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Analysis on the Effects of the Slits in the PDN with the Differential-Mode Signals

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1. Introduction

The power- and ground planes in PCBs are called the power-distribution network(PDN) and are known for causing cavity-mode resonance and possibly noise in the related system.

T. Okoshi uses a modal sum expressions to characterize the structure[1,2]. Expanding the circuit concept, M. Hampe et al examines the effect of loads like DeCaps on the power-bus resonance[3].

Lately, S. Kahng presented the performance of differential signaling in the PDN and the advantage in reducing the number of resonance frequencies and impedance level[4].

However, a question can be raised if the differential signaling will work well in the power-bus with a geometrical change like having slits shown in Z. Wang's work[5].

This study investigates the performances of the differential signal feeding between the power-bus with and without the slit, using a rigorous evaluation method, which is validated by the FDTD application of [4].

2. Theory

The slit power-bus structure can be modeled as a cavity having the PEC power- and ground planes and the PMC walls. Fig. 1 is the top-view of the PDN structure where 2 feeds provide currents IPI1 and IPI2, passing the structure through the holes at (XPI1, YPI1) and (XPI2, YPI2). The output port is placed at (XPO, YPO). Excluding the slit, the size of the power-bus is Wx*Wy*Wz. The sandwiched substrate is featured by Wz, 4.2 and 0.02 given as its thickness, relative dielectric constant and loss tangent[1-5].

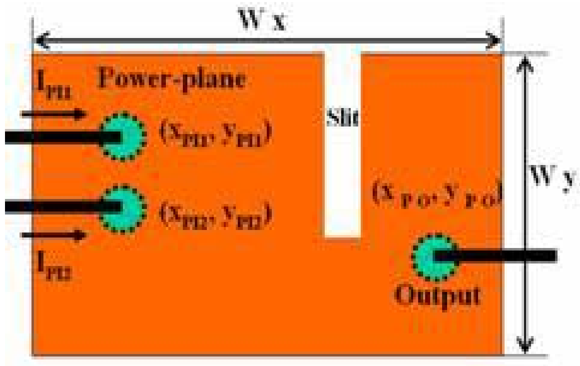

Figure 1: Top-view of t PDN having a slit.

Regarding the feeds, when IPI1 and IPI2 are in-phase and the same in magnitude, it is the common-mode signaling. Out-of –phase, they are the differential-mode signals. Ahead of working on the differential signaling with 2 feeds, the 1-feed case needs to be addressed as the basics. For this, a rigorous evaluation method is adopted, shown as follows[1-4].

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$$Z_B(f, X_f, Y_f) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\gamma_{mn} \cdot c_{mn}(X_0, Y_0) \cdot c_{mn}(X_f, Y_f) \cdot W_z / (W_{x\_B} \cdot W_{y\_B})}{\varepsilon\omega / Q + j(\varepsilon\omega - \dfrac{k_{xBm}^2 + k_{yBn}^2}{\omega\mu})} \qquad (1)$$

where

$$c_{mn}(X_i,Y_i)=cos(k_{xBm}X_i)\cdot\cos(k_{yBn}Y_i)\cdot sinc(k_{xBm}D_{xi})\cdot sinc(k_{yBn}D_{yi})\ D_{xi}=P_{xi}/2,\ \ D_{yi}=P_{yi}/2$$
$$k_{xBm}=m\pi/\ W_{x\_B},\quad k_{yBn}=n\pi/W_{y\_B},\quad \omega=2\pi f$$
$$Q=[\tan\delta+\sqrt{2/\omega\mu_0\kappa W_z^2}\,]^{-1} \qquad (2)$$

γ_{mn} is 1 and 4 for (m =0, n =0) and ($m\neq0$, $n\neq0$) each. When ($m\neq0$, n=0) or (m=0,$n\neq0$), γ_{mn} takes 2. $tan\delta$, ε , μ, f, P_i , j and subscript B denote loss-tangent, permittivity, permeability, frequency, port's width, square rooot of -1, and B-th rectangular part of Fig. 1, respectively.
This 1-feed case can be expanded to the differential and common-mode signaling by the superposition principle[4]. Furthermore, the slit structure can be solved by the segmentation scheme as done in [5] and details are not repeated here.

3. Results of Validation

Prior Firstly, the impedance is evaluated on the power-bus structurewith the differential signals so as to verify whether Eqn. (1) is numerically well-implemented. For the same environment as [4], Eqn. (1) and the FDTD approaches are used and compared. Stating again the structure, the geometry and frequency range are the same as [4], where 54mm33.5mm1.1mm, (27mm, 17.2mm), (27mm, 16.3mm), (41.8mm, 27.4mm) are given to Wx by Wy by Wz, (XPI1, YPI1), (XPI2, YPI2), and (XPO, YPO).

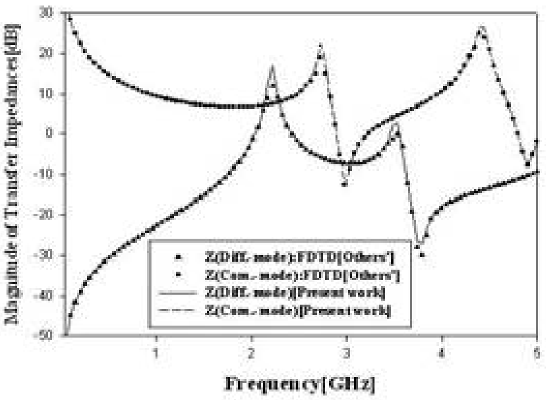


Figure 2: Differential & Common-mode signaling for the PDN without a discontinuity

The results are in good agreement between the present method and FDTD[3]. It is noticed that the differential signals lower the impedance level and outperforms the common-mode signals. As of now, a slit is considered starting from Fig. 3.

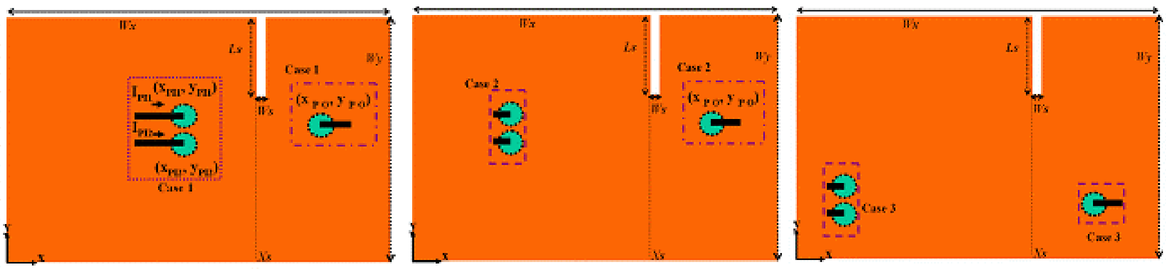
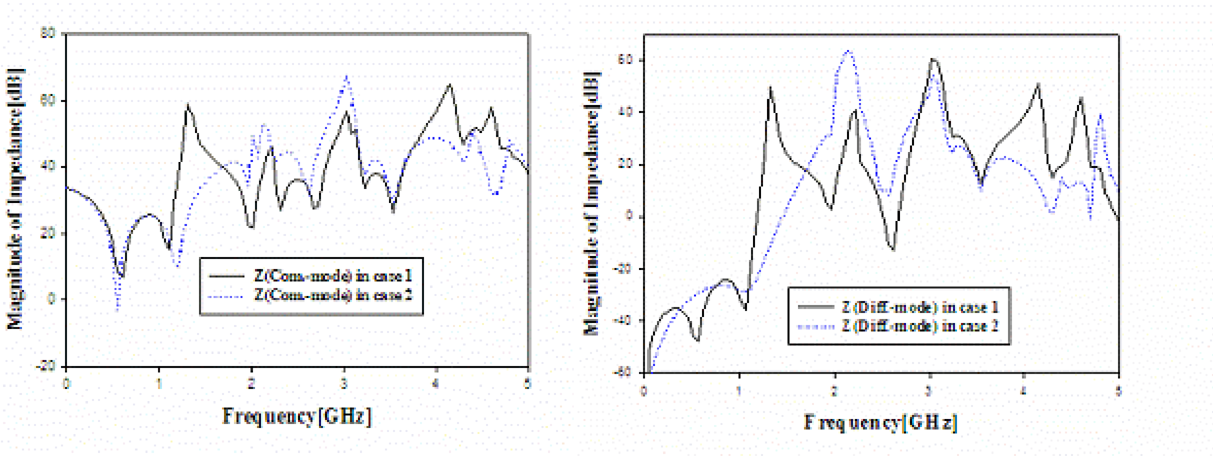
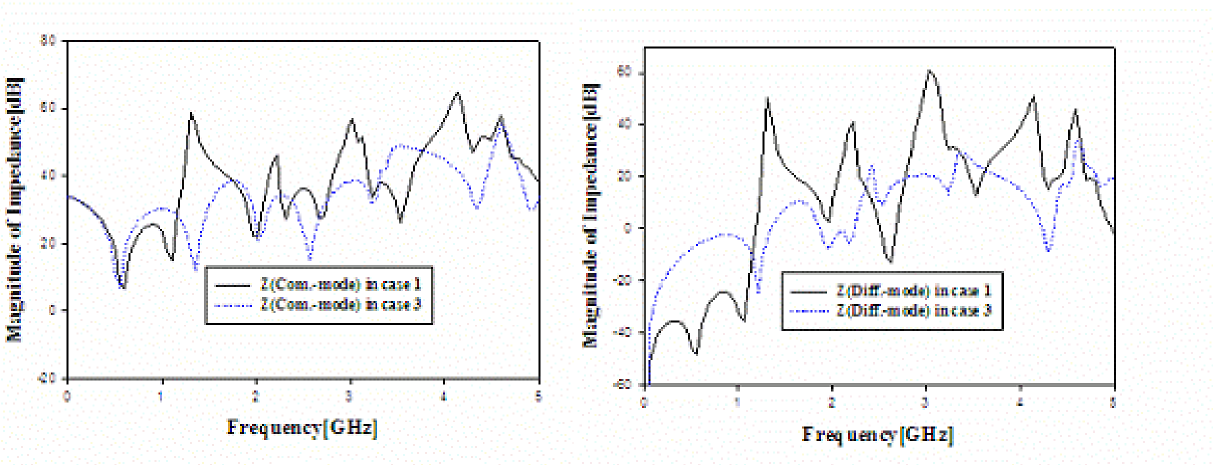


Figure 3: Three cases of port configuration of Differential & Common-mode signaling for the PDN with a discontinuity

Case 1 has (27mm, 17.2mm)~(27mm, 16.3mm), and case 2 has (18mm, 17.2mm)~(18mm, 16.3mm) for feeding with (41.8mm, 27.4mm) as (XPO, YPO) in common. Xs=36mm, Ls=10mm and Ws= 2mm are given to the slit. Also test case 3 is with (14mm, 7.9mm), (14mm, 6.9mm) and (41.8mm, 7.5mm) as (XPI1, YPI1), (XPI2, YPI2), and (XPO, YPO) in order. given 5 genes, 80 individuals, 100 generations, P_m of 0.01 and P_{Cr} of 0.80. The following is the cost function satisfying the required return loss over the generation. Compared to Fig. 2(without the slit), cases 1and 2 have an increased level of impedance with more resonance points despite the differential feeding, because the slit makes the current path longer and imbalance between 2 feeding paths.



(a) and (b) Impedance of cases 1 & 2 with Common-mode & Diff.-mode signaling



(c) and (d) Impedance of cases 1 & 3 with Common-mode & Diff.-mode signaling

Figure 4: Three cases of impedance profiles on Differential & Common-mode signaling for the PDN with a slit as a discontinuity .

Lastly, differential feeding can be much improved by selecting case 3-scheme. Seeing Fig. 4(d), the performance is remarkably improved with (14mm, 7.9mm), (14mm, 6.9mm) and (41.8mm, 7.5mm) as (XPI1, YPI1), (XPI2, YPI2), and (XPO, YPO), because the current path is placed so that fed signals be not disturbed by the slit.

4. Conclusion

The discontinuity of a slit is considered and its influence is rigorously analyzed on the differential signaling in the power-distribution network. And an effective way has been suggested to improve the performance.

Acknowledgments

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