# Improved EMC Characteristics of PCB due to the Appropriate Via-hole Position

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***Abstract*— That the position of the via-hole changes the resonant characteristics of the microstrip line with a single via-hole is analyzed. Thus, the resonant characteristics of the whole PCB mat be disappeared by the appropriate choice of the position of the via-hole, and EMC performance may be improved.**

***Keyword*— Via-hole discontinuity, Power/Ground plane resonance, PCB open edge radiation, Far-field radiation**

## I. INTRODUCTION

The recent trend of the digital convergence and the compact size of mobile equipments needs multilayer printed circuit board (PCB) structure and increases the complexity of internal routing of PCB. It inevitably increases the number of via-holes where the signal is transited from one layer to another in the PCB stackup. But the via-hole brings the structural discontinuities and so increases the electromagnetic compatibility (EMC) and signal integrity (SI) problems especially in the transmission of the high speed signal. Thus, a fast and accurate technique to consider the effect of via-hole discontinuity in the typical design process is needed.

Typically, the via-hole model in the PCB may be obtained by the full-wave analysis and the de-embedding techniques[1-3]. The full-wave analysis gives an accurate result, but much computational time. The via-hole modeling using a de-embedding technique gives a similar accuracy to a full-wave analysis and less computational time. When the electrical characteristics of a whole PCB having a number of via-holes is analyzed, the via-hole model obtained for a specific via-hole structure may be applied for all via-holes which have the same structure in the PCB. Thus the computational time for calculating the electrical performance of the whole PCB may be drastically reduced. However, in our recent research which analyzed the signal transmission characteristic due to the variation of the position of a via-hole in the PCB, the disappearance of the resonances took place.

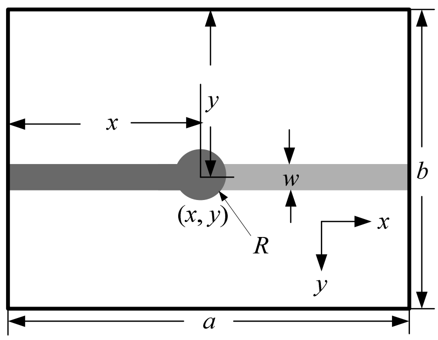
Therefore, in this paper the reason why the resonant frequencies are disappeared and the far-field characteristics due to that are presented.

## II. THE RESONANCE

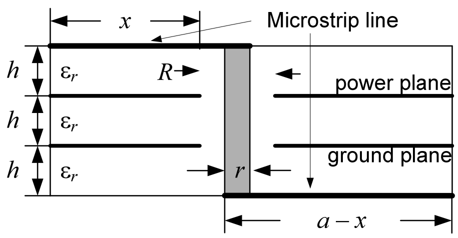
The resonance variation of the microstrip line due to the variation of the position of a single via-hole may be analyzed.

### A. 4-layer PCB

Figure 1 may be considered in order to analyze the resonance of the microstrip line with a single via-hole. The via-hole is located at ($x$, $y$) and the dimension of a 4-layer PCB is 100×100 mm$^2$. The characteristic impedance of the signal trace is 50 Ω and the diameter of the via-hole is 0.3 mm. The dielectric material separating each layer is FR-4 ($\varepsilon_r$ = 4.4) and its thickness is 0.6 mm. Other parameters are tabulated in Table I.




(a) Top View




(b) Side View

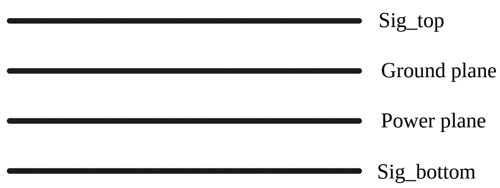
Fig. 1 Printed Circuit board with a via-hole

TABLE I
BOARD SPEC

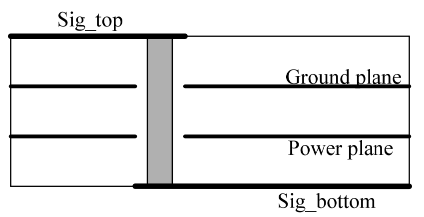
| Spec | Value | Unit |
|---|---|---|
| *a* | 100 | mm |
| *b* | 100 | |
| *h* | 0.6 | |
| *R* | 1 | |
| *r* | 0.6 | |
| *w* | 1 | |
| $\varepsilon_r$ | 4.4 | |

### *B. Power/Ground Plane Resonance*

In figure 2(a) which shows a miscrostrip line without a via-hole only the resonances due to the length of the line occurs. But in figure 2(b) which has a single via-hole there are some resonant points. The resonance comes from the structure in which a via-hole goes through both ground and power planes.




(a) 4-layer microstip line structure




(b) 4-layer microstrip structure with a via-hole

Fig. 2 Power/ground plane resonance mechanism

The region between the power plane and the ground plane is regarded as a parallel plate waveguide [4]. The resonance frequency can be calculated by equation (1)

$$f_{mn} = \frac{150}{\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \quad \text{[GHz]} \tag{1}$$

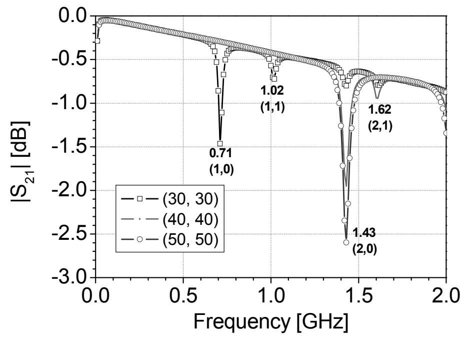
where *m* and *n* are the mode numbers in *x*-direction and *y*-direction, respectively and $\varepsilon_r$ is the relative permittivity of the dielectric material. The calculated resonant frequencies are listed in Table II.

TABLE II
P/G PLANE RESONANCE UNDER 2 GHZ

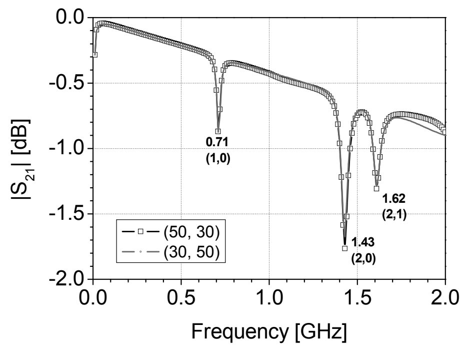
| mode (*mn*) | Frequency [GHz] |
|---|---|
| 10 | 0.71 |
| 11 | 1.02 |
| 20 | 1.43 |
| 21 | 1.62 |

### *C. Variations of resonant frequencies due to changes of via position*

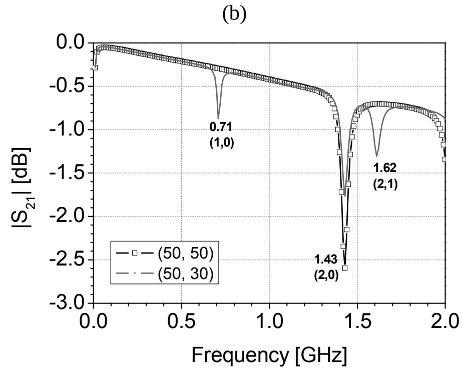
When the position of the via-hole is changed the resonant characteristic of the microstrip line with a single via-hole is varied as shown in figure 3.



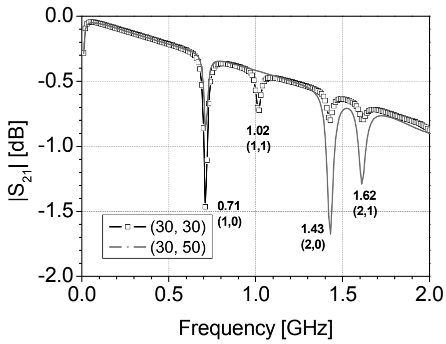

(a)




(b)




(c)




(d)

Fig. 3 Variation of resonance frequencies due to changes of via position

The comparison among the dip positions of $S_{21}$ magnitude for different via positions are shown in Figure 3. Figure 3(a) via-hole at (50, 50) is located at the center of the PCB and may perturb resonant modes at $f_{10}$, $f_{01}$, $f_{11}$, and $f_{21}$, and so non-perturbed resonant modes are shown at $f_{20}$ and $f_{02}$. Via-hole at (40, 40) is at the off centered position and may perturb resonant modes at $f_{10}$, $f_{01}$, and so resonant modes at $f_{21}$, $f_{02}$, $f_{12}$ are shown. Via-hole at (30, 30) is located relatively far from the center and so all resonant modes are shown. In Figure 3(b) via-hole at (50, 30) is located at the center in *x*-direction and the off-center in *y*-direction, and so resonant modes at $f_{01}$, $f_{20}$, $f_{02}$, and $f_{21}$ are shown. Via-hole at (30, 50) is symmetrically located relative to via-hole at (50, 30) along the diagonal direction, and so resonant modes at $f_{10}$, $f_{20}$, $f_{02}$, and $f_{12}$ are shown. In Figure 3(c) at (50, 30) via-hole is symmetric in the $x = 50$ plane and asymmetric $y = 50$ plane, and so four resonant modes are shown. When via-hole is moved along the *y*-direction to the position at (50, 50), the *x*-symmetry remains and the *y*-symmetry occurs newly. So, resonant modes at $f_{01}$ and $f_{21}$ disappear. In Figure 3(d) at (30, 30) via-hole is asymmetric in the $x = 50$ plane and the $y = 50$ plane, and so all resonant modes are shown. When via-hole is moved along the *y*-direction to via-hole at (30, 50), the *x*-asymmetry remains and only the *y*-symmetry occurs newly. So, resonant modes at $f_{01}$, $f_{11}$, and $f_{21}$ disappear.

## III. The Field Distribution Analysis

Each resonant mode of P/G planes in multilayer PCBs may have the different distribution of electromagnetic fields between the power plane and the ground plane. And, via-hole at the different position may give the different perturbation to the resonant field distribution.

### A. *Analysis of P/G plane field distribution with via-hole position*

The field distribution between the power plane and the ground plane is analyzed at the center between the power plane and the ground plane, shown in figure 4, in order to find the reason why the variation of the resonant frequency may be brought from the different position of the via-hole. The calculated field distributions are shown in figure 5.

Figure 5 shows that if the field distribution is interrupted by the position of the via-hole then some resonant frequencies are disappeared.

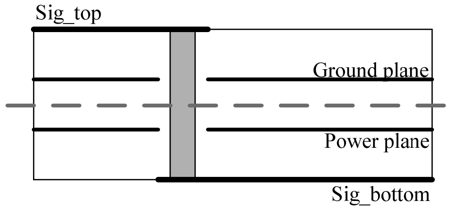
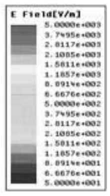
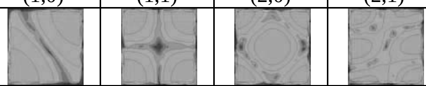
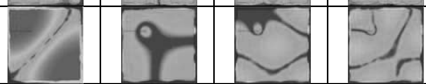
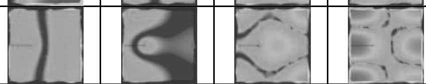
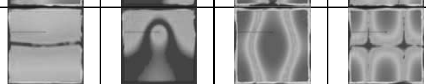
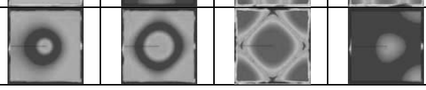



Fig. 4 The field observation plane




(a) The field scale

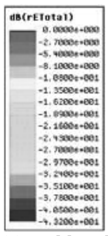
| Via position (*x*, *y*) | Field distribution 0.71 GHz (1,0) | 1.02 GHz (1,1) | 1.43 GHz (2,0) | 1.62 GHz (2,1) |
|---|---|---|---|---|
| Non-via |  | | | |
| (30, 30) |  | | | |
| (30, 50) |  | | | |
| (40, 40) |  | | | |
| (50, 30) |  | | | |
| (50, 50) |  | | | |

(b) The field distribution with via position

Fig. 5 The field distribution in P/G plane

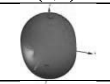
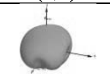
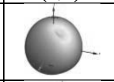
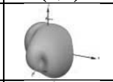
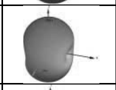
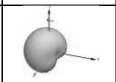
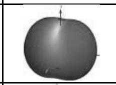
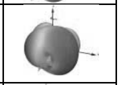
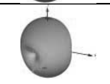
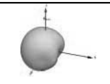
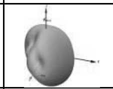
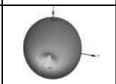
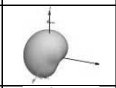
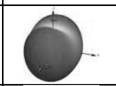
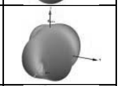
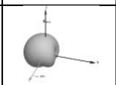
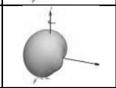
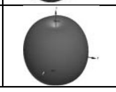
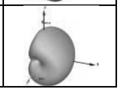
### B. *Far-field Radiation Pattern*

The figure 6 shows that the far-field radiation patterns are calculated at the resonant frequencies. The intensity of the radiated far-field is increased at the resonant frequency.




(a) Field scale

(b) Coordinate system

| Via position (*x*, *y*) | Intensity of radiated far-field | | | |
|---|---|---|---|---|
| | 0.71 GHz (1,0) | 1.02 GHz (1,1) | 1.43 GHz (2,0) | 1.62 GHz (2,1) |
| (30, 30) |  |  |  |  |
| (30, 50) |  |  |  |  |
| (40, 40) |  |  |  |  |
| (50, 30) |  |  |  |  |
| (50, 50) |  |  |  |  |

(c) Field pattern

Fig 6. Far-field radiation pattern

## IV. CONCLUSION

That the position of the via-hole changes the resonant characteristics of the microstrip line with a single via-hole is analyzed. Thus, the resonant characteristics of the whole PCB mat be disappeared by the appropriate choice of the position of the via-hole, and EMC performance may be improved.

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