한국항행학회논문지
Journal of Advanced Navigation Technology

Short Paper 기반 기술
J. Adv. Navig. Technol. 28(2): 246-249, Apr. 2024

고속 반도체 패키지 및 PCB 내 공통 모드 잡음 감쇠를 위한 소형화 된 인덕턴스 향상 파형 접지면 기반 차동 신호선

Inductance-Enhanced Corrugated Ground Planes for Miniaturization and Common Mode Noise Suppression of Differential Line in High-Speed Packages and PCBs

Tae-Soo Park · Myunghoi Kim*

School of ICT, Robotics and Mechanical Engineering, Research Center for Hyper-Connected Convergence Technology, Hankyong National University, GyeonggI-do, 17579, Korea

[Abstract]

In this paper, we present a miniaturized differential line (DL) using inductance-enhanced corrugated ground planes (LCGP) for effective common-mode (CM) noise suppression in high-speed packages and printed circuit boards. The LCGP -DL demonstrates the CM noise suppression in the frequency range from 2.09 GHz to 3.6 GHz. Furthermore, to achieve the same low cutoff frequency, the LCGP-DL accomplishes a remarkable 23.2% reduction in size compared to a reference DL.

Key word : Corrugated ground plane, Common mode noise, Differential line, Electromagnetic bandgap.

Ⅰ. Introduction

Common-mode (CM) noise suppression of differential signals has gained significant attention in high-speed printed circuit boards (PCBs) where microwave devices and high-speed digital circuits are integrated [1]-[3]. To effectively suppress the CM noise in high-speed PCBs, metamaterial (MTM)-based techniques have been introduced [4]-[9]. MTM-based differential lines offer advantages such as wideband bandwidth and high rejection levels for CM noise suppression.

In [4], a technique inspired by a mushroom-type electromagnetic bandgap (EBG) structure is presented for CM noise suppression in differential lines. CM noise is filtered out using an LC resonator induced from the mushroom patch and a via. However, a limitation arises as cost-effective through-hole vias cannot be used since the via is located below the signal lines. In [5], a quarter-wavelength resonator is employed to suppress CM noise without compromising differential signal transmission. Although the design is simple and well-established using microwave theory, it requires the use of a buried via, and the longitudinal length must increase for a reduction in the low cut-off frequency (f_L).

In [6]-[9], a stepped impedance resonator is utilized for CM noise suppression while maintaining good differential transmission. Various implementations are explored, including using a single ground layer [6], employing microstrip and striplines [7], and adopting corrugated ground planes [8],[9]. Differential lines based on a stepped impedance resonator exhibit superior characteristics. However, their miniaturization poses challenges since the length of the unit cell determines f_L, necessitating an increase in the unit cell size to lower f_L. This paper extends the exploration of stepped impedance resonators with a focus on achieving miniaturization.

Ⅱ. Proposed LCGP-DL

The proposed differential line is based on the EBG structure

https://doi.org/10.12673/jant.2024.28.2.246

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-CommercialLicense(http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 8 April 2024; **Revised** 17 April 2024
Accepted (Publication) 20 April 2024 (30 April 2024)

***Corresponding Author : Myunghoi Kim**

Tel: +82-31-670-5295
E-mail: mhkim80@hknu.ac.kr

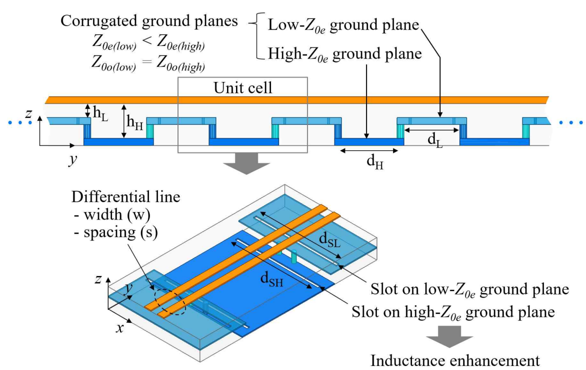


그림 1. 고속 반도체 패키지 및 PCB를 위한 인덕턴스 향상 파형 접지면 기반 차동신호선

Fig. 1. A proposed differential line using inductance enhanced corrugated ground planes.

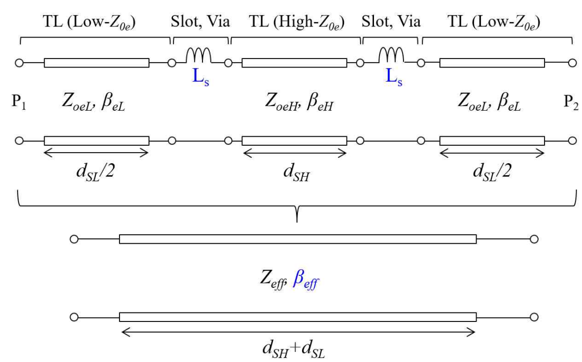


그림 2. LCGP-DL 공통모드 노이즈 잡음 감쇠 해석을 위한 등가회로

Fig. 2. An equivalent circuit model of the LCGP-DL for even-mode propagation.

incorporating corrugated ground planes with slots to enhance its inductance (LCGP). As depicted in Fig. 1, the LCGP-DL consists of two parts: low-Z_{0e} and high-Z_{0e} parts, featuring different even-mode characteristic impedances (Z_{0e}) and identical odd-mode characteristic impedances. The varied Z_{0e} forms a stepped impedance resonator that suppresses common-mode noise, while the identical Z_{0o} ensures good signal integrity for differential signals [9]. The low-Z_{0e} parts includes a differential line and a slotted ground plane, with a relatively thin dielectric thickness between them compared to the high-Z_{0e} part. The ground planes in low- and high-Z_{0e} parts are connected through vias to ensure a return current path for differential signals. Narrow slots adjacent to the vias are implemented to boost the inductance of the return current path, resulting in a reduced low cutoff frequency (f_L) for common-mode noise suppression and achieving miniaturization.

The unit cell of the proposed LCGP-DL comprises the high-Z_{0e} parts connected to two halves of the low-Z_{0e} part on either side, as shown in Fig. 1. Then, the equivalent circuit model of the unit cell to consider even-mode propagation is established as shown in Fig. 2. Low- and high-Z_{0e} parts are modeled as transmission lines (TLs) with the lengths d_{SL} and d_{SH}, respectively. The two TLs are connected through an inductor, L_S, the inductance of which is enhanced by slots. As examined in [9], increasing the unit cell size is necessary to reduce f_L, or the enhancement of inductance leads to a reduction in f_L. In the proposed LCGP-DL, the slots effectively increase inductance without requiring an increase in the unit cell size. This implies that the unit cell size of the LCGP-DL can be reduced to achieve the same f_L as the conventional DL without inductance-enhanced slots.

To investigate the impact of the inductance-enhanced slot on common-mode noise suppression, a dispersion analysis based on the unit cell is conducted. The scattering parameters (S-parameters) of the LCGP-DL unit cell are obtained through full-wave simulation using Ansys Inc., HFSS. The even-mode propagation of S-parameters from the equivalent circuit model is extracted as shown in Fig. 2 and compare them with full-wave simulation results. The mixed-mode S-parameters are extracted using the full-wave simulation. To obtain the dispersion characteristics of the LCGP-DL unit cell for even-mode propagation, the effective phase constant β_{eff} is extracted as follows.

$$\beta_{eff} = Re\left\{\frac{1}{d_L+d_H}cos^{-1}\left(\frac{(1+S_{cc11})(1+S_{cc22})+S_{cc12}S_{cc21}}{2S_{cc21}}\right)\right\}$$

S_{cc} indicates the mixed-mode S-parameters for common-mode propagation. To demonstrate the reduction in f_L of the LCGP-DL, we consider test vehicles of the unit cell both with and without L-enhanced slots. The dimensions of design variables are summarized in Table I.

The dispersion characteristics of the test vehicles are depicted in Fig. 3. For the same size of the unit cell, the f_L of the conventional DL without L-enhanced slots is 2.7 GHz, whereas that of the LCGP-DL is 2.1 GHz. The LCGP-DL achieves a significant reduction in f_L, up to 22.2%. The stopband of the LCGP-DL is formed from 2.1 GHz to 3.82 GHz, resulting in wideband suppression of common-mode noise.

Ⅲ. Analysis

In this section, we investigate the enhancement of inductance through the use of slots and its impact on achieving miniaturization. As depicted in Fig. 4, we extract partial inductance values of the LCGP for various slot lengths ranging

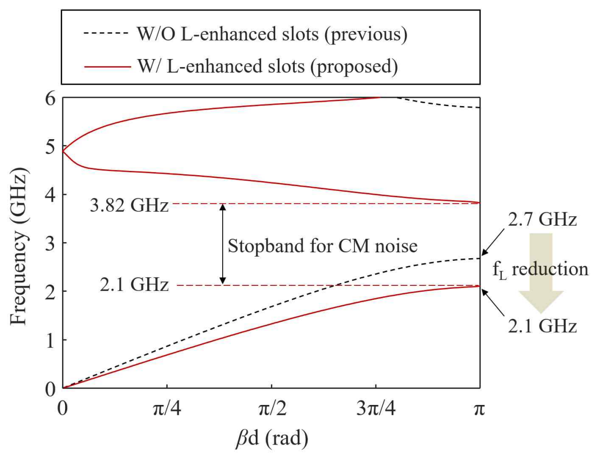


그림 3. 인덕턴스 향상 파형 접지면 영향 분석을 위한 LCGP-DL과 비 LCGP-DL 분산해석 결과 비교

Fig. 3. Dispersion analysis of the LCGP-DL and the reference DL for LCGP effect analysis.

표 1. LCGP-DL 해석 구조 설계 변수 및 치수

Table. 1. Design parameters and dimensions for dispersion analysis of LCGP-DL.

Parameter	Dimensions (mm)	Parameter	Dimensions (mm)
w	0.1	d_{SL}	9.0
s	0.1	d_{SH}	9.0
h_L	0.1	slot width	0.4
h_H	1.0	$Z_{0e(low)}$	75 Ω
d_L	9.2	$Z_{0e(high)}$	227 Ω
d_H	9.2	$Z_{0o(low)}$	52 Ω
via radius	0.2	$Z_{0o(high)}$	52 Ω

from 1 mm to 9 mm. This data is obtained using Ansys Q3D software. It is observed that the partial inductance value increases, as the slot length increases. The partial inductance values of 1 mm and 9 mm are 8.4 nH and 10.8 nH, respectively. The inductance value is enhanced up to 28.6 %.

In addition, the impact of slots on f_L and f_H is examined, as illustrated in Fig. 5. Increasing d_{SL} and d_{SH} results in a reduction of both f_L and f_H. The inductance-enhanced slot is beneficial for reducing f_L. Although the reduction in f_H may narrow the stopband bandwidth, it remains wideband within the GHz frequency range.

To demonstrate the miniaturization of the unit cell using LCGP-DL, test vehicles consisting of three unit cells without and with L-enhanced slots are considered, as depicted in Fig. 6. In dispersion analysis, the test vehicles are designed to have the same f_L of 2.1 GHz. The S_{cc21} and S_{dd21} of the test vehicles are obtained using full-wave simulation with HFSS, as shown in Fig. 7. The S_{cc21} bandwidth with -15 dB for test vehicles without L-enhanced slots ranges from 2.09 GHz to 4.15 GHz, while that of test vehicles with L-enhanced slots ranges from 2.09 GHz to

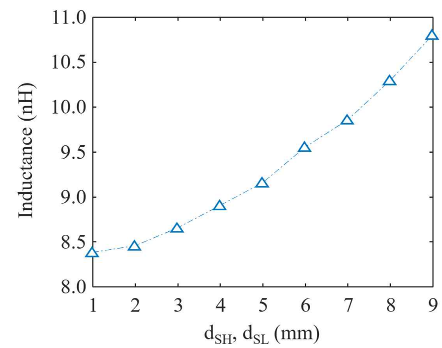
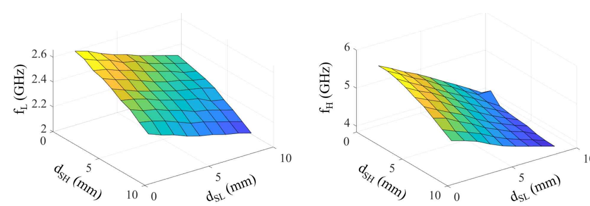


그림 4. LCGP-DL 설계 변수에 따른 인덕턴스 영향

Fig. 4. Inductance enhancement of LCGP with respect to various slot lengths.



(a) (b)

그림 5. 인덕턴스 향상에 따른 하측 차단 주파수 영향 분석

Fig. 5. The effect of inductance-enhanced slots on (a) low- and (b) high-cutoff frequencies of LCGP-DL.

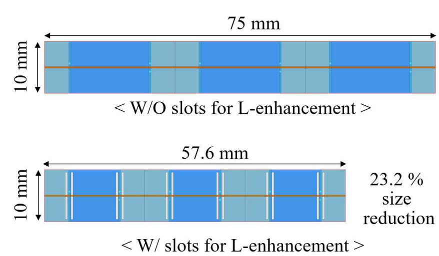


그림 6. LCGP-DL 소형화 분석을 위한 비 LCGP 구조와 LCGP 구조

Fig. 6. Test vehicles of differential lines without inductance-enhanced slots (reference) and with inductance-enhanced slots for demonstrating miniaturization.

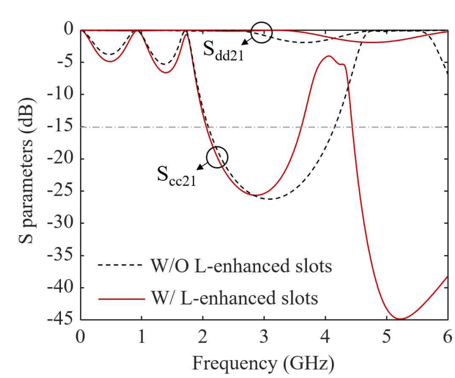


그림 7. 공통모드 노이즈 감쇠 특성 비교

Fig. 7. Comparison of CM noise suppression.

3.6 GHz. Despite the wider bandwidth of the test vehicles without L-enhanced slots compared to those with L-enhanced slots, the LCGP-DL still exhibits a wideband characteristic. Additionally, the S_{dd21} results in Fig. 7 demonstrate the good signal integrity of LCGP-DL for differential signaling.

The results indicate that the LCGP-DL facilitates miniaturization. The length of the test vehicle without L-enhanced slots is 75 mm, whereas that of the test vehicle with L-enhanced slots is 57.6 mm, representing a 23.2% size reduction. It is noteworthy that this outcome is achieved by simply etching the ground planes without enlarging the unit cell size or introducing additional materials.

Ⅳ. Conclusion

In this paper, we proposed the LCGP-DL as a solution for achieving a miniaturized differential line with effective common-mode noise suppression and robust differential signal transmission in high-speed PCBs. The implementation of the LCGP-DL involves a simple etching of ground planes, offering advantages such as wideband common-mode noise suppression, cost-effectiveness, and size reduction. We validated the performance of the LCGP-DL through dispersion analysis of the unit cell and full-wave simulation of mixed-mode S-parameters. Further investigation into the impact of the slot shape in the LCGP-DL is considered for future studies.

References

[1] F. Martin et al., “The beauty of symmetry: Common-mode rejection filters for high-speed interconnects and band microwave circuits,” *IEEE Microwave Magazine*, Vol. 18, No. 1, pp. 42-55, Jan. 2017.

[2] P. Zhou, T. Zhang and Y. Shi, “Overview of common-mode noise suppression techniques: From reflection to absorption,” *IEEE Microwave Magazine*, Vol. 24, No. 3, pp. 34-43, Mar. 2023.

[3] Z. Zhou, Y. Wei and S. Fang, “Progress review of wide-band common-mode filter in high speed interconnect system,” in *2023 8th International Conference on Computer and Communication Systems (ICCCS),* Guangzhou: China, pp. 131-137, 2023.

[4] C. -H. Tsai and T. -L. Wu, “A broadband and miniaturized common-mode filter for gigahertz differential signals based on negative-permittivity metamaterials,” *IEEE Transactions on Microwave Theory and Techniques*, Vol. 58, No. 1, pp. 195-202, Jan. 2010.

[5] G. -H. Shiue, C. -M. Hsu, C. -L. Yeh and C. -F. Hsu, “A comprehensive investigation of a common-mode filter for gigahertz differential signals using quarter-wavelength resonators," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 4, No. 1, pp. 134-144, Jan. 2014.

[6] C. Olivieri et al., “Analysis of near-field emissions from common-mode filters based on EBG structures,” *IEEE Transactions on Electromagnetic Compatibility,* vol. 59, no. 2, pp. 593-599, Apr. 2017.

[7] A. E. Engin, N. Modi and H. Oomori, “Stepped-impedance common-mode filter for differential lines enhanced with resonant planes,” *IEEE Transactions on Electromagnetic Compatibility*, Vol. 61, No. 5, pp. 1457-1464, Oct. 2019.

[8] M. Kim et al., “Application of VSI-EBG structure to high-speed differential signals for wideband suppression of common-mode noise,” *ETRI Journal*, Vol. 35, No. 5, pp. 827-837, Oct. 2013.

[9] M. Kim, “Periodically corrugated reference planes for common-mode noise suppression in high-speed differential signals," *IEEE Transactions on Electromagnetic Compatibility,* Vol. 58, No. 2, pp. 619-622, Apr. 2016.