Differential Signals for the Rectangular Power-Bus to Reduce the Radiation from PCB Edges

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Abstract

This paper conducts a study on the differential signaling scheme in the rectangular power-bus structure to tackle the edge radiation problems. It entails the examination of impedance and its resonance behaviors in the frequency domain with respect to feeding conditions. Also, the fields along the edges of the structure are evaluated as the source of radiation to the outside of the power-bus. Using example structures, it is shown the differential signaling can improve the problems and be affected by loading..

Index Terms—*Power-Bus, Resonance, Differential Signaling*

1. INTRODUCTION

PCBs are frequently used in the electric or electronic systems and equipment. In PCBs there are a number of layers stacked and configured in various ways, depedent upon the circuit performance, the flow of signals, grounding, etc. With the rising clock–speed and number of components, PCBs tend to have denser population, which ends up with complicating noise phenomena. Particularly, the power-bus structure of the power- and ground planes is found out to cause the noise in PCBs[1-6].

The resonance will occur from the power-bus structure and results in the mal-functions due to the noise in the overall equipment. So, coping up with the power-bus resonance needs accurate analysis techniques on it and methods to avoid the resonance. About modeling and predicting the resonance behaviors, T. Okoshi uses the modal expression[1]. J. Fan et al adopt the method of moment that is well-known for its accuracy to characterize the power-bus structure's resonance phenomena and takes into account the SMT DeCap's placement in the cavity-like structure[2]. Based upon [1] and circuit concept, M. Hampe et al introduce a robust and simpler form of the modal expression to consider the loads of the power-bus structure and provide the proper ways of selecting DeCaps to remove the resonance frequencies in the rectangular power-bus structure[3].

Alternative to the conditions of loading, those of feeding such as differential-mode signaling scheme have been recognized with a view to attacking the common-mode current due to the PCB power-bus noise like its resonance[4]. The FDTD technique is employed by C. Wang et al to characterize the change in the impedance according to differential and common mode signals in the power-bus [4].

In this paper, analyses are carried out on how the differential and common-mode signals change the one-feed structure problem. Especially, the fields along the edges of the power-bus planes are dealt with to approach the proper feeding methods in an effort to reduce the edge radiation. Furthermore, the effect of DeCaps is investigated on the differential signaling, when they are used in the power-bus structure. Representative rectangular geometries are used to show the characteristics of the differential and common-mode signaling, on the basis of a rigorous modal expression which is validated by the FDTD application of [4].

2. NUMERICAL METHOD

The 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 power-bus structure where two feeding lines provide currents IPI1 and IPI2, and are placed in the upper region, and pass the intermediate region through the holes on the planes whose centers are (X_{PI1}, Y_{PI1}) and (X_{PI2}, Y_{PI2}), and leave the ground plane and go down to the lower region. And the output port is located at (X_{PO}, Y_{PO}). A lumped element is loaded at (X_{Lu}, Y_{Lu}).

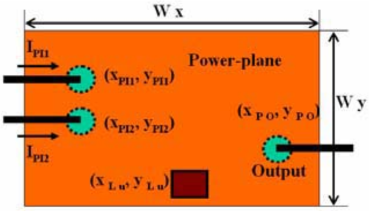


Figure 1. Top-view of a loaded power-bus structure with 2 feed signals.

The size of the rectangular power-bus is Wx*Wy*Wz. The PCB's substrate fills the intermediate region between the metal planes, and Wz, 4.2 and 0.02 are given as its thickness, relative dielectric constant and loss tangent, which is confined within the PEC and PMC boundaries. Regarding the feeds, typically speaking, when IPI1 and IPI2 are assumed in-phase and of the same magnitude, it is the common-mode signaling. If they are out-of –phase, they are the differential-mode signals

Prior to working on the differential signaling with two feeding lines, the structure with one feed needs to be modeled as the basis for the further task. As stated earlier, the modal analysis method using the double sum is adopted to evaluate the field and impedance on the rectangular power-bus structure accurately[1]. The double sum in [1] is good enough for the calculation of unloaded rectangular power-bus problems. If loading is considered, it goes through the use of matrix equations. Alternatively, a simple expression has been derived by M. Hampe et al to include the effect of loading in the double sum expression[4]. This is given as follows

$$Z_{Ld}(f, X_f, Y_f) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\gamma_{mn} \cdot c_{mn}(X_s, Y_s) \cdot c_{mn}(X_f, Y_f) \cdot W_z/(W_x W_y)}{\varepsilon\omega/Q + j(\varepsilon\omega - \frac{k_{xm}^2 + k_{yn}^2}{\omega\mu}) + \frac{\gamma_{mn} \cdot W_z}{W_x W_y}\sum_{u=1}^{Nu} c_{mn}^2(X_{Lu}, Y_{Lu}) \cdot Y_{Lu}} \tag{1}$$

where

$$c_{mn}(X_i,Y_i)=cos(k_{xm}X_i)\cdot\cos(k_{yn}Y_i)\cdot sinc(k_{xm}P_{xi}/2)\cdot sinc(k_{yn}P_{yi}/2)$$

$$k_{xm}=m\pi/W_x,\ k_{yn}=n\pi/W_y,\ \omega=2\pi f \tag{2}$$

$$Q=[\tan\delta+\sqrt{2/\omega\mu_0\kappa W_z^2}]^{-1}$$

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 and j denote loss-tangent, permittivity, permeability, frequency, port's width and $\sqrt{-1}$, respectively. Eqn. (1) considers N_u loads as

$$\sum_{u=1}^{Nu} c_{mn}^2(X_{Lu}, Y_{Lu}) \cdot Y_{Lu} \tag{3}$$

with the series equivalent circuit of the u-th load

$$Y_{Lu} = [R_{Lu} + j(\omega L_{Lu} - 1/(\omega C_{Lu}))]^{-1} \tag{4}$$

If a DeCap is placed in the structure, its ESR, ESL and Capacitance correspond to R_{Lu}, L_{Lu} and C_{Lu}, respectively.

On the basis of the technique up to this point, the one-feeding line case can be expanded to the differential signals as well as common-mode signals in that the superposition principle can be applied to this type of problem. Therefore, the common-mode impedance and the differential-mode impedance are calculated by using Eqn.'s (8) and (9) of [4] and is not repeated in this paper.

3. VALIDATION

Initially, the impedance is evaluated on the power-bus structure with the differential signals, but without any lumped-element loading, in order to verify whether Eqn. (1) is valid and 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 54mm×33.5mm×1.1mm, (27mm, 17.2mm), (27mm, 16.3mm), (41.8mm, 27.4mm) are given to $W_x \times W_y \times W_z$, ($X_{PI1}$, Y_{PI1}), (X_{PI2}, Y_{PI2}), and (X_{PO}, Y_{PO}).

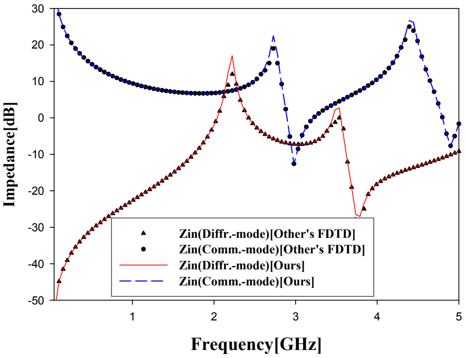


Figure 2. Unloaded 54mm×33.5mm×1.1mm power-bus' impedance of differential and common-mode signals: Comparing the double-sum and the FDTD.

For the modal analysis of double-sum, 400 is set as the truncation number for m and n, respectively. With regard to the accuracy, good agreement between the present method and FDTD[4] is shown in Fig. 2, except for negligible discrepancies at some peaks. Watching the two pairs of curves on the two-feed signaling, two things can be pointed out : Point 1 is that the differential signals lower the impedance from the common-mode signals. Point 2 is that the differential-mode signaling also generates the resonance spikes that will end up with potential noise in PCBs. Similar phenomena can be found in next experiment.

As the second example of a rectangular power-bus, a bigger structure is selected to show more resonance modes in the same frequency range. $W_x \times W_y \times W_z$, ($X_{PI1}$, Y_{PI1}), (X_{PI2}, Y_{PI2}), and (X_{PO}, Y_{PO}) are provided with 200mm×150mm×1.1mm, (50mm, 30mm), (50mm, 45mm), (169mm, 38mm).

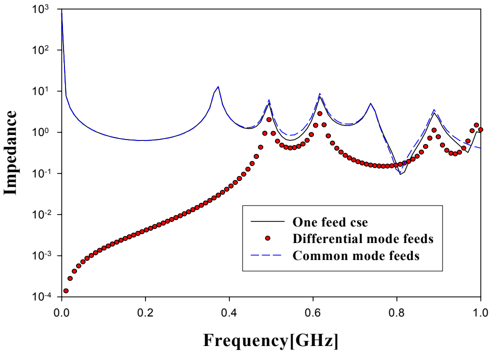
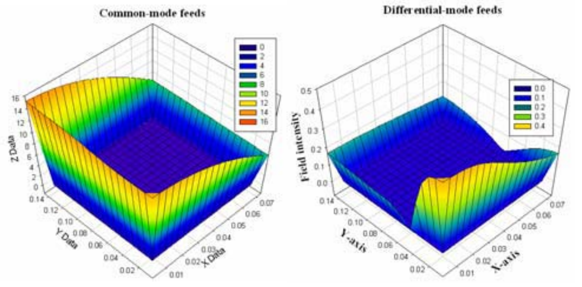


Figure 3. Unloaded 200mm×150mm×1.1mm power-bus' impedance of differential and common-mode signals: Comparing the double-sum and the FDTD.

The frequency ranges up to 1GHz for evaluating the impedance. Compared to Fig. 2, Fig. 3 has more resonance modes since this is greater in size. The one-feed case almost overlaps the common-mode signaling. Keeping in mind the closeness between the two feed points of this structure compared to W_x and W_y, the feeding system behaves like one feed. So the common-mode resembles the one-feed case. If a smaller sized structure uses these two feed points, they look relatively distant. Then the common-mode signaling becomes more different from the one feed system. Regarding the differential mode case, except for four resonance modes, it has much lower impedance. This leads to prediction that the differential mode signals have weakest fields along the edge, which is checked like the following results. The observation is made at 374MHz, the first resonance peak of the original structure.

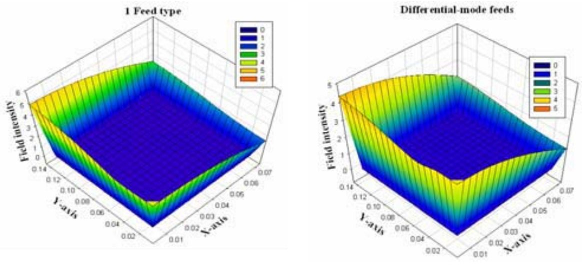


(a) (b)

Figure 4. Fields along the edges of Fig. 3 observed at 374MHz : (a) Common-mode signaling (c) Differential mode signaling

As the feeding is done near the corner of (0mm, 0mm), it is common that Fig.'s 4(a) and (b) show the field that remains strong along Y=0-edge. The common-mode shows the resonance behavior of field stretching over the whole area, but the differential mode signaling can reduce the edge field by the factor of 100 from the original radiation problem.

Lastly, it is shown two-feed signaling can be influenced by the loading of lumped elements. In this example, a DeCap is placed at the middle of the Y=0-edge. Its ESR, ESL and Capacitance are given 1Ohm, 4.2nH and 430pF, respectively. The one-feed case and differential-mode signaling scheme are dealt with about the edge fields at 374MHz for the observation.



(a) (b)

Figure 5. Loaded structure's fields along the edges of Fig. 3 observed at 374MHz : (a) One-feed case (b) Differential mode signaling

With the same feeding location as Fig. 4, the differential signals now raise the edge field level similar to the one-feed case. This results from the fact that the DeCap which is placed at the Y=0-edge disturbs the functions of the nearby feeds, though its use has damped the one-feed case by the factor of 3. To reduce the edge radiation from it, the feeds need to be placed farther from the DeCap.

4. CONCLUSION

This paper examines how differential and common-mode signals vary the resonance behaviors of one feed signaling for the rectangular power-bus structure. Without loading, the differential mode signals can enhance the mitigation of edge fields of the structure. And it is also given that DeCap loading influences the differential signaling and edge radiation.

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