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A CONSIDERATION ON FAR-FIELD EMISSION DUE TO THE GROUND BOUNCE OF PRACTICAL CMOS-IC MOUNTED PCB

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Abstract: A correlation between the frequencies of the radiated peak emissions due to the ground bounce of printed circuit boards (PCBs) and its input impedance at the excitation point was investigated. According to the finite-difference time-domain (FDTD) calculation, each radiation peak frequency corresponded to that of the appropriate input impedance, while it was largely affected by an internal resistance of the excitation circuit. An ideal voltage source made the radiation peaks located at the frequencies corresponding to the minimum input impedance, whereas an ideal current source made them at the frequencies of maximum input impedance. The eventual peak frequency should appear between a pair of these two frequencies depending upon the internal resistance of the excitation circuit. In order to examine the above finding for an actual semiconductor's switching operation, two-layered simple PCBs with an actual CMOS-IC were fabricated and the radiated emissions were measured in an anechoic chamber. As a result, it was found that an actual CMOS-IC behaved as between an ideal voltage and an ideal current excitation sources at cavity-mode resonance frequencies, while it was characterized by excitation of an ideal current source at imperfect cavity-mode resonance frequencies.

Key words: PCB, Ground bounce, CMOS-IC, EMI, cavity-mode resonance, input impedance.

1. Introduction

PCBs are one of the electromagnetic radiation sources from electronic devices. It is well known that a couple of the power-plane and the ground-plane behave as a resonator or a parallel plate antenna, so called ground bounce [1]. Although there are a lot of investigations reported on the frequency prediction of the radiated peak emissions due to such a ground bounce mechanism, a few critical points are still veiled. Some papers assert that peak frequencies are predictable from the minimum value of the scattering parameter S_{11} [2], while the others contend that from the maximum value of the input impedance between the both planes at the excitation point [3]. Fujiwara et.al. pointed out that the peak frequencies were decided by the ratio of an internal resistance in the excitation source circuit and PCB's input impedance, and verified it with the FDTD calculation and the measurement using two-layered simple plane PCBs driven by a signal generator as an excitation source [4]. It was shown that if the excitation source had an enough lower internal resistance than the input impedance of PCB, peak frequencies appeared on the minimum points of the input impedance. Then these peak frequencies moved toward to the maximum points of the input impedance in accordance with the increase of the internal resistance.

In this paper, a correlation between the peak frequencies of the radiated emission and its internal resistance of the excitation source circuit is verified from an actual pierce current due to IC switching effect by a practical CMOS-IC mounted on the fabricated PCBs. Also an imperfect resonance mode excitation (which we define in this paper as the resonance whose reactance component is never cross the zero level) will be mentioned. This is not able to predict easily from the input impedance or S_{11} parameter of PCB, while it can be recognized as the resonance mode by the measurement of radiated emissions.

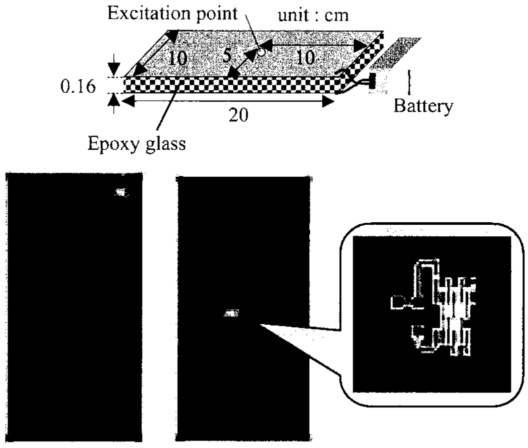
2. Measurement

2.1 Sample PCBs

Figure 1 shows the two-layered sample PCBs fabricated for this study, which have dimensions of 20 cm x 10 cm with a thickness of 1.6 mm of glass epoxy substrate. Two kinds of the sample PCBs were fabricated: one was center excitation PCB shown in Fig. 1(a) and the other was corner excitation PCB shown in Fig. 1(b). These had only one through-hole each at the excitation point of center (10 cm, 5 cm) or corner (1 cm, 1 cm). Flat packaged CMOS inverter IC (LS74HC04) was mounted with a 2-MHz clock oscillator. A six-volts DC power was supplied directly to the corner edge of both planes with batteries via a quite short lead. Figure 2 shows the digital circuit of the sample PCBs. The output pins were terminated by a 1608 sized chip capacitors of 470 pF. One of the output pins was used for the drive of input circuit. In order to increase the internal resistance of the excitation source circuit, 1608 sized pad for a chip inductance of 1.5 μH was provided between the power pin and the through-hole going pass to the power plane on the reverse. All devices are mounted on the ground plane, while the power plane had nothing but a through-hole.

2.2 Measurement method

The radiated emissions from the sample PCBs were measured in an anechoic chamber with a biconical antenna in the frequency range from 30 MHz to 300 MHz and a log-periodic antenna from 300 MHz to 1 GHz as shown in Figure 4. The sample PCB was put on the 1 m height table, and antenna was also set constantly at a height of 1 m from the ground plane. The distance between the PCB and the antenna was set just 3 m. Field measurement was made with a spectrum analyzer as rms peak voltages in the frequency range from 30 MHz to 1GHz. It was confirmed that the field strength of vertical polarization was higher than the horizontal polarization for each sample, which indicated the radiation due to the ground bounce mechanism.



(a) Corner (b) Center

Figure 1 Sample PCBs fabricated for this study.

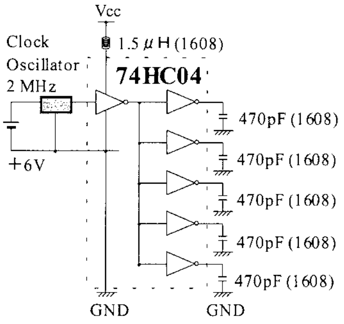


Figure 2 Digital circuit mounted on the sample PCBs.

3. Calculation

The FDTD method was employed to calculate the radiated emissions from the PCBs. Figure 5 shows the PCB model for calculation. The cell size was 2 mm x 2 mm x 0.4 mm, and 12 layers perfect matched layer (PML) was applied. The power and ground planes were assumed as perfect conductors with a thickness of zero. Epoxy glass substrate had 4.3 permittivity and 3.7 x 10^{-3} [s/m] conductivity with a thickness of 1.6 mm. Gaussian pulse was used as an excitation voltage source for the PCBs of which parameters were given to have a cut-off frequency over 1 GHz. Since it was quite difficult to keep symmetrical condition on the practically fabricated center excitation sample PCB due to the avoidable factors such as battery connection and mounting devices, the excitation point for the center excitation model was offset one cell from the exact center of the PCB (10 cm, 5 cm), while the corner excitation model was set as the same as the fabricated PCB. The internal resistance was set as four types of 1, 5, 10 and 50 ohm, respectively. Frequency characteristics of the input impedance at the excitation point were also extracted by the FDTD calculation.

4. Results

4.1 Corner excitation PCB

Figures 6 and 7 show calculated frequency characteristics of the input impedance and radiated emission for the corner excitation PCB, respectively.

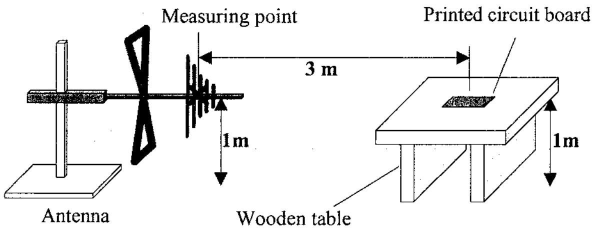


Figure 3 Setup for measuring the radiated emissions from a PCB.

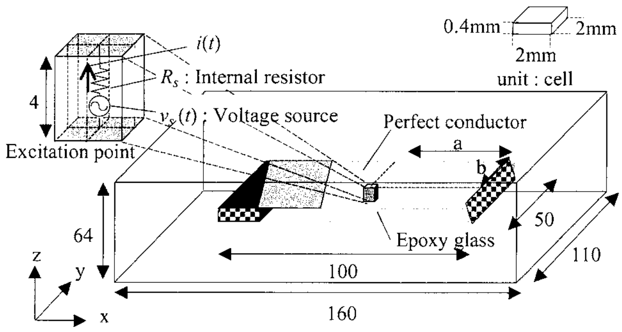


Figure 4 FDTD calculation model.

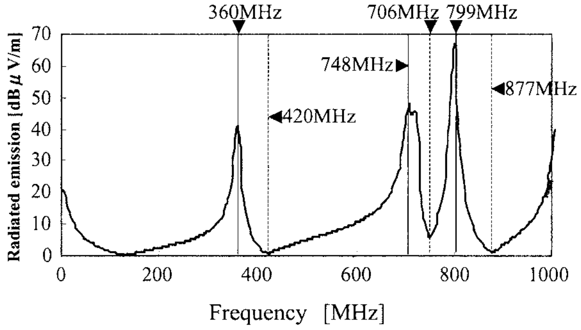


Figure 5 Calculated frequency characteristics of the input impedance of the corner excitation PCB.

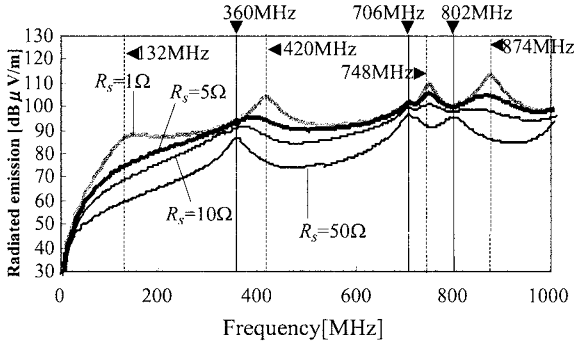


Figure 6 Calculated frequency spectra of the radiated emissions from the corner excitation PCB. The excitation voltage is 1.7 Vrms at all frequencies.

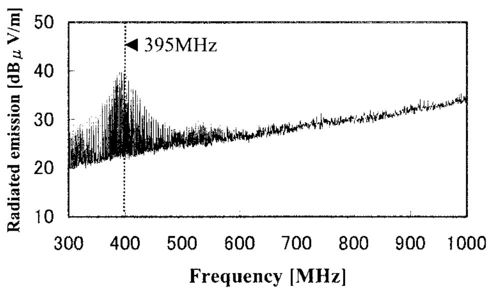


Figure 7 Measured frequency spectra of radiated emission from corner excitation PCB.

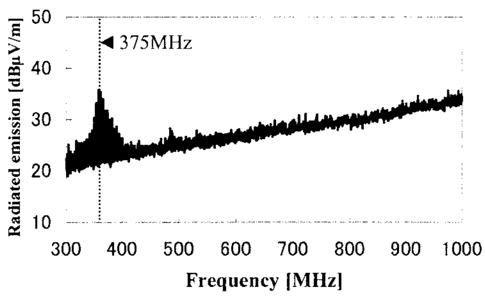


Figure 8 Measured frequency spectra of the radiated emissions from the corner excitation PCB with an additional inductance in the excitation circuit.

As shown in Figs. 5 and 6, radiation peaks correspond to the maximum or minimum of input impedance in accordance with the internal resistance of the excitation circuit. Measured radiated emission results are shown in Figs. 7 and 8. From Fig. 7, it can be assumed that the actual CMOS-IC has about from 5 to 10 ohm internal resistance at around 395 MHz for the first peak. The first peak frequency goes down to about 375 MHz with an additional inductance of 1.5 μH in the excitation circuit from Fig. 8. With regard to the other peaks that should appear at around 700 MHz and higher region, they did not come out due to the limited rise time of the CMOS-IC and the operation frequency of the clock oscillator. Although the IC of 74HC was changed to 74AS or the speed of an oscillator changed from 2 to 40 MHz, remarkable improvement was not achieved.

4.2 Center excitation PCB

Figures 9 to 12 show the calculated and measured results for the center excitation PCB in the same manner. From Fig. 9 and 10, it was found that the calculated peak of (2,0) mode around 700 MHz behave as the same as the case of the corner excitation PCB. From Figs. 11 and 12, the radiation peaks at 360 MHz due to imperfect (1,0) mode resonance are observed, while the peak which should appear over 700 MHz cannot be seen from the measurement results due to the same reason as the corner excitation PCB. If the excitation could perfectly be symmetry at the center of the PCB, (1,0) mode resonance should not appear. Presumably, the reason of its appearance is the effect of the attached battery and of the devices un-symmetrically mounted on the PCB. The difference from other resonance modes is that the frequency shift did not happen even when an additional inductance was inserted in the excitation circuit. Not only the measurement results, but also the calculation results indicate that the small peaks are stably aligned at 360 MHz as shown in Fig. 10. It is interesting to note that the resonance at 360 MHz cannot be distinguished in Fig. 9 from the input impedance. It is also invisible on the practical measurement result of the input impedance. Extra offset of the excitation point would make this invisible resonance to be visible [5].

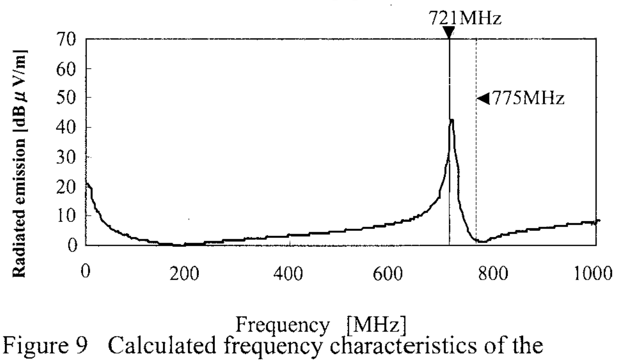


Figure 9 Calculated frequency characteristics of the input impedance of the center excitation PCB.

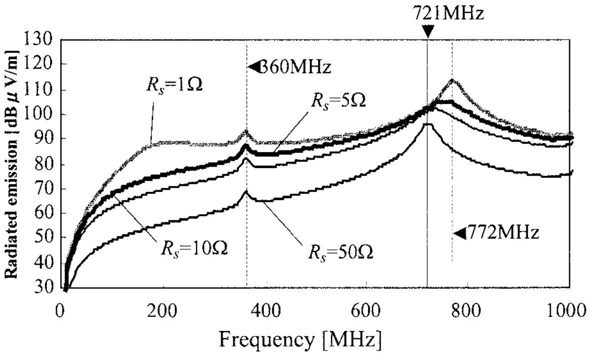


Figure 10 Calculated frequency spectra of the radiated emissions from the center excitation PCB. The excitation voltage is 1.7 Vrms at all frequencies.

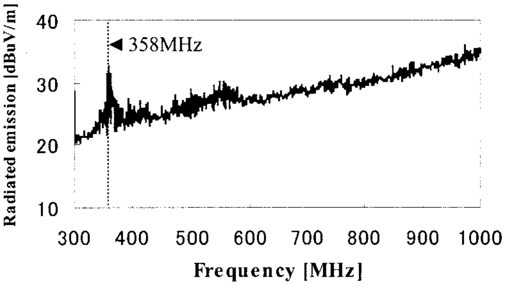


Figure 11 Measured frequency spectra of the radiated emission from the center excited PCB.

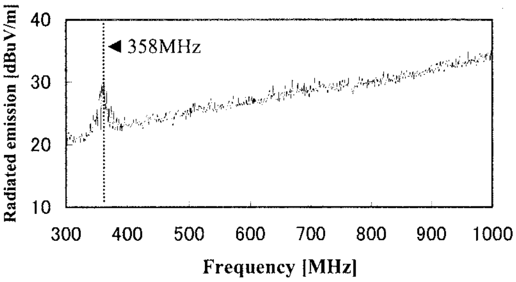


Figure 12 Measured frequency spectra of the radiated emission from the center excited PCB with an additional inductance in the excitation circuit.

5. Discussion

A ground bounce mechanism can be explained by a cavity-mode resonance of PCB's power and ground planes. The radiation based on this mechanism is explained as a parallel plate antenna. The maximum radiation power from a parallel plate antenna is generated under the condition of resonance where there is a zero reactance and an internal resistance matched with the load. Each resonance mode has two points of zero-crossing frequencies in the reactance component. The peak frequency of radiated emissions should appear between the two specified frequencies in accordance with the magnitude of the internal resistance. Generally, the gradient is very steep in the critical area. That is the reason why the internal resistance affects the location of the peak frequency drastically. On the other hand, (1,0) mode of the center excitation PCB is imperfect from the resonance point of view. The reactance component is never across zero level and the absolute input impedance keeps much lower than the internal resistance of the CMOS-IC. Due to this reason, the increase of the internal resistance does not affect the location of this specific peak frequency which is identical to that excited by an ideal current source.

6. Conclusion

A correlation between the frequencies of the radiated peak emissions and its internal resistance of the excitation source has been verified from the ground bounce due to IC switching effect of a practical CMOS-IC mounted on the fabricated PCBs. It has been confirmed that peak frequency is decided by the ratio of an internal resistance in the excitation source and PCB's input impedance. It is found that an actual CMOS-IC can be assumed about from 5 to 10 ohm internal resistance at around 395 MHz. In the case of an imperfect resonance mode excitation, it has also been found that the CMOS-IC behaves as an ideal current source. The behavior of the imperfect resonance mode would be the future work to be investigated.

References

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