A Metamaterial-Inspired and Embedded Structure to Damp the Resonance of the Power/Ground Planes

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***Abstract*—An effective method is proposed to enhance the SI and PI of a power-bus structure(PBS) in a layered medium PCB by suppressing the EMI-causing resonance mode. It is implemented by a complementary split-ring-resonator as a 1-cell metamaterial-inspired geometry formed in the PBS to remove the resonance that hinders the signal transfer from one layer to another. The method is verified by the full-wave simulation and impedance measurement and RE test.**

***Keywords*—Power-bus structure; Resonance; SI; Suppression**

I. INTRODUCTION

The PCB of a digital circuit in a communication system typically includes the power-bus structure comprising the power and ground planes. These two planes form a cavity where resonance modes occur[1-5]. The cavity-mode resonance will act like noise sources in the circuits, such as conducted or radiated emission[3, 6].

To secure the acceptable performance of the digital circuitry from the EMC point of view, two things need to be done. One is the accurate prediction of electromagnetic fields and waves guided in and emanated from the layered PCB. Based on the fields, electrical characteristics such as resonance and input impedance are predicted and pave the way to provide PCB component designers with the generation of the SSN noise and unwanted emission. When the problem such as performance degradation due to the EMI noise is expected before finalizing the circuit design, the countermeasure should be come up with. Considering the reported cases of the malfunction of digital circuits, the ground-bounce noise is put the blame on, and it results from the resonance generated in the power/ground planes. In order to damp the resonance phenomenon, decoupling capacitor(DeCap)s are frequently adopted in practice and their effects can be clearly accounted for [4,5]. However, it is never an easy task to decide more than one DeCap and their positions simultaneously, as the multi-unknown problem. For this, an array of DeCaps are adopted and placed in an area, but it is recognized as something impractical and costly.

In this paper, a method is proposed to take advantage of a distributed element, which is printable for repeatability and embeddable in the layers of the PCB structure. To be more specifically, a complementary split ring is carved on the metallic ground to prohibit a resonance mode that captures the signal from the top layer to the bottom one. That is to say, the anti-resonance of the ring shaped slot will cancel the resonance of the power/ground planes. A test power-bus is given and its impedance profile with the resonance is obtained. And it will be shown that the formation of a metamaterial-inspired slot in the intermediate metal layer removes the unwanted resonance and lets the signal flow from port 1 to port 2. The validity of the proposed method is confirmed by the 3D EM simulation and experiment of the fabricated prototype.

II. THE CONVENTIONA WAY TO DAMP THE RESONANCE WITH DECOUPLING CAPACITORS

Prior to the description of the proposed method, it is worth mentioning the basic shape of the power/ground planes and the conventional scheme to deal with the impedance hike at the resonance frequencies. The geometry of the rectangular power-bus unit is illustrated as follows.

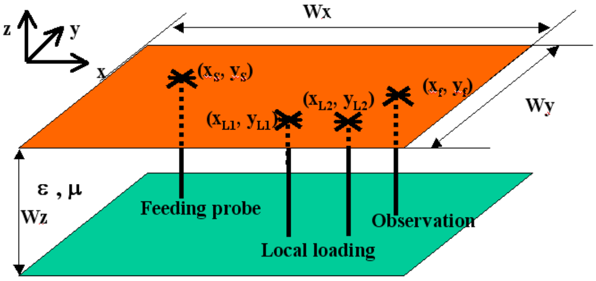

Fig. 1. The basic form of the power-bus structure with discrete elements.

The top and bottom planes form a cavity of the size $W_x \times W_y \times W_z$. When current I_s is fed at (X_s, Y_s), and elements are loaded at (X_L, Y_L), impedance $Z_{Ld}(f, X_f, Y_f)$ observed at (X_f, Y_f) is given as follows[4,5].

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

where

$$c_{mn}(X_i, Y_i) = \cos(k_{xm} X_i) \cdot \cos(k_{yn} Y_i) \cdot sinc(k_{xm} P_{xi}/2) \cdot sinc(k_{yn} P_{yi}/2)$$
$$k_{xm} = m\pi / W_x, \quad k_{yn} = n\pi / W_y, \quad \omega = 2\pi f$$

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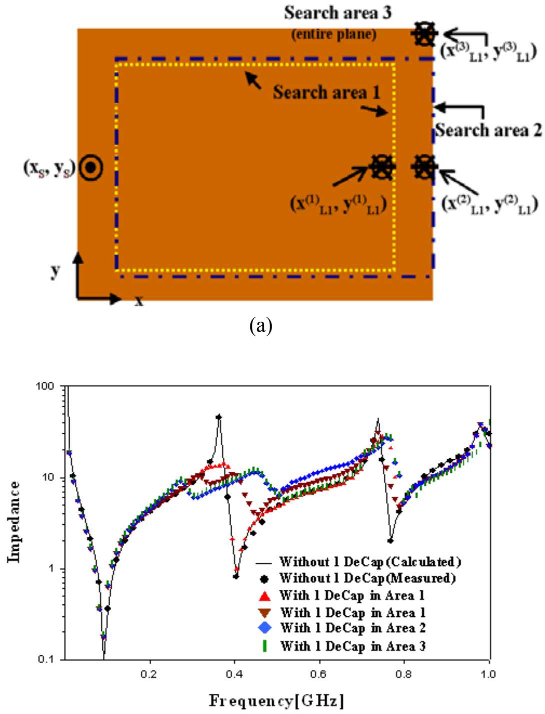
$$Q = [\tan\delta + \sqrt{2/\omega\mu_0\kappa W_z^2}\,]^{-1} \tag{2}$$

γ_{mn} is 1 and 4 for (m=0, n=0) and (m≠0, n≠0) each. When (m≠0, n=0) or (m=0,n≠0), γ_{mn} takes 2. $tan\delta$, ε , μ, κ, f, P_i and j denote loss-tangent, permittivity, permeability, conductivity frequency, port’s width and $\sqrt{-1}$, respectively. The term <*Loads*> means the averaging contribution of the discrete elements, and its mathematical expression is found in [5]. The impedance profile of a power-bus has resonance frequencies, and the first one as the TE$_{10}$-mode is designated as the target for noise suppression, which entails the right choice of a DeCap. If we set *ESR*, *ESL*, and *C* for the DeCap at 1Ω, 2nH, 0.1nF to suppress the first resonance mode, the loaded in the power-bus of 200mm×150mm×1.5mm as the overall size, ε_r=4.1, μ_r=1, κ=59.6·10^{9}S/m and $tan\delta$=0.02. The candidate areas of the placement are sketched in the following.



(a)

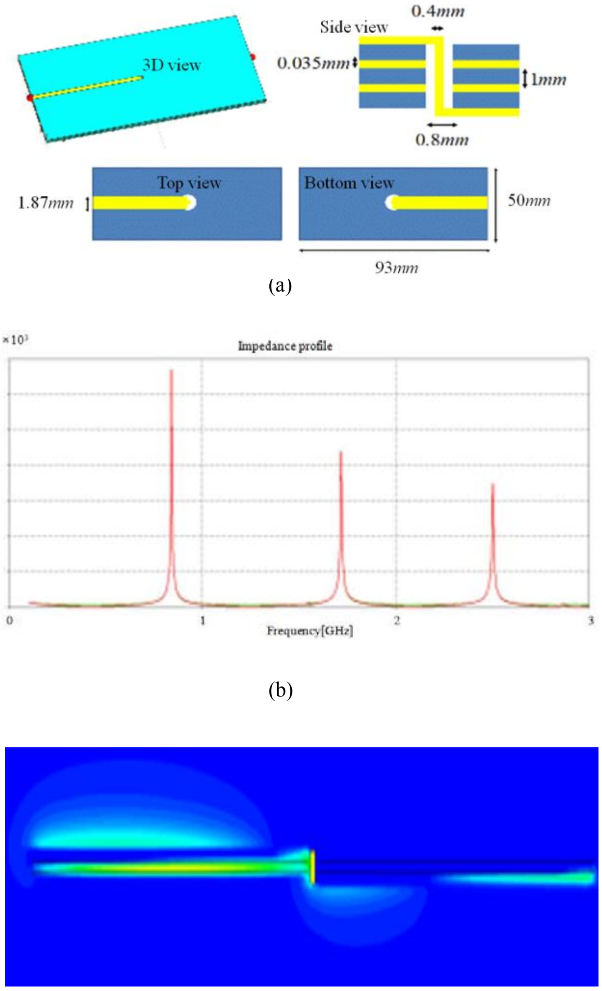
(b)

Fig. 2. The possible placement of the DeCap and the change in the impedance profile (a) Three areas to hold the DeCap (b) Impedance profiles of the cases of no-DeCap and three possible DeCap mounting areas.

Fig. 2(a) shows the central area and its expansion to one edge together with the entire area to include all the corners and edges for the DeCap placement. The result of placing the aforementioned element in the three different regions of the power-bus structure is associated with the impedance profile of Fig. 2(b). Without the DeCap as a loading element, the impedance curve goes up and down with the peaks as the resonance modes. It is noteworthy that the predicted impedance by the calculation agrees with the measured data. Using the DeCap of the *R-L-C* given above, the impedance of the resonance frequency drops by at least 40Ω. The DeCap placed at a corner of area 3 brings the most remarkable damping effect, which is followed by that in area 2. It is inferred that when the DeCap is loaded on an edge of the power-bus structure, it will work. However, the scheme to use discrete elements has a few limitations such as inaccurate and varying values of *ESR* and *ESL*, and unsuitability of integration into layer stacking and gluing.

III. PROPOSED METHOD TO REMOVE THE RESONANT NOISE WITH AN EMBEDDED SPLIT-RING SLOT

By far, the way how the DeCap is utilized for treating the ground-bounce noise and its limitations have been addressed. To overcome the drawbacks that the use of the discrete element has, a new approach is suggested to circumvent the problems of hard-to-control parasitics and inconvenience of inserting a lumped element into the PCB. Considering how to avoid the restrictions of the discrete loads, we take advantage of a metamaterial-inspired anti-resonance maker realized by a complementary split ring resonator (CSRR) to suppress the unwanted resonance mode. To clearly present the positive effect achieved by the CSRR, a three layered PCB including the power/ground planes in the middle is taken as a test case.



(a)

(b)

(c)

Fig. 3. The test structure and its frequency response (a) Geometry (b) Impedance profile (c) Signal blocked by the resonance at 1.7 GHz.

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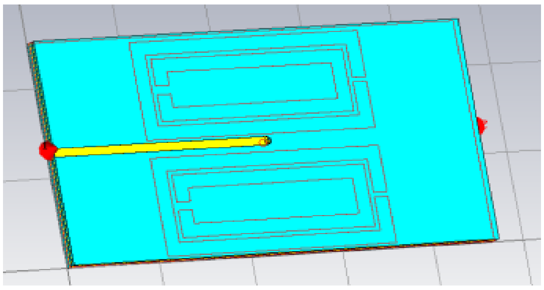
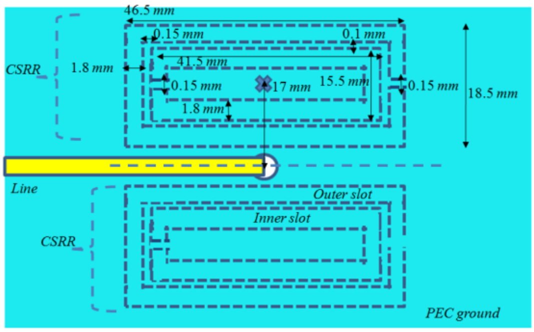
A test vehicle in Fig. 3(a) is determined to consist of the power and ground planes connecting the input-port layer(top) with the output-port layer(bottom), and the impedance match for both the port layers. Especially, the transversal size and the thickness of the middle layer as the power-bus region are set to have a resonance at 1.7 GHz, which is a commercial communication service band(Other bands such as 2.4 GHz or 5.4 GHz are possible to take). The scenario here is that a digital PCB circuit for the PCS wireless connectivity service is deteriorated by the unwanted noise from its internal power-bus region. Fig. 3(b) is the impedance profile having several resonance peaks, and one of them occurs at 1.7 GHz. At that frequency, the impedance goes over 4000, which leads to poor SI and PI, and troublesome radiated emission. The resonance prevents the port-to-port signal from flowing, which ends up with malfunction. Fig. 3(c) shows that the field as the RF signal from port 1 is captured within the power and ground planes at the resonance. Therefore, we form a pair of split-ring shaped slots on the ground plane of the middle layer as follows.



(a)



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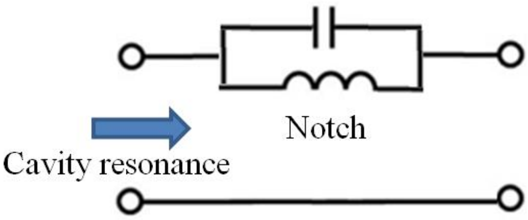

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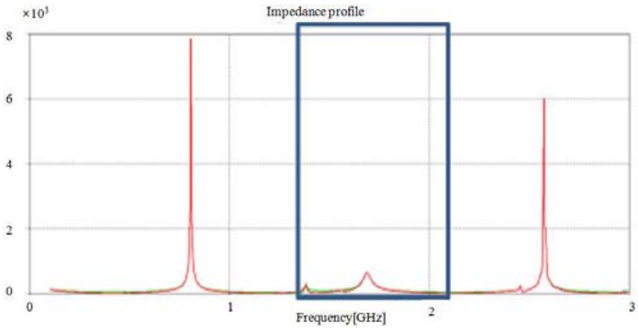

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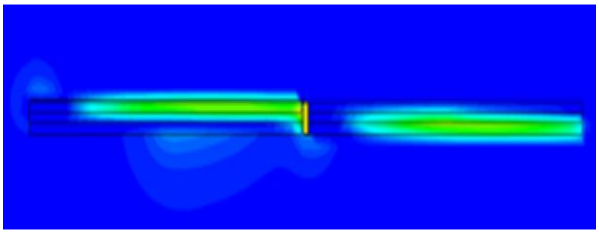
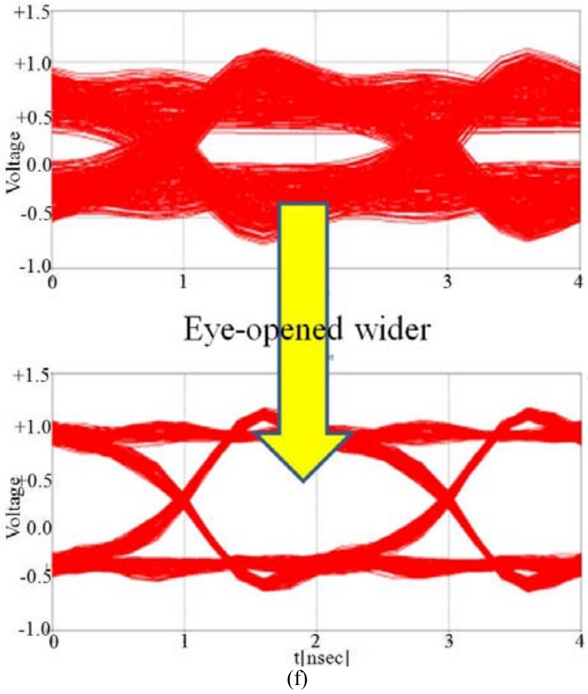


(e)



(f)

Fig. 4. The proposed structure and the improvement by the suppression of target the resonance (a) Geometry with the CSRRs (b) Detailed geometrical information (c) CSRRs as a notch filter for the cavity resonance mode (d) Impedance level falling (e) Signal passing through the layers at 1.7 GHz (f) Enhanced eye-diagram.

The CSRRs are designed to cancel the resonance at 1.7 GHz under the name of anti-resonance as shown in Fig. 4(a). The details of their geometrical information including the positions are given in Fig. 4(b) and their function is described in Fig. 4(c) that suppresses the dominant cavity mode at 1.7 GHz. The impedance level has dropped by more than 5 times and the resonance at 1.7 GHz has been almost removed as

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given in Fig. 4(b). Owing to this, the signal from the top layer can pass all the layers and reach the bottom layer as observed in Fig. 4(e). These results imply that the level of the radiated emission must be put down much. Finally, in terms of the SI, the signal at the 1.7 GHz band will have much less distortion compared to the case without the CSRRs as is proven in Fig. 4(f). Hence, the suggested method is thought to be applicable to secure the SI/PI and EMI reduction to relevant PCB structures.

IV. CONCLUSION

We have proposed an effective method to improve the SI and PI of a power-bus structure(PBS) in a layered medium PCB by suppressing the EMI-causing resonance mode. It is realized by a complementary split-ring-resonator as a compact and embeddable geometry formed in the PBS to remove the resonance that hinders the signal transfer from one layer to another. The method was verified by a number of experimental tests.

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