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Study of Crosstalk Between Microstrip Lines Through a Ground Slot of PCB

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Abstract - **Recently, 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 ground slots. In this paper, we calculated electromagnetic coupling between microstrip lines on different layers in 3 layers printed circuit board with a narrow ground slot. To calculate electromagnetic coupling between microstrip lines through a ground slot, the multi-conductor transmission lines method is used. Per-unit-length parameters between a slot and a microstrip line was derived using the spectral domain approach. From the analysis results, we showed that electromagnetic coupling between lines on different layers through a ground slot can be calculated using MTL method.**

Index Terms — **electromagnetic coupling, multi-conductor transmission lines, ground slot, three layers PCB.**

1. Introduction

Recently, with the progress of information technology an operating speed of electronic devices becomes very fast. And also demands of miniaturizing PCBs increase since electronic devices are becoming small and lightweight. Miniaturization of the PCBs makes those ground to be small, and some defects of the ground, such as ground slots, may appear. If these ground slots are placed near any transmission lines, the transmission line's characteristics must be affected by these slots[1]-[2]. These ground slots may become the cause of undesired crosstalk when they couple electrically.

In this paper, the authors focus the electromagnetic coupling between two microstrip lines on different layers through a ground slot. For the analysis of complicated configuration like a PCB with some ground slots and microstrip lines, numerical analysis methods have usually been used but they consume a long calculation time and a large computer memory. To calculate such situation easily, the multi-conductor transmission lines (MTL) method is used [3]. To calculate using the MTL method, each per-unit-length parameter is needed. Especially, the mutual per-unit-length parameter can be derived by the electromagnetic field distribution around a ground slot. Then, this electromagnetic field distribution around the ground slot will be calculated using the spectral domain approach [4].

2. Theory

To use the MTL method, we need to derive the per-unit-length parameters. The per-unit-length mutual parameter between a microstrip line and a ground beyond a slot can not be derived easily since the propagation mode of a ground slot is mainly TE_{10} mode. Then, the mutual capacitance is derived using the voltage between the strip and the reference ground by integrating the electric field excited by the slot as will be described later. As shown in Fig. 1, we assume that the strip and slot have the center to center space s. Equivalent circuit of this configuration is shown in Fig. 2. Where C_s and C_m which can be derived using the phase constant and the characteristic impedance are respectively the per-unit-length self capacitance of the ground plane 1 and the microstrip line, and C_{ms} is the per-unit-length mutual capacitance between them. To obtain the capacitance matrix $\boldsymbol{C}$, we will derive the matrix $\boldsymbol{P}$ in which the entries are referred to as the coefficients of potential[3]. $\boldsymbol{P}$ is defined as $\boldsymbol{P}=\boldsymbol{C}^{-1}$. $\boldsymbol{P}$ and each charges and voltages are related as

$$\begin{bmatrix} V_m \\ V_s \end{bmatrix} = P\times\begin{bmatrix} Q_m \\ Q_s \end{bmatrix} = \begin{bmatrix} P_m & P_{ms} \\ P_{ms} & P_s \end{bmatrix}\begin{bmatrix} Q_m \\ Q_s \end{bmatrix}$$

(1)

where V_m and V_s are the voltages of the strip conductor and slot, respectively. And Q_m and Q_s are the charge of the strip conductor and the slot, respectively. The diagonal components P_m and P_s are reciprocal of each self-capacitance C_m and C_s respectively. The off-diagonal element P_{ms} is the ratio of the charge Q_s given by the slot and the voltage V_m excited in the strip conductor if Q_m=0 and shown as

$$P_{ms} = \left. {V_m}/{Q_s} \right|_{Q_m=0} = \left. {V_m}/{C_s V_s} \right|_{Q_m=0}, \tag{2}$$

where Q_s is the imaginary slot charge and it is defined as $Q_s=C_sV_s$ using the voltage V_s and the per-unit-length capacitance C_s. Since the condition Q_m=0 must be hold in Eq.(2), V_m is the voltage s away from the center of the slot when the strip conductor is not exist. Finally, $\boldsymbol{C}$ is derived as

$$C = P^{-1} = \begin{bmatrix} {1}/{C_m} & P_{ms} \\ P_{ms} & {1}/{C_s} \end{bmatrix}. \tag{3}$$

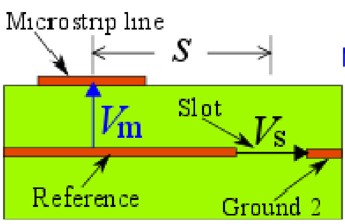


Fig. 1. Calculation model of per-unit-length mutual capacitance.

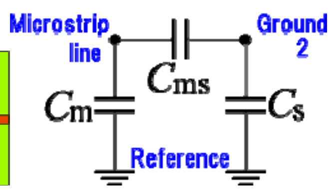


Fig. 2. Equivalent circuit model.

3. Analysis

(1) Analysis Model

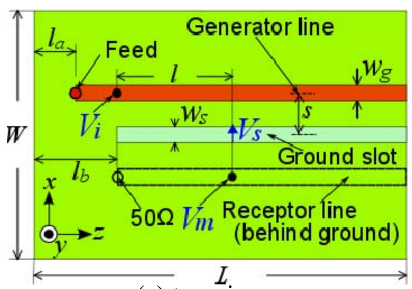
In order to validate we calculate coupling voltages between the microstrip lines and the ground slot on the PCB using the MTL method. And we also compare the MTL results with the results using the FDTD method.

In the case of the FDTD method, the configuration of the PCB is shown in Fig.3. The PCB consists of a dielectric substrate which has thickness T=1.6 mm, length L=200 mm and width W=200 mm and is made by FR4 of relative permittivity ε_r=4.4. The strip conductors with width w_g and the characteristic impedance of about 50 Ω are placed on one side or both sides of the PCB. One strip conductor is generator line with feed point and the other strip with 50 Ω is receptor line. The ground plane which has a slot with width w_s is placed in the center of the PCB. The length of the generator line is longer than the slot length because its length is long enough to suppress the higher mode wave at the feed point. The center to center space between each strip and the slot is s. The slot voltage V_s and receptor line voltage V_m at l away from the near end are calculated, respectively. The voltage V_i at the point l_b away from the feed point of the generator line is also calculated as the incident voltage. The FDTD calculation is finished after the propagation wave passes through the observation point to remove the reflection wave from results. Consequently there is no reflection wave in the results.

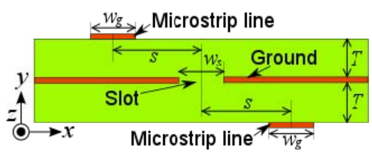
In the case of the MTL method, the PCB length L and width W are infinite. Each per-unit-length parameter of the line is calculated using the SDA. And also to implement perfectly matching, far ends of the strip lines and the slot are terminated by the characteristic impedance matrix $\boldsymbol{Z}_c$ [3]. Other conditions are same as the FDTD method.

(2) Results of Coupling Voltages

The voltages V_s in the ground slot excited by the electromagnetic coupling of the generator line are calculated using the MTL method and the FDTD method when the receptor line is not placed. The magnitude of the calculated results normalized by the incident voltage V_i is shown in Fig.3. In this figure, the coupling voltages decrease as the space s increases. The results of the MTL method and of the FDTD method are almost same regardless of the space s. Though the difference of the MTL and FDTD results is larger as frequency increases, the maximum is about 2 dB up to 10 GHz.



(a) top view



(b) cross view

Fig. 3 Configuration of analysis model.

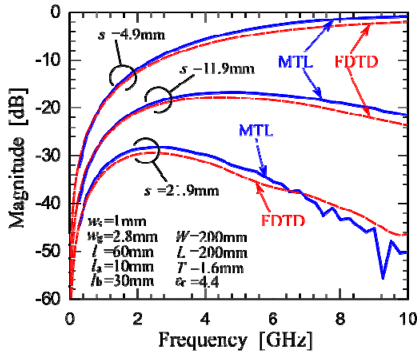


Fig. 3 Analysis results of normalized voltages V_s.

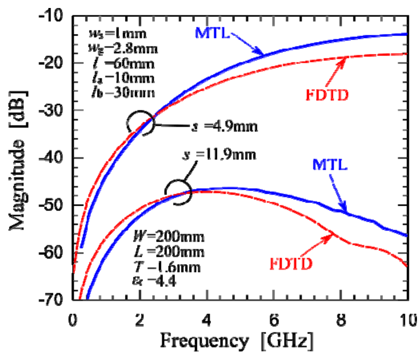


Fig. 4 Analysis results of normalized voltages V_m.

The voltages V_m in the receptor line excited by the generator through the slot are calculated using the MTL method and the FDTD method. In this calculation, the direct coupling between the generator line and the receptor line is ignored, since this coupling is considered too small. The calculated results normalized by the incident voltage V_i is shown in Fig.4. In this figure, both results are similar at low frequencies, but the differences are larger as frequency increases.

4. Conclude

In this paper, we analyzed the electromagnetic coupling between a microstrip lines and a ground slot on a PCB using the MTL method. To calculate the electromagnetic coupling using the MTL method, per-unit-length parameters of the microstrip lines and the slot were calculated using the SDA. Finally, we showed the validity of the method by comparing results using the MTL method with numerical results using the FDTD method though errors of the coupling between microstrip lines are large. The cause of the difference is that errors of the coupling calculation are added.

References

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