Analysis of EM Emission Characteristics by Arbitrarily Oriented Microstrip Lines Based on TEM Cell Electric and Magnetic Coupling Fields

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Abstract— In this paper, we analyzed electromagnetic (EM) emission characteristics with arbitrarily oriented microstrip lines on a printed circuit board (PCB). The designed DUTs are based on line patterns between an integrated circuit (IC) and electronic parts on a PCB. These represent EM models of interconnect line, signal propagation, and IC itself. The method of lines (MoL) is used to calculate the coupling capacitance matrix between the microstrip lines and the transverse electromagnetic (TEM) cell. This matrix is also used to calculate self-inductance and coupling inductance. In order to apply this method to real system modules, a model library for coupling factors was built with variations of length and direction of microstrip lines. The comparison results between measurement and modeling shows good agreement below 200 MHz.

1. INTRODUCTION

The electromagnetic compatibility (EMC) problem of automotive ICs or high speed PCBs is caused by increase of RF interference between electronic systems at high operating frequency. In particular, the increasing complexity of PCB patterns aggravates the EM interference problem because the patterns act as antennas. Therefore the EM interference becomes a matter of concern in reliability of the system adopting automotive ICs or high speed PCBs. Various researches have been carried out about the conducted EM characteristics of PCB patterns or ICs.

It is known that coupling factors of microstrip lines mounted on a TEM Cell can be modeled by lumped circuit elements [1]. However further research on radiated EM characteristics is still needed although several measurement methods of electric and magnetic field coupling based on a TEM Cell were reported [2, 3]. In this paper, we designed some test PCB patterns for modeling and estimation of radiated EM interference. The radiated coupling factors between a TEM Cell and PCB patterns are calculated by using the MoL which is a very efficient method in comparison with other field solving methods. The accuracy of the model was evaluated through comparing simulated results of the MoL with measured results. Eventually, EM emission characteristics on the complex PCB patterns can be predicted by using the model library which is composed of the modeled parameters of PCB lines.

2. PCB PATTERN SET UP

The fabricated DUTs were designed with microstrip lines on PCB which were based on a real layout with an IC and interconnect lines as shown in Figure 1. In order to analyze the EM emission characteristics of a real PCB module designed patterns are categorized into three groups according to current direction on PCB, line direction, and IC modeling considering current flowing direction on an IC. In Group A, an IC is modeled in relation to capacitive and/or inductive effects according to current flowing direction on IC. Current is fed by a SMA connector mounted on the designed DUTs which are a two-direction type, a one-direction type, and a no-direction type as shown in Figure 1. The magnetic field effects of in-phase and out-of-phase signal direction on interconnects are evaluated with the DUTs in Group B which are designed with variations on current direction, interconnect line spacing, and line width. The DUTs in Group C are designed with variations on signal line directions and line lengths. The designed microstrip lines are fabricated on FR4 substrates with the thickness of 1.55 mm.

3. ANALYSIS PROCEDURE

The MoL which is considered as a special finite difference method is more effective in accuracy and simulation time than the regular finite difference method. The coupling capacitance between the microstrip line and the TEM Cell septum can be easily calculated by using quasi-static approach.

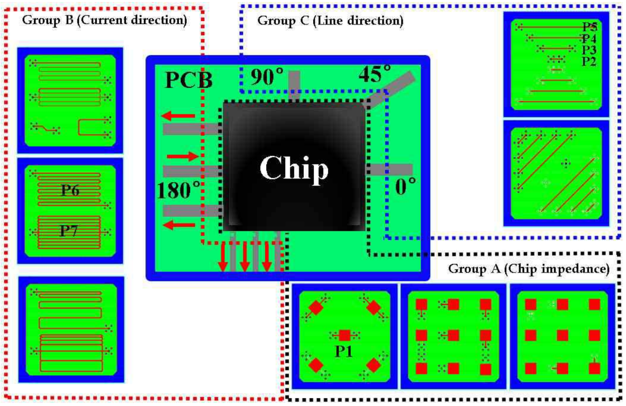


Figure 1: Examples of microstrip lines.

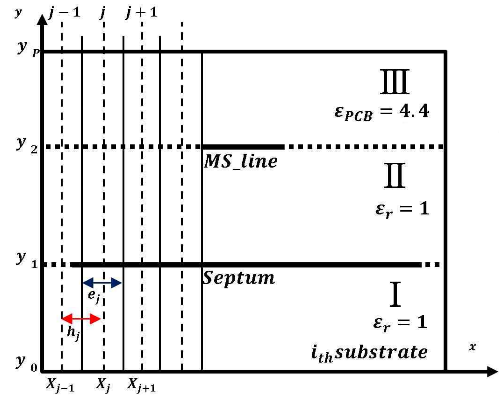
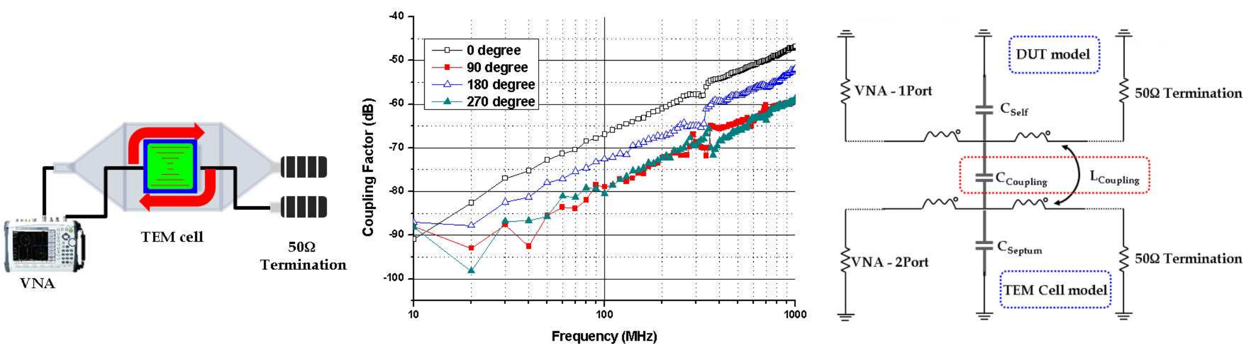


Figure 2: Cross section between TEM cell and microstrip line with finite ground planes [4].

Table 1: Coupling parameters for designed microstrip lines.

		P5 (70 mm)	P4 (50 mm)	P2 (30 mm)	According to direction		
Coupling Parameters	$C_{Coupling}$ [fF]	29.4	19.4	8.4	Fixed		
	$L_{Coupling}$ [pH]	135.8	81.7	30.2	$\cos(\alpha) L_{Coupling}$, where α=angle		
TEM Cell	Left Taper	TLIN1 TLIN2 TLIN3			Z=39.8 Ω	Z=61.3 Ω	Z=49.4 Ω
	Central	L_1 C_1 L_1			C_1 [fF]	56.1	
					L_1 [nH]	27.8	
	Right Taper	TLIN6 TLIN5 TLIN4			Z=49.4 Ω	Z=61.3 Ω	Z=39.8 Ω

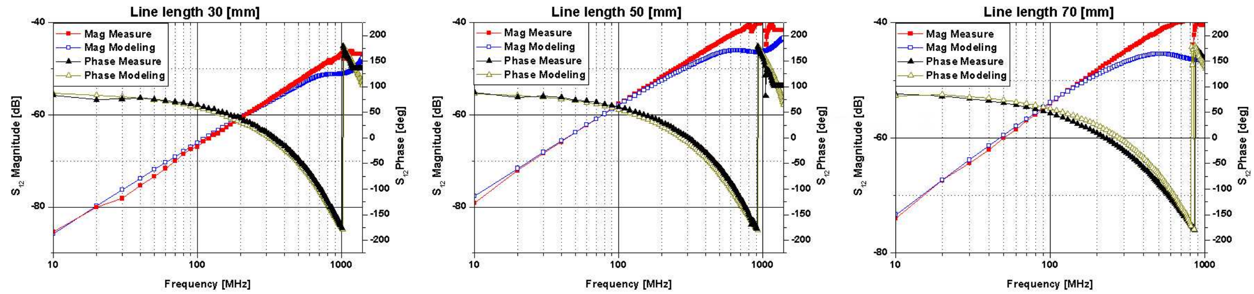


(a) (b) (c)

Figure 3: (a) Test environment, (b) coupling factors, and (c) model of coupling between the microstrip line and the TEM Cell septum.

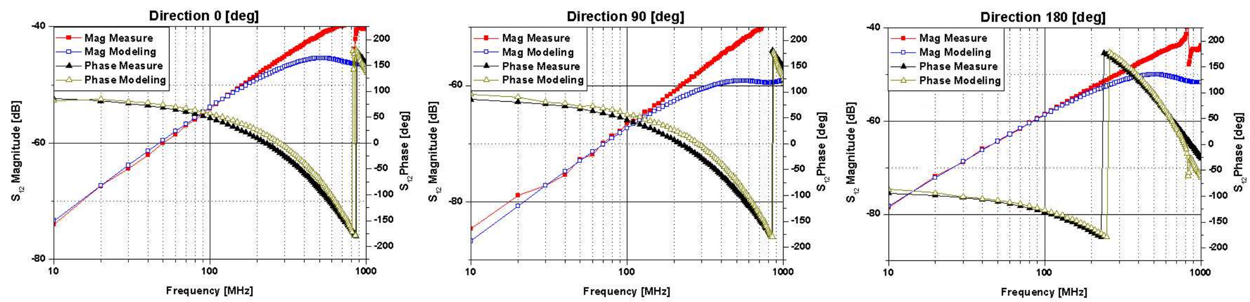
The crosssection between the microstrip line and the TEM Cell in Figure 2 is used for coupling capacitance calculation [4].

The MoL simulation for the microstrip line can be directly expressed as the reduced capacitance matrix, and therefore does not need any manipulation [4]. By obtaining the reduced capacitance matrix for the given microstrip lines we can calculate the inductance matrix [5]. The TEM Cell model described in Table 1 is built by using generic TLIN transmission line models supported in Agilent ADS. The TLIN represents an ideal transmission line and is fully characterized by only two parameters such as characteristic impedance and electrical length. The each taper of the TEM Cell is divided into three sections to model change in characteristic impedance along the electrical length of the taper. Table 1 shows the extracted coupling parameters for the three microstrip lines with different line length in the direction of the DUT. This table is an example of a model library described in Section 4.



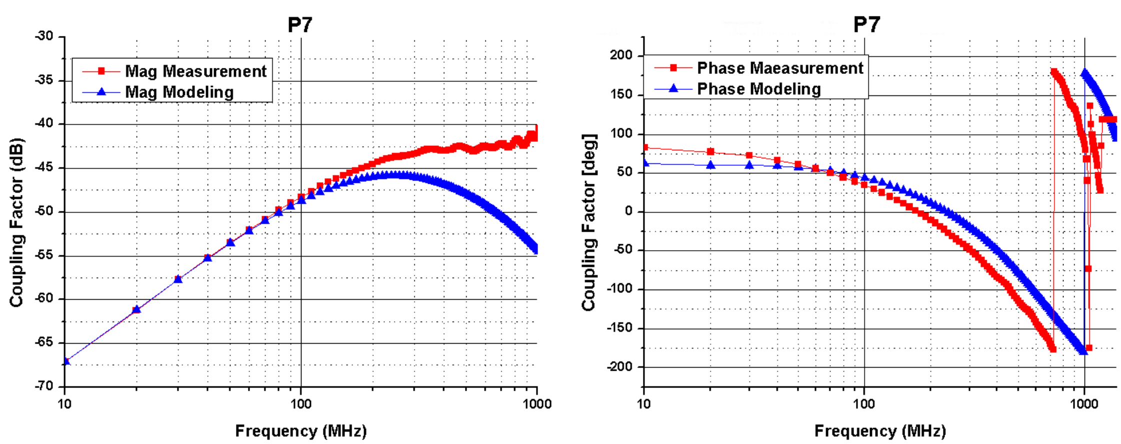
(a) (b) (c)

Figure 4: Measurements and modeling of the coupling for: (a) P3, (b) P4, and (c) P5.



(a) (b) (c)

Figure 5: Measurements and modeling of the coupling for: (a) 0 degree, (b) 90 degree, and (c) 180 degree of P5.



(a) (b)

Figure 6: Comparison between measurement and modeling using a library for: (a) magnitude and (b) phase of P7.

4. SIMULATION AND MEASUREMENT RESULTS

Figure 3 shows the test environment, the plot of measured coupling factors according to direction of the DUT and the model of coupling between the microstrip line and the TEM Cell septum. The designed pattern on a 2-layer PCB was tested with the angle of direction of 0, 90, 180, and 270 degrees [6]. The measured results show that the coupling factor of the 0-degree case differs from that of the 180-degree case. Regardless of the direction of the DUT, the capacitive coupling always exists. In contrast, the inductive coupling between the TEM Cell septum and the DUT is minimized when the DUT is positioned perpendicularly with respect to the TEM Cell septum.

Figure 4 shows the comparison results between the measured coupling factors and the modeling parameters according to the microstrip line length. As shown in Figure 4, the phase of coupling factor shows good agreement between the measured and simulated results. However the magnitude of coupling factor is somewhat different at higher frequency. Figure 5 shows the results according to the angle of direction of the DUT. The comparison results of Figure 5 are similar to those of Figure 4. Therefore this modeling method based on a lumped element model can be applied to system modules operated under 200 MHz.

In order to analyze coupling factors of group B designed according to current direction, the model library for coupling factors of microstrip lines is used. This library is created with variations of line direction and line length as shown in Table 1. As shown in Figure 6, the magnitude of the coupling factor shows good agreement between the measured and modeling results below 200 MHz. There is slight discrepancy in the phase of the coupling factor.

5. CONCLUSION

Using the MoL modeling technic, we analyzed coupling factors between the TEM Cell septum and the microstrip lines. In order to apply this method to real system modules, a model library for coupling factors was built with variations of length and direction of microstrip lines. The comparison results between measurement and modeling shows good agreement below 200 MHz. Therefore we can use this lumped element model to analyze EM emission characteristics of the system module with the operating frequency up to 200 MHz without other complicated EM tools.

ACKNOWLEDGMENT

This research was supported by a grant "High efficient heat rejection and supply technologies for zero emission vehicle (10035530)" from the Korea Evaluation Institute of Industrial Technology.

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