Electromagnetic Noise and Radiation Mitigation in Power Delivery Networks

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***Abstract*—A growing interest in AI and deep learning applications necessitates the development of efficient power delivery networks (PDNs) to manage broadband impedance in high-speed switching environments. This paper evaluates the electromagnetic performance of horizontal, vertical, and embedded PDNs in fan-out packages, with particular emphasis on vertical and embedded configurations, both less explored for noise mitigation. Simulations indicate that embedded PDNs significantly reduce common-mode (CM) and differential-mode (DM) radiation, achieving levels between 20-78 dBμV. Additionally, measurements show that embedded PDNs maintain a lower electric field strength of 1.9 V/m for DM radiation as compared to 2.7 V/m for horizontal PDNs and 11.4 V/m for vertical PDNs. Advanced shielding with 5-μm thick Cu-CoNiFe layers further reduces magnetic field emissions by 30-45 dB. These findings demonstrate that embedded PDNs are a more effective solution for electromagnetic interference (EMI) mitigation in future electronic systems, offering superior noise control and reduced crosstalk.**

Keywords*—Common-Mode(CM); Differential-Mode (DM); Electromagnetic Interference (EMI); Power Delivery Networks (PDNs).

I. Introduction

The development of smaller and high-density electronics implies that power delivery networks (PDNs) in printed circuit boards (PCBs) are becoming more central to maintaining performance while addressing electromagnetic compatibility (EMC) challenges [1]. A typical PDN supplies power from DC-DC converters to components like memory and logic circuits [2]. Already, horizontal PDNs that employ surface-mounted components (see Fig. 1), have been extensively studied for noise patterns and radiation mitigation techniques. The latter include component placement optimization and trace routing, aimed at reducing common-mode (CM) and differential-mode (DM) radiation. However, as devices shrink and performance expectations increase, horizontal PDNs face limitations due to parasitics and space constraints.

While vertical and embedded PDNs offer potential advantages, there is limited research on their noise mitigation performance, especially in terms of CM and DM radiation. Additionally, embedded PDNs in fan-out packages show promise for reducing electromagnetic interference (EMI) by minimizing the area of loop currents and by bringing components closer to the ground plane (return path signal). However, to date, an analysis of their emission patterns and noise suppression capabilities has yet to be comprehensively presented.

This paper provides a detailed comparison of the electromagnetic performance of vertical and embedded fan-out PDNs, focusing on their CM and DM radiation characteristics. We also evaluate advanced shielding techniques, such as Cu-CoNiFe layers starting with our previous work in [3] to more effectively mitigate EMI. The goal of this study is to provide valuable insights into optimizing vertical and embedded PDNs for future high-performance electronics.

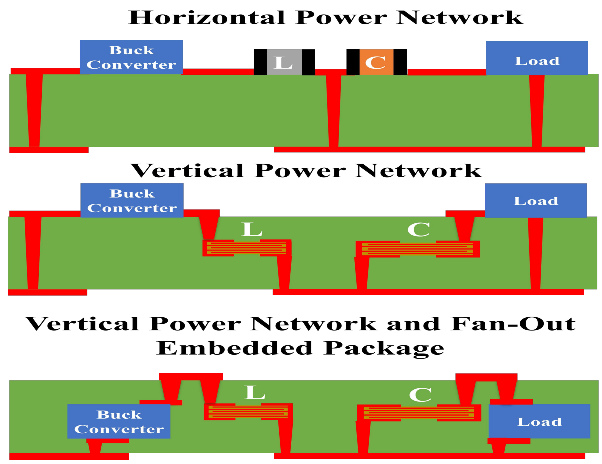

Figure 1. Illustrative horizontal and vertical power networks, and fan-out embedded package.

II. Common and Differential Radiators in Various PDN Scenarios

CM and DM radiation is investigated for three different PDN configurations: horizontal, vertical, and embedded fan-out packages such as those illustrated in Fig. 1. In the horizontal PDN, active and passive components were placed on top of the PCB, while in the vertical design, passive components were embedded within cavities between PCB layers. In the embedded fan-out configuration, both active and passive components were integrated directly within the PCB. CM radiation was excited by injecting a signal at the switching node between the DC-DC converter and the ground plane, while DM radiation was induced by exciting the loop formed by the load, inductor, and capacitor.

Simulations using Ansys HFSS® and measurements taken at a distance of one meter showed that both horizontal and vertical networks had radiation levels ranging from 30 to 100 dBμV. Notably, vertical networks had slightly better performance, whereas the embedded layout achieved significantly lower CM radiation, in the range of 20-78 dBμV as depicted in Fig. 2. A similar trend was observed for DM radiation. In the near-field, and at 1 cm distance, the embedded system showed

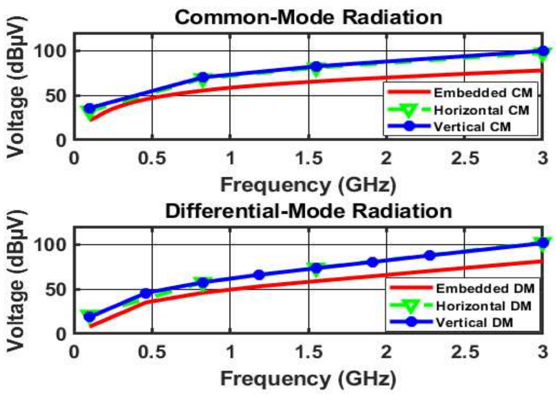

Figure 2. CM and DM radiation of the proposed scenarios.

TABLE I. Electric Field Values for CM and DM Emissions at 100 MHz Across Different PDN Scenarios at 1cm Distance.

PDN Scenarios	CM Radiation (V/m)	DM Radiation (V/m)
Horizontal	17	2.7
Vertical	11.4	8
Embedded	2.8	1.9

maximum electric field strength of 1.9 V/m as compared to 2.7 V/m for the horizontal PDN and 8 V/m for the vertical design layout. The higher radiation in the vertical system was due to the disruption of the return path caused by vias. In the case of the embedded system, coupling was minimized by keeping components closer to the ground plane and reducing the radiation loops. The analysis data are summarized in Table I, where the advantages of the embedded PDN in reducing CM and DM radiation are clearly demonstrated.

III. Comparative Analysis of PDN Configurations for EMC Performance

Table II provides a comparison of the vertical, horizontal, and embedded PDNs based on the aforementioned study. As noted in Table I, the embedded PDN configuration outperformed horizontal and vertical networks by controlling DM and CM noise. Specifically, the embedded PDN exhibits lower radiated emissions and minimal crosstalk, making it the most effective solution for reducing EMI in advanced electronic packages. Embedded components benefit from more effective shielding as compared to discrete components. The embedded PDNs feature smaller loop areas and closer proximity to the ground plane. This helps minimize DM and CM noise generation to improve signal integrity by reducing crosstalk. Furthermore, advanced EMI shielding using multilayer technology with materials like Cu-CoNiFe reduces crosstalk even more. As demonstrated in Fig. 3, a 5-μm thick, four-layer Cu-CoNiFe suppressed magnetic field emissions by 30-45 dB when used to shield embedded inductors. As a result, Cu-CoNiFe coatings achieve superior noise control within embedded PDNs.

IV. Conclusions

Our EMI/EMC analysis demonstrates that fully-embedded PDNs significantly outperform traditional horizontal and vertical PDNs in noise reduction. It was found that embedded PDNs achieved substantial reductions in CM and DM radiation, with the electric field strengths as low as 2.8 V/m for CM and 1.9 V/m for DM at 100 MHz. By contrast, horizontal PDNs exhibited field strengths of 17 V/m and 2.7 V/m, respectively, and the vertical PDNs showed 11.4 V/m and 8 V/m. This implies that for the studied layouts, embedded PDNs provided 4 to 6 times reduction in CM radiation. Furthermore, advanced shielding materials, such as 5-μm thick Cu-CoNiFe, enhanced noise suppression, reducing magnetic field emissions by 30-45 dB. These findings highlight that embedded PDNs can be a superior choice for advanced electronic packaging, combining space efficiency with exceptional EMI control and signal integrity.

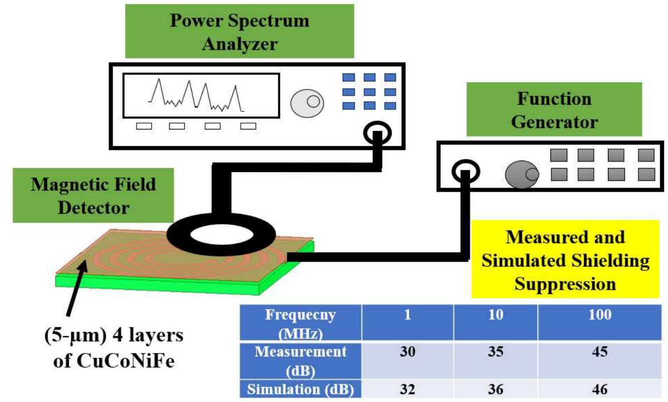

Figure 3. Measurement setup and results of the magnetic field emission using 4 layers of Cu-CoNiFe of 5-μm thickness.

TABLE II. Comparison of Vertical and Horizontal PDNs Configurations.

Characteristic	Horizontal PDN	Vertical PDN	Embedded PDN
DM noise control	Potentially higher DM noise	Higher DM noise risk	Superior DM noise control
CM noise control	Challenging CM noise control	Improved CM noise control	Excellent CM noise control
Radiated emissions	30-100 dBμV	30-100 dBμV	20-78 dBμV
Coupling and crosstalk	Higher crosstalk potential	Lower crosstalk	Minimal crosstalk

Acknowledgement

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