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Study on the Mitigation of the Resonance due to the Power-Bus Structure using Periodic Metal-Strip Loaded Sheets

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Abstract – This paper investigates a method to tackle the resonance problems of the rectangular power-bus structure(PBS) using thin sheets loaded with periodic metal strips. The equivalent surface impedance of the proposed loading is calculated and involved in the expression of the impedance that accounts for in the PBS, in order to improve the resonance behavior of the original structure. The effects of the strips and the immediate surroundings are illustrated by a number of numerical experiments. Also the restrictions of the technique are addressed.

Keywords: Power-bus, Resonance, Strip loaded sheets, Inductive surface, Metamaterials

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, dependent 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 [1-4].

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]. S. Kahng goes further 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 localized lumped elements 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 local SMT components for the removal of the electrical noise source, we sometimes resort to the global distribution of them over the plate to assure the decrease of the impedance level of the PBS. This scheme is pointed out to lower the level in a wider frequency band. This results from the fact the paths of currents from the power plane through the ground plane in the PBS can't be long. At the same time, in terms of electromagnetism, the boundary condition on the metal planes changes due to the widespread components. Namely, it is worth coming up with how to change the boundary conditions like the global placement of the elements. One good idea about it is to handle the surface boundary conditions.

In this paper, for the purpose to suppress the unwanted resonance mode noise over a broad band, the surface of the PBS winds up with the change in material's characteristics and stratification where PEC strips are assumed to periodically sit on a very thin slab backed by one of the two metal planes in the PBS. The slab will be ordinary lossy dielectric or magnetic material, but very thin enough to be replaced by a sheet. And the sheet has strips on its top and is expressed as the surface impedance [5]. The analysis is rigorously carried out, regarding the way the sheet affects the properties of the PBS, to find out the solution to damp the spurious resonance modes.

2. Theory

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 with a current feeding line which is placed in the upper region, and passes the intermediate region through the hole on the planes whose center is (X_S, Y_S), and leaves the ground plane and goes down to the lower region. And the output port is located at (X_f, Y_f). A lumped element is loaded at (X_{Lu}, Y_{Lu})

The size of the rectangular power-bus is $W_x \times W_y \times W_z$. The PCB's substrate fills the intermediate region between the metal planes, and W_z, 4.2 and 0.02 are given as its thickness, relative dielectric constant and loss tangent,

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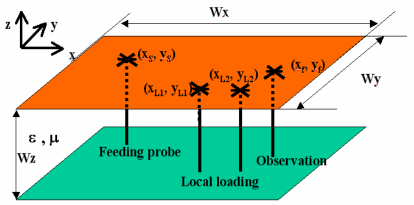

Fig. 1. Power-bus structure with 1 feed

which is confined within the PEC and PMC boundaries.

The governing conditions are solved by 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.

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

where

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

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

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

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 and j denote loss-tangent, permittivity, permeability, frequency, port's width and $\sqrt{-1}$, respectively. This has been about the original geometry. Now the PBS with the strips loaded on the PEC backed slab is illustrated.

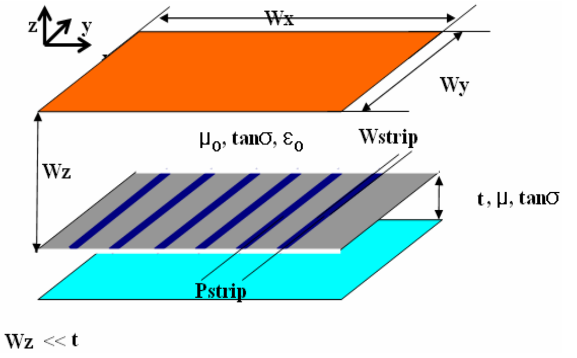

Fig. 2. PBS loaded with periodic metal strips on the grounded sheet

The impedance observed at the strip array surface into the slab is represented as

$$Z_S=Z_{inSlab}\,||\,Z_{Pstrip} \quad (3)$$

where

$$Z_{Pstrip}=j0.5Z_{0Slab}k_0P_{Strip}\log(2P_{Strip}/\pi W_{Strip})/\pi$$

and

$$Z_{inSlab}=Z_{0Slab}\frac{Z_{GND}+Z_{0Slab}\tanh(\gamma_{Slab}t)}{Z_{0Slab}+Z_{GND}\tanh(\gamma_{Slab}t)} \quad (4)$$

For the surface impedance Z_{Pstrip}, we assume P_{strip} is far greater W_{strip} as in [5]. Also, t ranges from 4μm~40μm, and is much smaller than Wz. And the modified surface boundary condition is reflected on, when Eq. (3) is included in Eq. (1) in the following way.

$$C_{mn}=\frac{ab\varepsilon_d\left(W_Z+\frac{2X_S}{\omega\mu_d}-\frac{2R_S}{\omega\mu_d}\tan\delta\right)}{W_Z^2} \quad (5)$$

$$R_{mn}=\frac{W_Z^2}{ab\omega\varepsilon_d\left(\frac{2R_S}{\omega\mu_d}+W_Z\tan\delta+\tan\delta\frac{2X_S}{\omega\mu_d}\right)}$$

with

$$Z_S=R_S+jX_S \quad (6)$$

As for C_{mn} and R_{mn}, the corresponding terms are shown in [4] and are not repeated in this paper.

3. Validation of the method

Firstly, the accuracy of the calculation method adopted in this paper here is tested by being compared to the measurement with respect to the basic PBS of Fig. 1. Eq. (1) is evaluated with the 160000 mode numbers(with the truncation number for both m and n set to 400). The geometry of interest takes 156 mm×106 mm×508 μm just for experimental purpose with $X_S = X_f$= 117mm and $Y_S = Y_f$ = 79.5mm. FR4 as the dielectric is used(ε_r=4.4, $tan\delta$=0.02).

As shown in the figure, the calculation scheme turns out robust to have reliable accuracy, agreeing with the counterpart. Also, it is noticed that the resonance modes appear as the peaks in the impedance profile, which are believed to cause the radiated emission as well as the ground-bounce. So it is clear to try to avoid the aftermath in the wake of the unwanted EMI problems by suppressing the impedance levels of the resonance modes. Here a simple but natural need arises like targeting a specific resonance mode frequency to remove or more in an extended frequency band. This leads us to the practice that circumvents the dominant resonance mode, say, TE_{10} at 475 MHz in a couple of ways such as suppressing only the

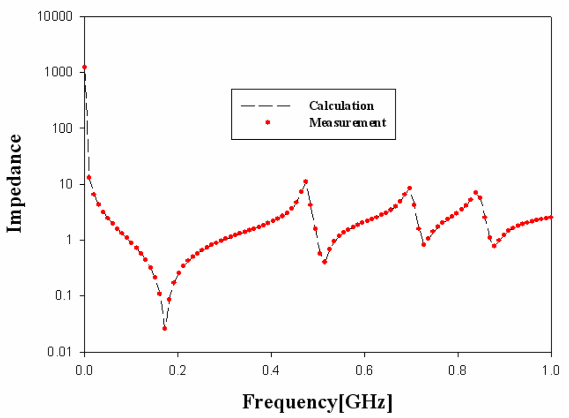

Fig. 3. Comparison between the calculation and measurement results with regard to the basic PBS.

target resonance frequency without affecting the rest of the entire band of interest or perturbing the overall impedance profile. If a local element is employed, only one specified resonance mode can be selectively damped. However, this paper suggests the variation in the surface boundary condition of the PBS which influences the impedance behavior in the whole frequency range. To see what happens in details, we define a number of cases of parametric differences for engineered sheets: material-wise, there will be lossy dielectric slabs or magnetic slabs on which PEC periodic strips reside, and the slabs will have different thickness numbers. Geometry-wise, strips' period will be varied.

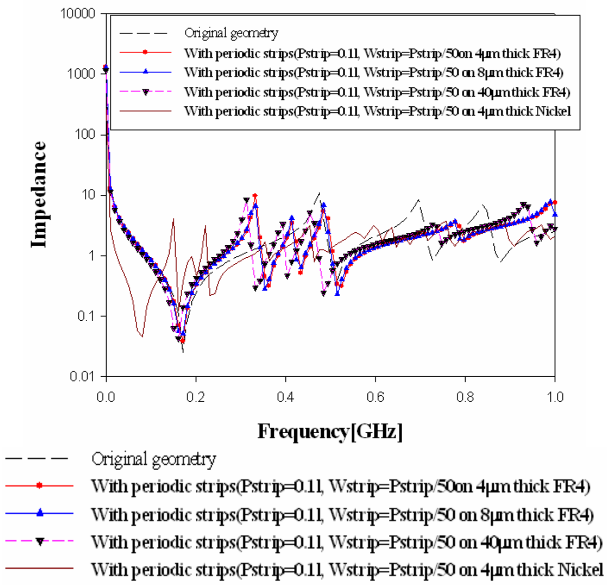

Fig. 4. Impedance profile vs. changing thickness of the dielectric layer(except for Nickel as a comparative study)

Periodic strip loaded FR 4 sheets with $P_{strip} = Wx/5.2$ and $W_{strip} = P_{strip}/50 = Wx/260$ make influence on the whole frequency in Fig. 4, splitting the original TE10 mode peak and reducing the impedance level at 475 MHz by 9 Ω. However, there are three peaks occurring lower than 475 MHz, while higher resonance frequencies are much suppressed. Things totally change with a magnetic material Nickel(μ_r=250 assumed for the frequency band here) of the unchanged thickness. It brings the remarkable mitigation effect in a much wider band. Now we will go further in exploiting the solution to remove the two peaks(@<300 MHz) in the case of the strips on Nickel, though they are lower than the resonance modes in other cases.

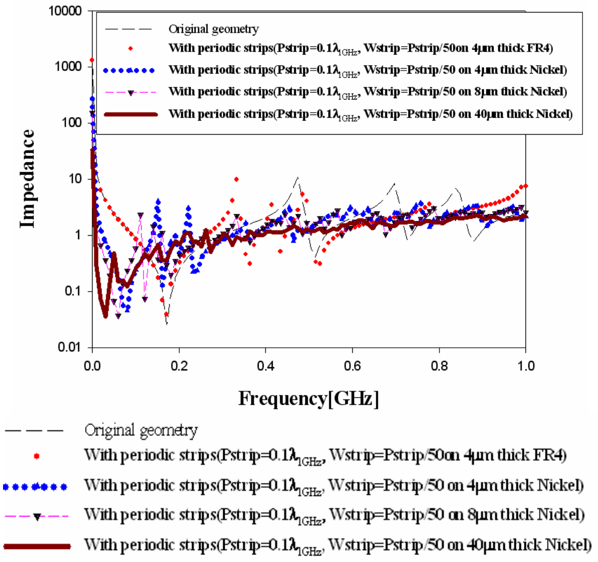

Fig. 5. Impedance profile vs. changing thickness of the magnetic layer(except for FR4 as a comparative study).

We are trying the different values of the magnetic slab's thickness. Starting from 4 μm through 8 μm, we can watch that the resonance modes of the original structure including TE_{10} are dispersed and disappearing in the whole frequency band. Definitely, the metal strips add their inductive property to that of the grounded slab. In particular, it shows greater improvement in damping the resonance modes, when strips go along with the magnetic material slab. Finally, we take into account the situation where the geometric change of the strips, for example, P_{strip} can be constructively influential on the use of the magnetic slab and whether the change in periodic strips has limitations in the proposed solution.

Investigating what really matters in enhancing the problem, it is noticed that inductive features of the slab loaded with strips will weaken the magnetic fields on the PBS. So to increase Z_{Pstrip} the factor of the period(P_{strip}) is made 100 times greater, which is interpreted lowering the capacitance between the neighbor strips by widening the gap. Within the boundary given by the practicality, varying the gap raises the inductiveness(X_L) with the FR 4 slab. But this doesn't work very well. With low X_L due to FR 4(non-magnetic), the larger Z_{Pstrip} renders the whole inductance

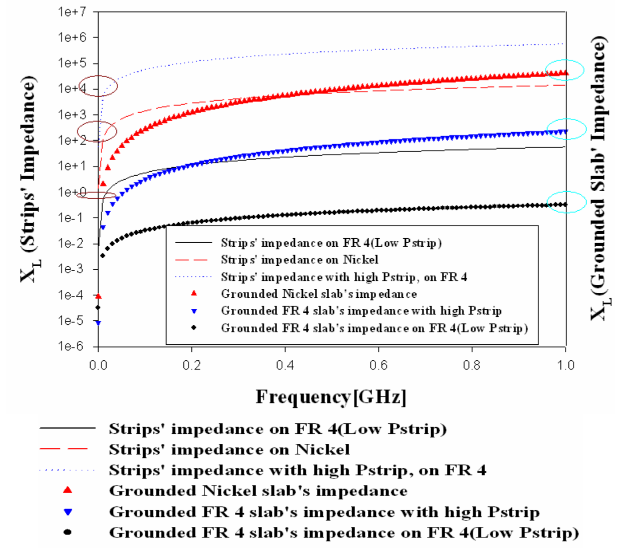

Fig. 6. Frequency behaviors of the inductive reactance of Z_{Pstrip} and Z_{inSlab}.

more dependent on the X_L of Z_{inSlab}, because the smaller impedance has the stronger effect than the larger one in a shunt connection. Therefore, both Z_{Pstrip} and Z_{inSlab} should be significantly high as the curve (···) and the curve(▼) in Fig. 6. This condition gives rise to the curve(▬) in Fig. 5 as the best enhancement.

4. Conclusion

In this paper, we proposed and examined a method to attack the resonance problems of the rectangular power-bus structure(PBS) using thin sheets loaded with periodic metal strips. The equivalent surface impedance of the proposed loading is calculated and involved in the expression of the impedance that accounts for in the PBS, in order to improve the resonance behavior of the original structure. Through the experiments, we are convinced the periodic strips sitting on the grounded slab work as inductive surface impedance sheet and give rise to the excellent solution in mitigating the resonance modes in a broader frequency band..

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