wideband frequency range, thus reducing the radiated emissions. However, for the edge-located EBG structure, the performance is not verified and its experimental results are not presented.

This letter presents a new PPW combined with an EBG structure using a defected ground structure (DGS) [12] to overcome the noise problems caused by edge excitation. The proposed edge-located DGS-EBG (EL-DGS-EBG) PPW mitigates resonant modes over a wideband frequency range. To verify the suppression of the PPW modes induced by the edge excitation, the EL-DGS-EBG is compared with a conventional PPW without any EBG structure and a PPW with an edge-located MT-EBG (EL-MT-EBG) structure. Experimental demonstrations show the significant suppressions of PPW modes and electromagnetic radiated emissions for the proposed EL-DGS-EBG PPW.

II. EDGE-LOCATED EBG PPW

The proposed EL-DGS-EBG PPW consists of two parts. The first part is the two parallel conductors placed inside, which is similar to a conventional PPW. The other part is the EBG array, which is located on the boundary of the PPW, as shown in Fig. 1. The proposed EBG cell in the array forms high characteristic impedance (Z_o) by etching a conductor. An increase in the Z_o of the EBG cell results in broadening the stopband bandwidth [12]. Hence, it can suppress resonant modes and radiated emissions over the wideband frequency range as compared to the EBG structure without a DGS. The high-Z_o EBG cell consists of three conductors: A cross-type conductor connects to a rectangular patch through a conductive via structure, and a rectangular-shape conductor exists on the bottom. It notes that a rectangular patch is not connected to the adjacent patches on the same layer. Dimensions for the EBG cell are defined in Fig. 1(c). One of the significant design variables is the width of the cross-type conductor (w_e) or the length of the DGS (w_d). The design variable mainly affects the stopband of the EBG structure and widens the stopband as described in [12].

To experimentally verify the performance of the EL-DGS-EBG PPW, three test vehicles are fabricated using a commercial PCB process. FR-4 and copper are used as the dielectric material and the conductor, respectively. The copper thickness is 17 µm. As shown in Fig. 2, the conventional PPW (i.e., without any EBG structures), the EL-MT-EBG PPW, and the proposed EL-DGS-EBG PPW are fabricated. For edge excitation, input ports A, B, and C

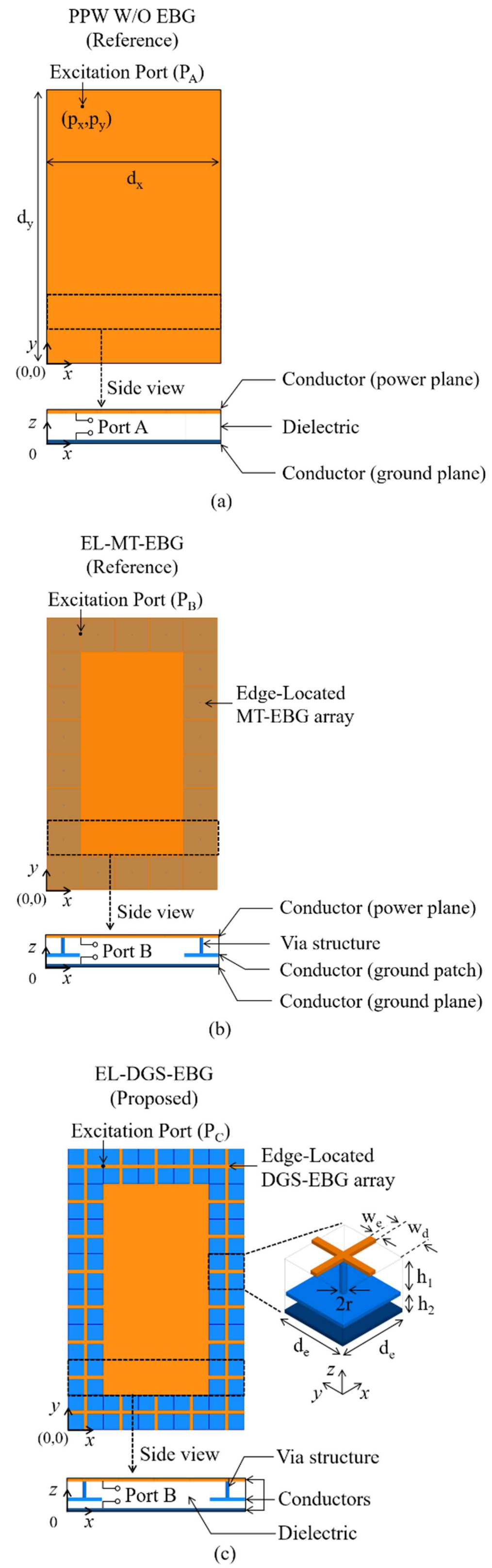
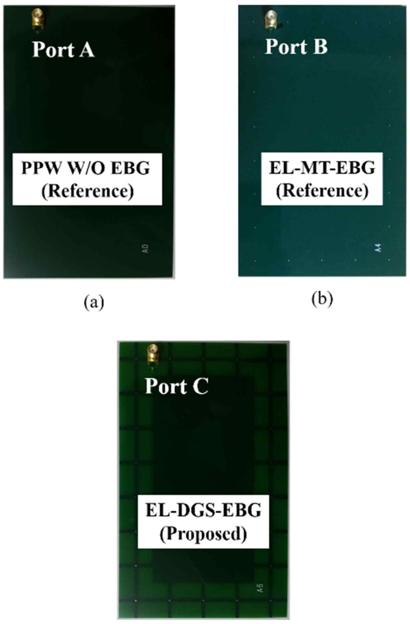


Fig. 1. (a) A PPW without EBG structure, (b) a PPW with edge-located mushroom-type EBG structure, and (c) a PPW with edge located defected ground structure EBG structure.



(a) (b) (c)

Fig. 2. Test vehicles fabricated using a printed circuit board process with FR-4. (a) A PPW without EBG structures, (b) a PPW with edge-located mushroom-type EBG structures, and (c) a PPW with edge-located DGS-EBG structure.

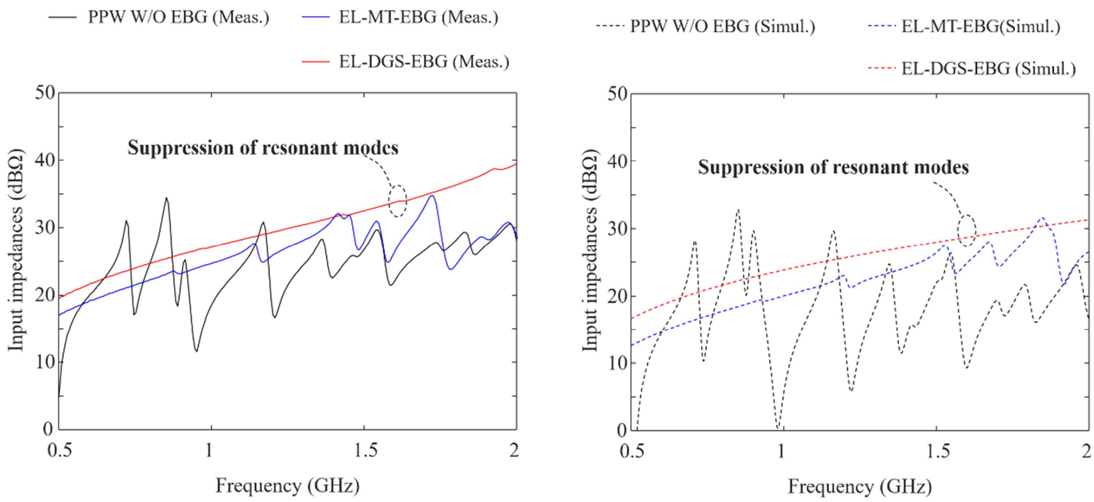
Table 1. Dimensions and design variables

Parameter	Dimension (mm)	Parameter	Dimension (mm)
d_x	100	d_e	20
d_y	160	h_1	1.2
p_x	20	h_2	0.1
p_y	150	r	0.2
w	2	w_d	9

are implemented using SMA connectors on each test vehicle. The relevant dimensions and port locations are shown in Table 1. For the EL-MT-EBG and EL-DGS-EBG structures fabricated herein, the stopbands can be estimated using a full-wave simulation. The result shows that the low and high cut-off frequencies of the stopband for the proposed EL-DGS-EBG structure are 0.27 GHz and 2.49 GHz, respectively, while those of the EL-MT-EBG structure are 0.33 GHz and 1.5 GHz, respectively. For the frequency range within the stopband, the edge excitation is expected to be significantly suppressed for the EL-DGS-EBG PPW.

III. RESULTS AND DISCUSSION

The input impedance graph illustrates the resonant modes induced by the edge excitation of the PPW. The input impedances Z_A, Z_B, and Z_C of the conventional PPW, the EL-MT-EBG PPW, and the EL-DGS-EBG PPW are extracted from the measurements of scattering parameters by using a vector network analyzer, as shown in Fig. 3. Moreover, the input impedances and electric field distributions are obtained using a full-wave simulation based on the FEM method. The measurements and the simulation results shown in Fig. 3(a) reveal that the edge excitation of the conventional PPW produces numerous PPW modes with transverse magnetic (TM) fields, which results in serious noise problems such as radiated emissions. The simulation results illustrated in Fig. 3(b) also show good agreement with the measurements presented in Fig. 3(a). Various resonant modes in the conventional PPW are observed over the frequency range of 0.5 GHz to 2 GHz. For the EL-MT-EBG PPW, some of the resonant modes are suppressed but the significant resonant modes above the



(a) (b)

Fig. 3. (a) Comparison of input impedance measurements for three test vehicles and (b) comparison of simulated input impedances.

frequency of 1.0 GHz are still observed.

The resonant modes in the stopband of the EL-MT-EBG are not successfully suppressed. This can be explained by investigating the electric field distributions at the resonant mode, as shown in Fig. 3(c). The excited noise is not suppressed and is in fact coupled to the PPW surrounded by the MT-EBG array, thus inducing the resonant modes of the PPW inside. In contrast, the resonant modes in the proposed EL-DGS-EBG PPW are significantly suppressed over the wideband frequency range. In addition, the electric field distributions illustrated in Fig. 3(c) show that the DGS-EBG array successfully mitigates the excited noise and that this noise is not coupled to the PPW inside. From the results, we can clearly see that the EL-DGS-EBG PPW substantially suppresses the resonant modes as compared to the previous methods.

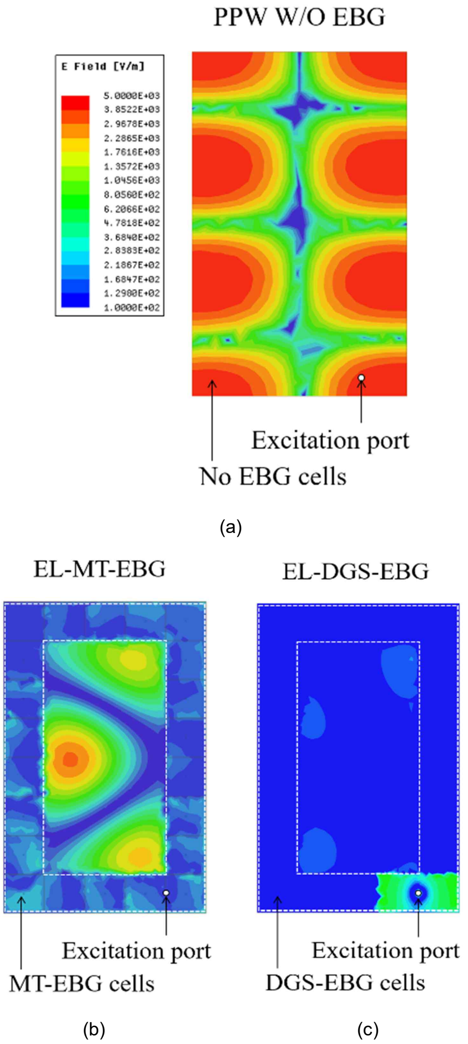


Fig. 4. Comparison of electric field distributions of (a) PPW without EBG structure, (b) edge-located mushroom-type EBG structure, and (c) edge-located DGS-EBG structure.

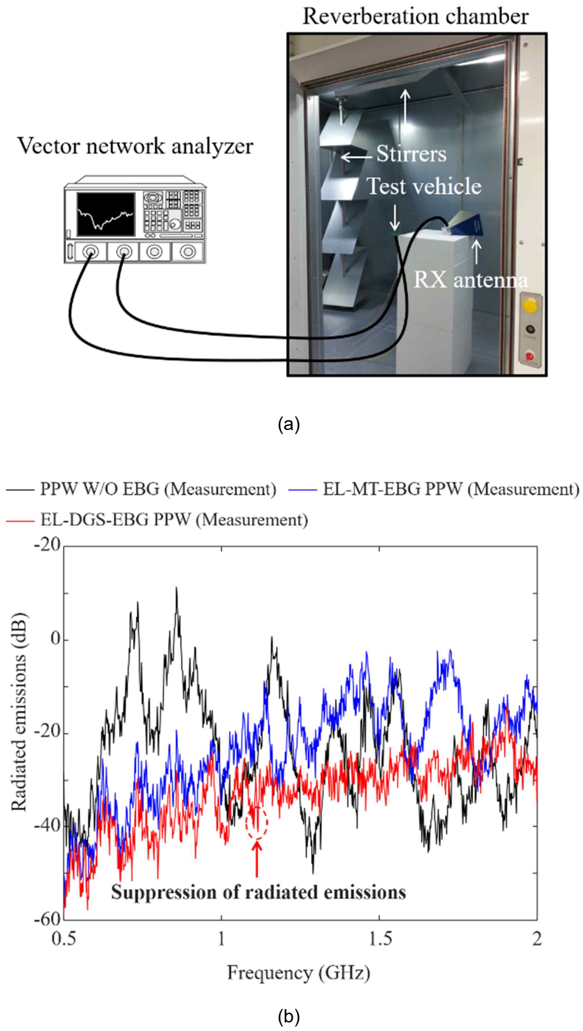


Fig. 5. (a) Measurement setup with a reverberation chamber and (b) comparison of measurements for test vehicles.

To further demonstrate the effect of the PPW mode suppression, the radiated emission characteristics are measured using a reverberation chamber. The reverberation chamber is a new method to assess the radiated emissions from a planar circuit and a board [13]. The measurement setup and the measurements of the radiated emissions are illustrated in Fig. 4. As predicted in the input impedance result, the conventional PPW severely radiates electro-magnetic noises, which result from the numerous TM modes induced by the edge excitation. In addition to the conventional PPW, the EL-MT-EBG PPW fails to reduce the radiated emissions in the frequency range from 1.0 GHz, which is anticipated from the input impedance result. In contrast, the proposed EL-DGS-EBG PPW substantially reduces the radiated emissions induced by PPW modes over the frequency range of 0.5 GHz to 2.0 GHz, as shown in Fig. 5(b). At 1.9 GHz, the peak of the radiated emission of the EL-DGS-EBG PPW is observed. However, it is not significant considering the overall characteristics of the radiated emission suppression. In consequence, we experimentally demonstrated that the EL-DGS-EBG PPW suppresses the resonant modes and significantly improves the radiated emission characteristics as compared to the conventional PPW and the EL-MT-EBG PPW.

IV. CONCLUSION

A PPW with the EL-DGS-EBG structure is presented to suppress the resonant modes induced by edge excitations. The wideband suppression of the PPW modes is proved by the measurements of the input impedance and the radiated emission characteristics. As compared to the conventional PPW and the EL-MT-EBG PPW, the proposed EL-DGS-EBG PPW substantially mitigates the resonant modes induced by edge excitations. The EL-DGS-EBG PPW can be applied to a power distribution network for high-speed switching circuits and microwave devices. Previously, for the applications, the edge placements of the circuits and devices were not preferred because of the PPW mode excitation problem. However, the EL-DGS-EBG PPW enables us to place the circuits and devices at the edge of the board without the edge excitation problem. The edge placement of the circuits and devices provides the advantages of high design flexibility, simple board-to-board connections, and noise-tolerant systems.

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Jonghyun Cho
received his B.S., M.S., and Ph.D. in Electrical Engineering from Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, in 2008, 2010, and 2013, respectively. He also worked at KAIST as a postdoctoral assistant until the end of 2014. At KAIST, he successfully carried out several projects, including 3D-IC TSV modeling, silicon and glass interposer design, and POP PKG design for mobile phone AP. Since 2015, he has been working at Missouri S&T EMC laboratory as a visiting assistant research professor. His current research interests include SI/PI/RFI issues on systems including chips, PKG, PCB, 2.5D and 3D-IC, and WPT.

Myunghoi Kim
received his B.S., M.S., and Ph.D. in Electrical Engineering at the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea, in 2003, 2005, and 2012, respectively. From 2005 to 2008, he was a researcher for signal integrity and EMC analysis of the missile electronic systems in Agency for Defense Development (ADD), Daejeon, Korea. He was a visiting researcher at Silicon Image Inc., Sunnyvale, CA, in 2011. He was a senior member of the engineering staff at Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea, from 2012 to 2015. In 2015, he joined the Department of Electric, Electronic and Control Engineering, Hankyong National University, Anseong, Korea, as an assistant professor. His current research interests include signal and power integrity for high-speed packages and PCBs, electromagnetic shielding analysis using a reverberation chamber, and slow-wave/electromagnetic bandgap structures for EMI/EMC.