Analysis of Coupling Between a Ground Slot and a Microstrip Line

Teruo Tobana, Takayuki Sasamori and Yoji Isota
Dept. of Electronics and Information Systems, Akita Prefectural University
Yurihonjyo, Akita, 015–0055 Japan, Email: tobana@akita-pu.ac.jp

Abstract

By advance of miniaturization of electronic devices, a ground of a printed circuit board is tend to be small and complicated and the ground may have some defects, such as connectors or clearance halls of vias. In this paper, we analyze the coupling between a microstrip line and a slot in a ground on a PCB using the MTL method to examine an effect of the signal integrity for the slot in the ground. To calculate by using the MTL method, per-unit-length parameters, such as the self or mutual capacitances and inductances, of a microstrip line and a slot are calculated using the FDTD method. Finally, we show the validity of the method in this paper, comparing results using the MTL method with numerical results using the FDTD method. It is shown that the proposed method is validated by comparing results by the MTL method with results by the FDTD.

1. Introduction

Recently, with the progress of information processing technology an operating speed of electronic devices becomes very fast. Consequently the problem of undesired emission from such fast electronic devices arises. Since electronic devices are becoming small and lightweight, demands of miniaturizing PCBs in these devices increase. Miniaturization of the PCBs makes those ground to be small, and some defects of the ground, such as for connectors or clearance halls of vias, may appear. Particularly, when many clearance halls are arranged along a line intensively, some slots are formed in the ground. These slots may be coupled with other electromagnetic sources and behave like an antenna and become the cause of undesired emission.

In this paper, the authors focus on coupling between a microstrip line and a slot placed closely. For the analysis of complicated configuration like a PCB with a slot and a microstip line, some numerical analysis methods, such as the finite difference time domain method, have usually used but it consumes long calculation time and large computer memory. In order to estimate the coupling between a microstrip line and a slot easily and fast, the multi-transmission line method (MTL) is used. In this case, it is considered that the slot and the microstrip line are regarded as the coupled lines. Each self and mutual per-unit-length parameters are calculated by using the FDTD method. Finally we discuss validity of the method by comparing results using MTL method and results using FDTD method.

2. Per-unit-length parameters of microstrip line and a slot

There is the MTL method to analyze coupled transmission lines that consists of any number of parallel conductors [1]. In this method, the per-unit-length parameters, capacitances and inductances, are needed. Per-unit-length parameters of the microstrip line with a slot can be calculated by 2D field solver, such as the finite element method. But, per-unit-parameters of the slot and the mutual parameters

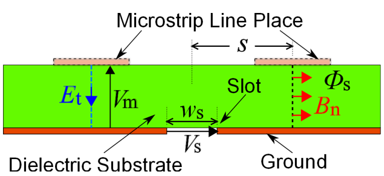


Figure 1: Cross section of analysis slot model.

between the line and the slot can not be calculated easily since a signal in a slot is not propagated in quasi-TEM modes. Then we use the FDTD method to calculate them.

The characteristic impedance Z_s and the effective relative permittivity ϵ_{es} of a slot line can be calculated using the approximately equation [2]. Using Z_s and ϵ_{es} and the speed of the light in vacuum c_0, per-unit-length self capacitance C_s and self inductance L_s of a slot line are given as, respectively

$$C_s = \frac{\sqrt{\epsilon_{es}}}{c_0 Z_s}, \qquad L_s = \frac{Z_s\sqrt{\epsilon_{es}}}{c_0}. \tag{1}$$

The current I_s flowing in a slot line is formally calculated by Z_s and the voltages V_s on the slot line.

In following part, the per-unit-length capacitance matrix $\boldsymbol{C}$ and inductance matrix $\boldsymbol{L}$ for a microstrip line and a slot line are calculated. It is considered that only a slot line with width w_s is placed in the ground plane as shown in Fig.1. The per-unit-length capacitance matrix $\boldsymbol{C}$ is calculated using the coefficients of potential $\boldsymbol{P}$ indicated as $\boldsymbol{P}=\boldsymbol{C}^{-1}$ [3]. Diagonal elements, p_{11} and p_{22}, of $\boldsymbol{P}$ are each reciprocal of self capacitance when the other charge is zero and are given by

$$p_{11} = \frac{1}{C_m}, \qquad p_{22} = \frac{1}{C_s} \tag{2}$$

where C_m is the per-unit-length self capacitance of the microstrip line. Since the off-diagonal elements, p_{12} and p_{21}, are given as

$$p_{12} = p_{21} = \left.\frac{V_m}{Q_s}\right|_{Q_m=0} = \left.\frac{V_m}{C_s V_s}\right|_{Q_m=0} \tag{3}$$

where Q_m is the charge of the microstrip line and Q_s is the charge of the slot line, V_m is the voltage at a distance s from the center of the slot line when the line conductor does not exist. Therefore the per-unit-length capacitance matrix $\boldsymbol{C}$ is given by

$$\boldsymbol{C} = \boldsymbol{P}^{-1} = \begin{bmatrix} \frac{1}{C_m} & \frac{V_m}{C_s V_s} \\ \frac{V_m}{C_s V_s} & \frac{1}{C_s} \end{bmatrix}^{-1}. \tag{4}$$

The mutual inductance L_{ms} between a microstrip line and slot line is given by

$$L_{ms} = \frac{\Phi_m}{I_s}$$

where Φ_m is magnetic flux penetrated between microstrip line and ground when the line conductor does not exist. Therefore the per-unit-length inductance matrix $\boldsymbol{L}$ is given by

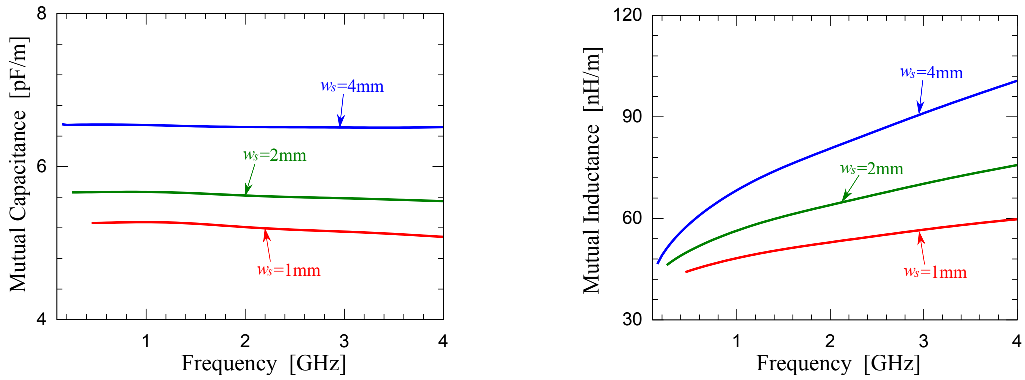
$$\boldsymbol{L} = \begin{bmatrix} L_m & L_{ms} \\ L_{ms} & L_s \end{bmatrix} \tag{5}$$

where L_m is the per-unit-length self inductance of the microstrip line. The calculated mutual capacitance and inductance for various slot line width w_s and space s=4.4mm are shown in Fig.2. As seen in Fig.2(a), the mutual capacitances are approximately frequency independent and increase as the slot width increases. For each slot width, lower frequency limit in which the capacitance can be calculated is present. As seen in Fig.2(b), the mutual inductance increase as the frequency increases and also increase as the slot width increases. It is considered that the parameters increase as the slot width increases because the space s between the microstrip line and the slot line becomes small.

3. Analysis

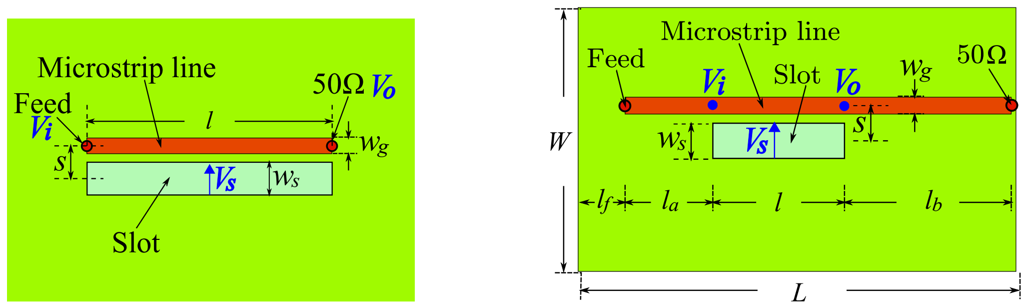
3.1 Analysis model

In order to validate the derived per-unit-length parameters, we calculate the coupling between a microstrip line and a slot using MTL method. And we also compare the results using the MTL with results using the FDTD method.



(a) Mutual capacitance (b) Mutual inductance

Figure 2: Per-unit-length parameters for various slot width.



(a) MTL method (b) FDTD method

Figure 3: Configuration of PCB model.

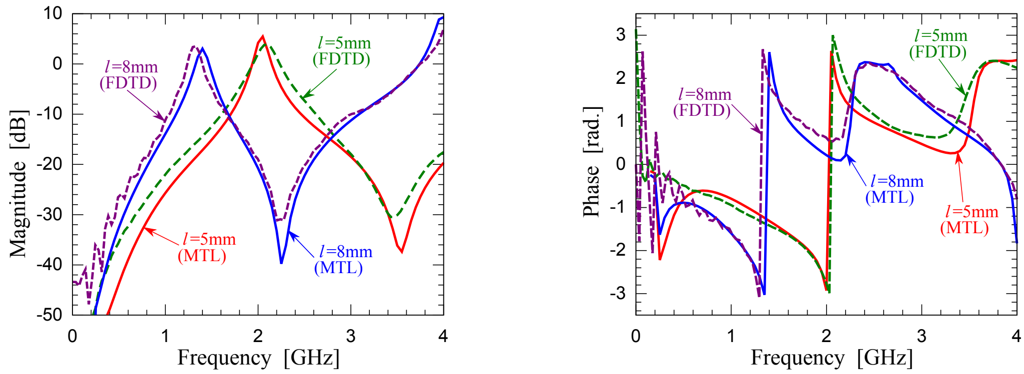
In the MTL method, the configuration of the microstrip line and the slot on the PCB is used as shown in Fig.3(a). The microstrip line which has the width w_g=2.8mm and length l, the characteristic impedance of about 50Ω if the slot does not exist. A signal circuit of output impedance 50Ω is connected to one end of the microstrip line and an 50Ω resister is connected to the other end. The slot with width w_s and length l in the ground is placed parallel in the position s from the microstrip line. The PCB consists of a dielectric substrate which has thickness T=1.6mm and infinite length, infinite width and is made by FR4 of relative permittivity 4.3. The ground plane is placed on the other side for the lines. The voltages, V_i in the feed point and V_o in the termination point, V_s in the center of the slot, are calculated. However, V_i is only incident voltage and reflection voltages is removed.

In the FDTD method, the configuration of the microstrip line and the slot on the PCB is used as shown in Fig.3(b). The microstrip line is longer than the slot length because its length is long enough to ignore the reflection wave and the higher mode wave created in the termination. The additional microstrip line length l_a and l_b are 80mm and $(140 - l)$mm, respectively. The PCB has length L=240mm and width W=120mm. The voltages, V_i at the point in the microstrip near the end of slot and V_o at the point near the other end of the slot, V_s in the center of the slot, are calculated. Other conditions are the same as the case of the MTL method.

3.2 Analysis results

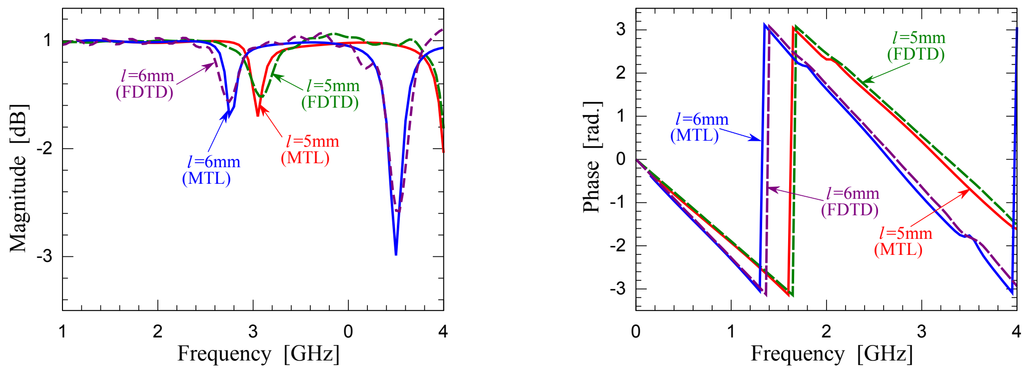
The calculated results which are the voltages V_s in the slot normalized by the incident voltages V_i with the slot width w_s=2mm and space s=4.4mm, the various slot length l using the MTL method and FDTD method are shown in Fig.4. The magnitude value and the phase value are respectively shown in 4(a) and 4(b). As seen in Fig.4(a), the large voltages are observed at about 1.4GHz for l=8mm and at about 2.1GHz for l=5mm. These large voltages are caused by the half-wavelength resonance of the slot line. For each slot length, the resonant frequency calculated by MTL method and the resonant frequency calculated by FDTD method are almost same except some frequency shift. And also the phase characteristics obtained by each method have good agreements as shown in Fig.4(b).

The calculated results which are the voltages V_o in the microstrip line normalized by the incident



(a) Magnitude (b) Phase

Figure 4: Normalized voltages in the slot V_s/V_i for W_s=2mm and various l.



(a) Magnitude (b) Phase

Figure 5: Normalized voltages in the microstrip line V_o/V_i for W_s=2mm and various l.

voltages V_i with the slot width w_s=2mm and space s=4.4mm, the various slot length l using the MTL method and FDTD method are shown in Fig.5. The magnitude value and the phase value are respectively shown in Fig.5(a) and Fig.5(b). As seen in Fig.5(a), the sharp dip is observed at about 2.1GHz for l=5mm. This dip is caused by coupling to high Q resonance of the slot. For each slot length, the frequencies of the dip calculated by MTL method and the frequencies of the dip calculated by FDTD method are almost same. And also the phase characteristics obtained by each method have good agreements as shown in Fig.5(b). Therefore these results validate the effectiveness of the proposed method which derives the per-unit-length parameters of a microstrip line and a slot line.

4. Conclusion

In this paper, we analyzed the coupling between a microstrip line and a slot in the ground using the MTL method. To calculate the coupling between the microstrip line and the slot by using the MTL method, per-unit-length parameters, such as the self or mutual capacitances and inductances, of the microstrip line and the slot were calculated using the FDTD method. We showed the validity of the proposed method by comparing results using the MTL method and numerical results using the FDTD method.

References

[1] C.R.Paul, *Introduction to electromagnetic compati-bility*, John Wiley & Sons, Inc. , New York, 1992.

[2] K.C.Gupta, R.Garg, I.Bahl, P.Bhartia, *Microstrip lines and slotlines*, Artech house publishers, Boston, 1996.

[3] C.R.Paul, *Analysis of multiconductor transmission lines*, John Wiley & Sons, Inc. , New York, 2008.