Prediction of the Radiated Emission(RE)s due to the PCB Power-Bus' Resonance Modes and Mitigation of the RE Levels

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Abstract

PCB Power-Bus (comprising power/ground planes) impedance and fields are evaluated by an efficient series expansion method that is suggested in this paper. It is used to investigate the structure's radiated emission(RE) levels and find acceptable ways of loading the power/ground planes such as decoupling capcitor(DeCap)s, balanced feeding and slits, in order to reduce the interferences. Also, the calculations and measurements of a proposed geometry are verified by vector fitting as a analysis model to check the behavior of the slit.

Key words : PCB Power/Ground Planes, Vector Fit, Modal Expansion, RE, Resonance.

Ⅰ. Introduction

To facilitate the components and circuits for numerous essential functions in one body, modern communication systems are designed to have layers of PCBs. Standard layering of the PCBs has a pair of metal planes facing each other for DC-power supply and grounding. They are called PCB Power-Bus or Power/Ground planes.

The PCB power/ground planes form a cavity, composed of the top and bottom planes as the PEC boundary condition and the PMC walls[1]~[6]. It is well-known that the structure generates EMI noise at its resonance frequencies. To inspect the noise-generation principles through impedance profiles, a modal double sum analysis has been tried[1]. Besides, a single sum expression has been suggested to reduce the computational time[4]. A modified double sum expression is derived, needing no matrix manipulation in considering local geometrical irregularities[5].

Along with the impedance watch, it is important to identify the fields in the vicinity of the cavity far-region as radiated emission(RE) level, an indicator of electromagnetic interference toward adjacent circuits. This RE level can be predicted by the radiation integral, using the structure's fields as the source.

This paper suggests the followings. First, a novel single sum expression is derived to calculate the fields and impedance of the power/ground planes with arbitrary loads. Second, the use of the proposed method on the decoupling capacitor(DeCap) loaded structure shows the effectiveness in RE reduction. Third, a two-feed technique is applied to reduce the level of RE, based upon the suggested calculation method. Fourth, slit-loading in the rectangular power/ground planes is included to see the validity of the derived expression. Finally, the vector fitting technique is adopted to verify the calculated and measured results with building up an equivalent model.

Ⅱ. Theory

Lately, the PCB level EMC problems have drawn much attention for many reasons. One is that a variety of potential noise sources are formed by way of the PCB. This resonating structure can be illustrated as in Fig. 1.

The top as the ground and the bottom as the power-metal plane are identical in size with $Wx \times Wy \times Wz$. The DC current is carried along the feeding probe situated at (X_s, Y_s). And it is used as port 1. Port 2 is any arbitrary observation point at (X_f, Y_f) where induced voltage is observed. Loads are placed at (X_L, Y_L). The intermediate region between the two planes is the dielectric substrate and 4.2 and 0.02 are given as its relative dielectric constant and loss tangent, respectively. Referring to the structure's boundary conditions again, the two planes are the PEC and

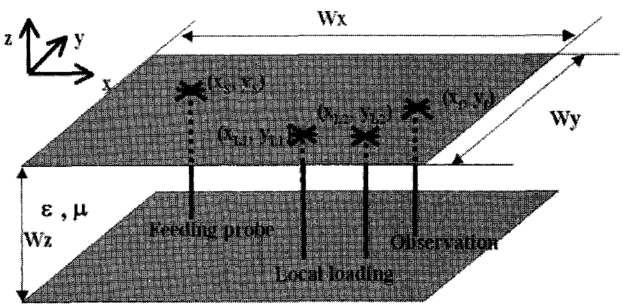

Fig. 1. Cavity model for a power/ground plane structure with ports and loads.

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the walls are the PMC. Then, impedance due to E_z is expressed as the following equation that's validated by comparing others' methods[3],[4]

$$Z_{Ld} = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{\gamma_{mn} \cdot c_{mn}(X_s,Y_s) \cdot c_{mn}(X_f,Y_f) \cdot W_z/(W_xW_y)}{\varepsilon\omega/Q + j(\varepsilon\omega - \frac{k_{xm}^2 + k_{yn}^2}{\omega\mu}) + \frac{\gamma_{mn} \cdot W_z}{W_xW_y}\sum_{Lu=1}^{NLu} c_{mn}^2(X_{Lu},Y_{Lu}) \cdot \tilde{Y}_{Lu}} \quad (1)$$

where

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

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

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

Lu : *integer, NLu* : *Total number of loading elements* (2)

γ_{mn} is 1 and 4 for (m=0, n=0) and ($m \neq 0$, $n \neq 0$) each. When ($m \neq 0$, n=0) or (m=0, $n \neq 0$), 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 NL_u loads with the series equivalent circuit of the Lu-th load

$$\tilde{Y}_{Lu} = [R_{Lu} + j(\omega L_{Lu} - 1/(\omega C_{Lu}))]^{-1} \quad (3)$$

When resonance modes need damping, loads are replaced by DeCaps. However, the single-sum is highly preferred to cut down computational cost of the double-sum with big truncation numbers. Therefore, a new single sum expression is derived to take into account the loads like Υ_{Lu} as follows

$$Z_{Ld}(f,X_f,Y_f) = \sum_{n=0}^{\infty} \tau \cdot \gamma_n \cdot c_{0n}(X_s,Y_s) \cdot c_{0n}(X_f,Y_f) \cdot \frac{\{\cos(\xi_n X_-) + \cos(\xi_n X_+)\}}{\xi_n \sin(\xi_n)} \quad (4)$$

where

$$\gamma = W_zW_x\omega\mu/(j2W_y),$$

γ_n : 1 for n = 0 or 2 for $n \neq 0$.

$$\xi_n = \sqrt{\kappa^2 - k_{yn}^2 - \varsigma^2},\ \varsigma = \sqrt{Y_{NLoads} \cdot \gamma_{mn} \cdot W_z \cdot \omega\mu/(jW_xW_y)},$$

$$X_\pm = W_x - (X_s \pm X_f),\quad Y_{NLoads} = \sum_{Lu=1}^{NLu} c_{mn}^2(X_{Lu},Y_{Lu}) \cdot \tilde{Y}_{Lu} \quad (5)$$

Based upon the one-feeding line case, in order to decrease the impedance level of the structure's resonance behaviors, the differential-mode signaling is used and can be characterized with no difficulty, since the superposition principle is applied from the one-feeding case to the multi-feeding in this structure.

Therefore, the common-mode(two currents(I_{PI1} and I_{PI2}) of the same magnitude and in-phase) impedance and the differential-mode(I_{PI1} and I_{PI2} of the same magnitude but out-of-phase) impedance are calculated by using the Eqn.'s (8) and (9) in [6].

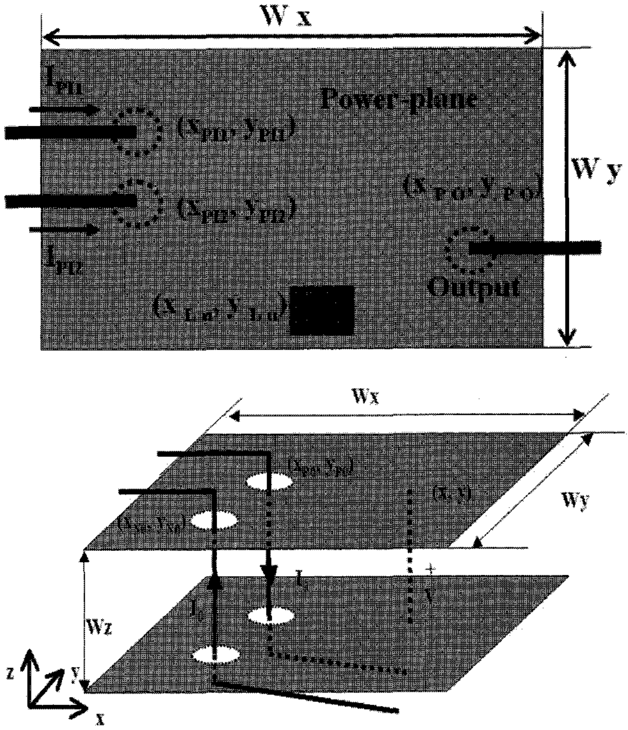


Fig. 2. Top- and 3D views of a power/ground plane structure with two feeds.

As an alternative way to change the impedance property concerning the structure, the slit is introduced in the planes. Actually, the slit has been conventionally recognized a trouble-maker in signal integrity problems in that it will cause the scattering of the injected signal.

However, when it comes to the change of the electromagnetic field behavior into a better direction, the slit can be utilized for mitigating the structure's resonance. From the standpoint of numerical analysis on the slit structure, the whole geometry is segmented to rectangular blocks and each of them is characterized by using Eqns (1) through

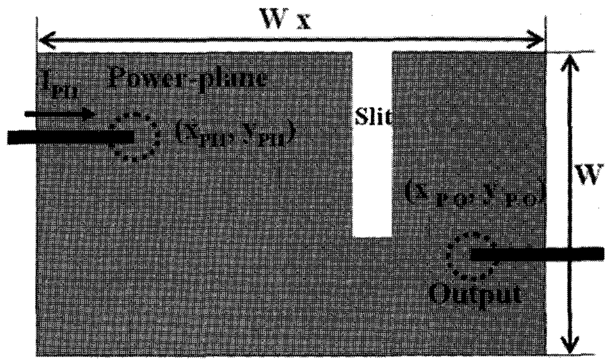


Fig. 3. Slit power/ground plane structure.

(5), and then segments' properties are combined. After performing a full-wave analysis on a geometry, we can build an equivalent circuit model to investigate the slit as a load plays an appropriate role in experiencing electrical changes. If the agreement is checked between the numerical and circuital simulations, we can confirm the validity of using the slit.

The equivalent circuit is identified based upon the vector fitting method as in [6] and the work starts from the following rational function.

$$FitFunction(S) = \sum_{i=1}^{N_p} \frac{\mathrm{Re}\, s_i}{S - p_i} + C_l + Q_h S \quad (6)$$

where $S = j\omega, j = \sqrt{-1}$, and Res_i, P_i, N_p, C_l, and Q_h denote the i-th residue and pole, the constant, and first-order term, respectively. These values are found by equating *FitFunction(S)* to the samples of the frequency response.

Local loads, slits and balanced feeding techniques above are used, the electromagnetic field strength will tend to be maximum at resonance modes, and they will propagate past the edges of the planes to the external region. The electromagnetic fields at resonance modes in one structure will reach its upper and lower PCB layers and nearby systems. The radiation out of the edges can be explained as that of magnetic currents due to E_z is induced on the walls first, and then this fictitious current radiates. As for this, the radiation integral in the following is employed[7].

$$\underline{E} = (jk_0 W_z e^{jk_0 r}/(4\pi r)) \oint_{Rim} \underline{M}_s(\underline{r}') e^{jk_0 \underline{r}'\cdot\hat{e}_r} (\hat{e}_r \times \hat{e}_l) d\underline{l} \quad (7)$$

$\underline{M}_s(\underline{r}')$ is the induced magnetic current at $\underline{r}'$ on the walls, $\hat{e}_r$ and $\hat{e}_l$ and are the normalized position vectors of the observation and source points. k_o is the free-space wave-number. Given that W_z is far less than W_x or W_y Eqn (7) takes a line integral along the periphery(edges instead of open-end surface). Also, the above equation can be approximated as the far-zone field for simplicity.

Ⅲ. Numerical Validation and Measurement

Firstly, the input impedance evaluation is performed through the proposed Eqn. (4) with respect to the power/ground planes of 220 mm by 150 mm by 1.5 mm, and compared to the result of Eqn. (2). For this simulation, no loading of local components is considered. And the DC current is fed at (X_s=0, Y_s=0) from bottom to top. The frequency range of interest ranges from 0 through 1 GHz.

The two methods produce the overlapping results. The conventional double sum was truncated at (m=400, n=400), but Eqn. (4) was done up to 1,200 terms. On the contrary, the suggested single sum expansion lowers the computation

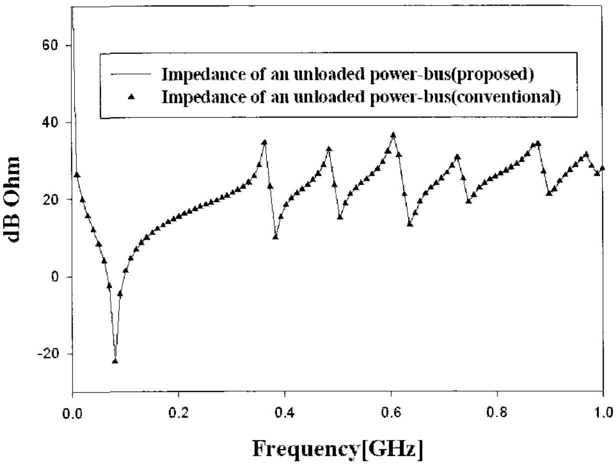


Fig. 4. Comparing the conventional and proposed methods for an unloaded structure's input impedance.

time by less than 1/100, with assuring the accuracy. Beyond 200 MHz, peaks of resonance modes (1, 0), (0, 1), (1, 1), (2, 0), (2, 1) and (0, 2) occur in order.

Next, the power/ground plane structure is loaded with components. DeCaps are used in the structure. Resonance modes at 370 MHz and 730 MHz are targeted for damping by DeCaps. Using optimization techniques considering two DeCaps, the followings are obtained. DeCaps 1 and 2 have (1 Ω, 4.6 nH, 47 pF) at (220 mm, 75 mm) and (12 Ω, 1.5 nH, 47 pF) at (0 mm, 75 mm), respectively. In the second place, Eqn. (4) is used with those input parameters for Y_{NLoads} to present the damping performance on the desired resonance modes. In addition to the input impedance evaluation, the maximum of $|\underline{E}|$ as RE level is calculated with respect to the original resonance modes. In particular, the RE levels of the power/ground planes before and after damping the specified resonance modes are compared along with the impedance profiles.

Seeing the solid and dotted lines as the original power/

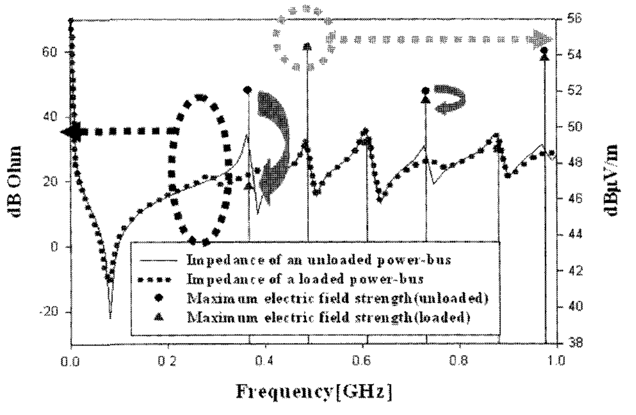


Fig. 5. Impedance and RE before and after loading DeCaps in the power/ground planes.

ground planes and loaded case, the impedance levels at the aforementioned resonance modes are reduced by 13 dB and 4 dB as can be predicted and this notifies that if the level of one resonance mode(lower resonance mode frequency of 370 MHz) sees large reduction, the other target resonance mode will go through relatively small reduction. This can be confirmed by the fact that the RE levels at 370 MHz and 730 MHz come down from 52 dBμV/m and 52 dBμV/m to 47 dBμV/m and 51 dBμV/m, respectively. It is proven that the damping of the resonant impedance point can reduce the RE level out of the power/ground planes. Now, the calculation of the impedance is carried out on the power-bus structure with the differential signals. Through this experiment, we will come to realize how accurate the proposed single-sum calculation is, when examined by the comparison with the results of the double-sum and the FDTD application for the same environment for simulation[7].

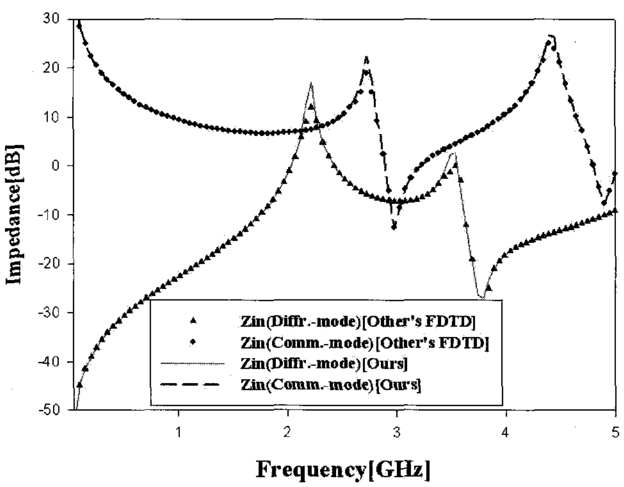


Fig. 6. Differential- & common-mode feeding results on the power/ground planes.

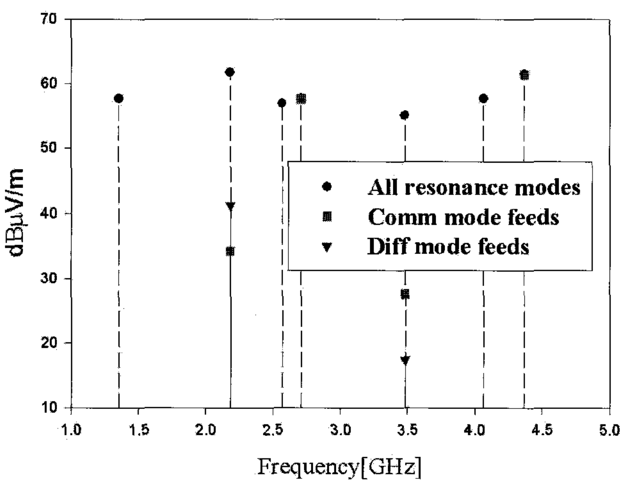
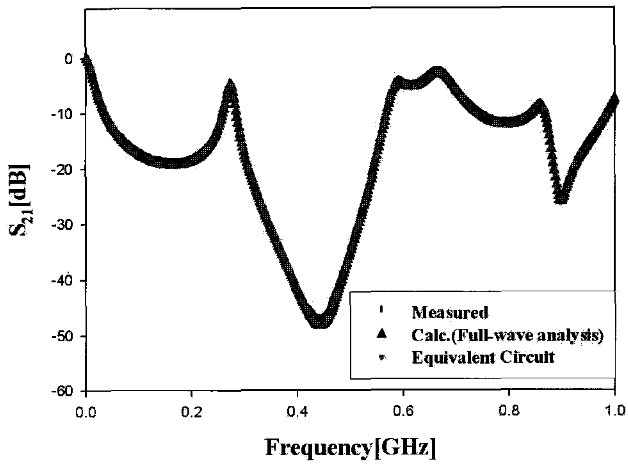
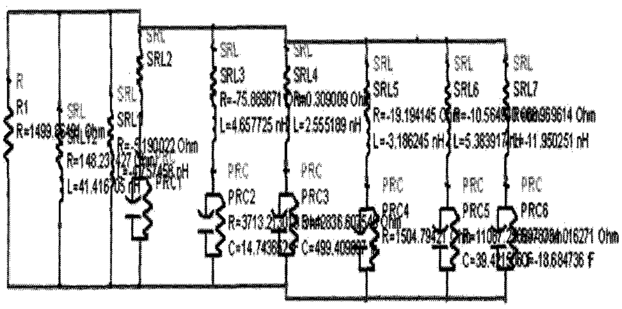


Fig. 7. Radiated emission levels with differential- & common- mode feeding results.

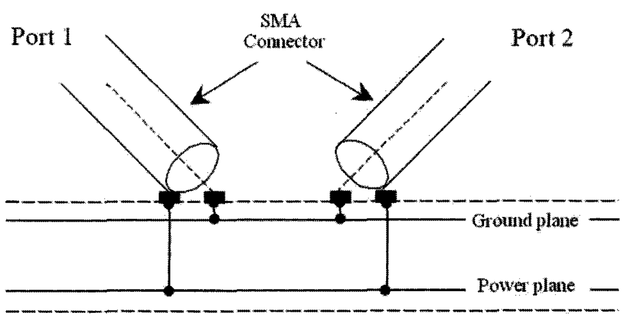
The structure and frequency range are the same as [7], where 54 mm×33.5 mm×1.1 mm, (27.0 mm, 17.2 mm), (27.0 mm, 16.3 mm), (41.8 mm, 27.4 mm) are given to $W_x \times W_y \times W_z$, (X_{P0}, Y_{P0}), (X_{N0}, Y_{N0}), and (X, Y). Fig. 6 shows the good agreement between the present method and the FDTD in [7] except for negligible discrepancies at some peaks. Seeing the compared curves of the two feed signals, the differential mode has lower impedance than the common-mode, and is superior to the one-feed case when good conditions are met such as right placement and proper distance between the feeds in practice The following is the



(a) Frequency responses



(b) An equivalent circuit



(c) Measurement scheme

Fig. 8. Frequency responses, an equivalent circuit and measurement scheme on the slit-loading in the power/ground planes to mitigate the structure's resonance.

RE prediction with the differential feeding as well as common-mode feeding.

Examining the comparison, the improvement is found at the resonance frequencies of the original one feed structure to the reduced RE level introduced by the two freed system.

Finally, an experiment on the reduction of the resonance at a specific point, 300 MHz here, is conducted by leaving a slit with the geometry at X=120 mm whose length and width are 70 mm and 5 mm. The calculation is done by the proposed method and it is accompanied by the measurement. Also, vector fitting is carried out to build an equivalent transfer function and related model for the calculation and measurement.

The vector fitting scheme adopted here for the scattering parameter S_{21} has been exploited with the order of 15 through 30 and it is found out there is no big difference between the trial values. Fig. 7 shows the excellent agreement between all the works. This means vector fit model has been successfully set to predict the equivalent elements. Let alone, the slit-loading can mitigate the initial 300 MHz-resonance by an acceptable margin.

Ⅳ. Conclusion

The radiated emission from the power/ground planes is estimated by a new single modal sum expression derived to calculate the field and impedance as well as resonance properties of the structure with arbitrary lumped loads. It could reduce computation time by 1/100 or less from the conventional method, with the same accuracy. Using the proposed method, the resonance problems of the power/ground planes could be improved by adopting a DeCap, a slit and the differential feeding technique. This way of resonance-damping was confirmed to effectively lower the RE levels at the original resonance modes through experiments.

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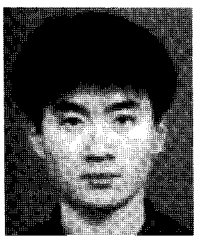

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