공통 모드와 차동 모드 전류로 부터 발생하는 방사성 방출에 대한 연구

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Study of Radiated Emissions from Common-Mode and Differential-Mode Currents

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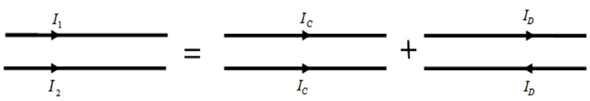
Abstract - This paper builds a printed circuit board to calculate the radiated emissions due to the common-mode and differential-mode currents. The calculated results agree with the measured values. Based on the calculated values, it is shown clearly that the common-mode radiations are the dominator of the radiated emissions from the device. The radiated emissions due to the common-mode currents can easily dominate the radiated emissions from the printed circuit board.

1. INTRODUCTION

Consider a pair of parallel wires carrying currents I_1 and I_2 as shown in figure 1. These currents can be divided into two types of currents, differential-mode currents I_D and common-mode currents I_C, as

$$I_1 = I_C + I_D \tag{1}$$
$$I_2 = I_C - I_D \tag{2}$$

The radiated emissions due to common-mode currents can be the dominant radiated emissions in the total emissions. The radiated emissions of the differential-mode currents in I_1 and I_2 tend to substrate, because differential-mode currents flow in equal magnitude but in opposite directions. The differential-mode currents can be modeled with transmission line modes. On the other hand, the radiated emissions of the common-mode currents tend to add, because the common-mode currents are directed in the same direction and have equal magnitude. And the common-mode currents can be modeled as dipole antenna models. Thus smaller amounts of common-mode currents can produce the same level of radiated emissions as the differential mode currents.



<Figure 1> Common-mode and differential-mode currents on wires

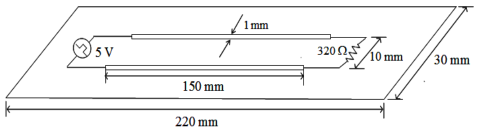
The purpose of our study is to investigate the radiated emissions from common-mode and differential-mode currents. As a result, A printed circuit board and the calculation of the radiated emissions due to common-mode and differential-mode circuits need to be presented.

2. NUMERICAL ANALYSIS

2.1 PCB model

In order to investigate the radiated emissions of the common-mode and differential-mode currents, a test printed circuit board was constructed. And the radiated emissions were measured in a semianechoic chamber that was used for testing EMC.

The test board specification is shown in Figure 2. The size of the PCB is 220 mm length, 3 mm width and 1.6 mm thickness of the dielectric substrate that has a relative permittivity of approximately 4.7. A parallel of copper wires 1 mm in width and 150 mm in length are located on the dielectric substrate. The distance between the parallel wires is 10 mm. A load impedance of 330 Ω is chosen to make the impedance matching. The trace is driven by a 10 MHz clock oscillator that is attached to the another end of the pair of wires and powered by batteries. The output of the oscillator is a 10 MHz trapezoidal pulse with a duty ratio is 50 %, rise and fall time is 4 ns. The practical circuit model has been made as shown in figure 3.



<Figure 2> Test board specification

<Figure 3> Practical test board model

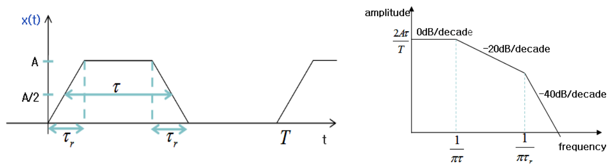
In the semianechoic chamber, the device was placed on a 1 m tall table which was rotated to detect the maximum emissions. The receiving biconical antenna was placed 3 m away and was horizontally to the table. So the radiated emissions of the far field at 3 m were measured in the frequency range of 30 Mhz to 200Mhz.

2.2. Differential-mode Circuit

The signal voltage source drives a differential-mode currents which flow on the two wires. The prediction process of differential-mode radiation consists of performing a Fourier analysis of the trapezoidal source signal, then treating each harmonic as a sinewave for calculating radiation.

First step, calculating trapezoidal waveform spectrum uses complex exponential fourier series. we obtain the results as following:

$$20\log_{10}\left(\begin{matrix} amplitude\,of \\ harmonics, \end{matrix}\right) = 20\log_{10}\left(\frac{2A\tau}{T}\right) + 20\log_{10}\left|\frac{\sin\pi\tau f}{\pi\tau f}\right| + 20\log_{10}\left|\frac{\sin\pi\tau_r f}{\pi\tau_r f}\right| \tag{3}$$



<Figure 4> Trapezoidal signal and normalized spectrum

Second step, calculating the radiations from the differential -mode circuit carrying such spectrum. The applied equation is:

$$E_{DM}(f) = \frac{Z_0 \pi A}{\lambda^2 D} \times \frac{V_{DM}(f)}{Z_C} \quad [V/m] \tag{4}$$

where, Z_0 : the free space impedance=120π or 377Ω,
λ : the wave length,
A : the differential-mode circuit loop area,
D : the measured distance 3 m
$V_{DM}(f)$: the harmonics amplitude
Z_C : the circuit impedance

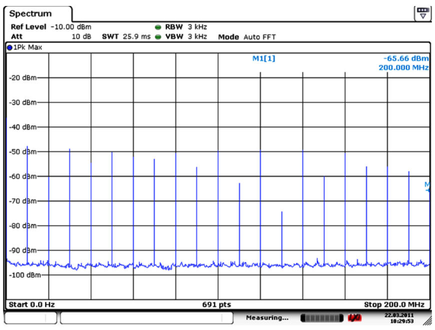
2.3 Common-mode Circuit

Two fundamental EMI sources mechanisms lead to common-mode currents on the board, including: the voltage drops due to the line inductance, the common-mode currents due to the capacitance coupling between the two wires. These two mechanisms drive common-mode radiations from the test board. In frequency domain, the equation for common-mode current radiations is given as:

$$E_{CM}(f) = \frac{Z_0 l}{2\lambda D} I_{CM}(f) \quad [V/m] \tag{5}$$

Where, l is the wire length, and the common-mode current distribution $I_{CM}(f)$ is measured using a current probe which is a function of the frequency (f).

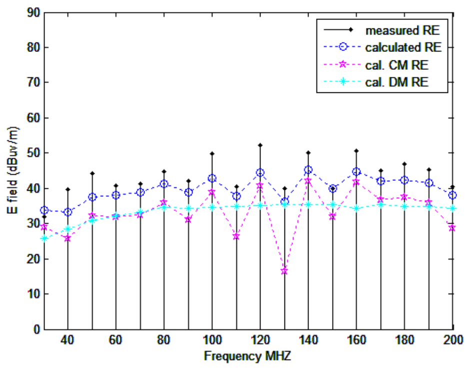
In order to measure the common-mode current, we inserted the board into the current probe that was connected to the spectrum analyzer. The current probe was moved slowly from one side to another side to record the maximum common-mode currents on this device with the spectrum analyzer was set on the MAX HOLD state. Figure 5 shows the measured common-mode current distribution.



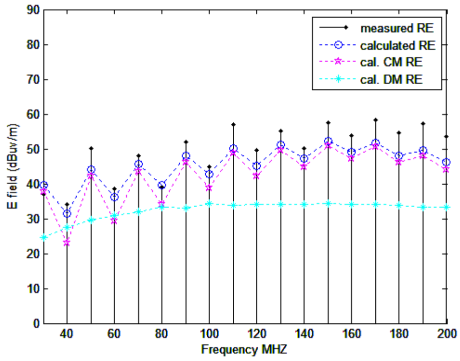
<Figure 5> Common-mode current distribution

2.4 Results and Discussions

According to the above, the calculated radiated emissions were obtained from the sum of the differential-mode radiations and the common-mode radiations. Figure 6 compared the calculated and measured radiations. Note that the sum of the differential-mode and common-mode calculated radiated emissions agreed with the measured values in the frequency range of 30 ㎒ to 200 ㎒. In Figure 6, it was clearly shown that the common-mode radiation was the dominant contributor of the radiated emissions.



<Figure 6> Radiated emissions for matched circuit



<Figure 7> Radiated emissions for opened circuit

Futhermore, we measured the same configuration device with the circuit was open. The calculated and measured radiated emissions were shown in Figure 7. In this case, the load impedance was the free space impedance for the opened circuit. Thus the differential-mode radiation was smaller than the matched circuit. In Figure 7, the results further confirmed that the common-mode radiation can significantly dominant the radiated emissions from the printed circuit board.

3. CONCLUSIONS

In this paper, a printed circuit board had been developed to investigate the radiated emissions due to common-mode and differential-mode currents. Except measuring the radiated emissions from the test board in a semianechoic, we also calculated the radiated emissions based on the differential-mode circuit and common-mode circuit. The calculation values agreed with the measurement values. And the results clearly showed that common-mode radiations can significantly dominate the radiated emissions. Therefore, the radiated emissions from the common-mode currents was the dominant contributor to the radiated emissions from the printed circuit board.

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