Circuit Model Analysis for Traces Crossing Slotted Ground Plane

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1. Introduction

Recently, there has been a growing interest for slotted ground plane structures. It is common to introduce slots in the power/ground planes in high-speed printed circuit boards (PCBs) design. In mixed signal circuits, split power/ground planes can isolate a noisy digital circuit from the sensitive analog circuit. Slots in the power/ground planes are also employed in PCBs with multiple power supplies in order to provide DC isolation among different supplies [1]. However, power/ground partitioning generates undesired electromagnetic effects such as signal integrity (SI) degradation, electromagnetic interference (EMI) and ground bounce in general [2].

To understand these problems systematically, this paper proposes a simple and accurate equivalent circuit model, which provides clear insight into the coupling mechanism between the microstrip line and the slot.

2. Circuit Model

Fig 1 shows the model investigated in this paper and Fig 2 shows the proposed equivalent circuit model of a signal line crossing over a ground slot. When a signal flowing along the microstrip line crosses a ground slot, the current in generated by the coupling between the signal traces and slot line. Coupling between the microstrip line and slot can be modeled by an ideal transformer with turn ratio \( n \) given by [3].

\[
n = \frac{Z_{\text{in}}}{Z_{\text{L}}} \approx \frac{Z_{0,\text{strip}}}{Z_{0,\text{slot}}} \tag{1}
\]

The impedance of the slot line is dispersive, so that the turn ratio determined by (1) varies with frequency. However, it was found that this variation is not so critical that value of \( n \) in the middle of its variation range can yield relatively accurate results.

Among various parameters, in deciding the resonance frequency, the length of slot plays an important role. Relationship between the slot length \( L_s \) and resonance frequency \( f_{\text{res}} \) given by [4].

\[
L_{\text{eq}} = L_s + 2\Delta \tag{2}
\]

\[
f_{\text{res}} = \frac{c}{\sqrt{\varepsilon_r \cdot L_{\text{eq}}}} \tag{3}
\]

where \( \Delta \) is end reactance ratio of a shorted slot, \( \varepsilon_r \) is relative permittivity of dielectric substrate, \( f_{\text{res}} \) is
resonance frequency, $L_{eq}$ is electrical resonant length. Generally, electrical resonant length is little larger than real resonant length because of inductive effect coming from end of a slot when slot trace is cut vertically.

This equivalent circuit model can be simplified by a series-connected shunt $L$-$C$ resonant circuit, since microstrip line coupled to the slotline can be considered as an effective short-circuited $\lambda/4$ line and it acts like a parallel $L$-$C$ resonance circuit near the resonant frequency. The parameter $L_{s1}$ dominantly affects the high frequency, especially, 7 GHz to 10 GHz. The resistance of the equivalent circuit can be written

$$R_{s2} = \frac{Z_{c}^{slot}}{\alpha(L_{eq}/2)}$$

and the capacitance of the equivalent circuit is given by

$$C_{s2} = \frac{\pi}{4(2\pi f_{res})Z_{q}^{slot}}$$

The inductance of the equivalent circuit is found as

$$L_{s2} = \frac{1}{(2\pi f_{res})^2 C_{s2}}$$

Equations (4), (5) and (6) can be derived from the transmission parameter $S_{21}$ of the individual two-port resonator network when $S_{21}$ is expressed in terms of the admittance of resonator.

3. Experimental results

To verify the model proposed here, we measured the transmission characteristics of an experimental model shown in Figure 1 and compared with those calculated from the equivalent circuit model shown in Fig 2. The structure under consideration is a microstrip line on the top surface of a dielectric substrate with a slot on a ground plane. Table 1 shows the geometrical parameters. This circuit model analysis was performed using Advanced Design System (ADS), a circuit simulator from Agilent Technologies. Signal port was terminated with 50-Ω load.

Fig 3 shows the theoretical and measured $S$-parameters for the microstrip line with slotted ground plane. Very good agreement is observed from 0.01 to 10 GHz.

4. Conclusion

We proposed accurate circuit model to analyze the structure having traces crossing a slotted ground plane. The calculated $S$-parameters using the equivalent circuit show an excellent agreement with measurement ones over the wide frequency band. Therefore, this model is expected to be useful for the analysis of various slotted ground plane structures.

Acknowledgments

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Table 1: Information of parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
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<tbody>
<tr>
<td>$W_m$</td>
<td>2.85 mm</td>
<td>Trace width</td>
</tr>
<tr>
<td>$W_s$</td>
<td>1.5 mm</td>
<td>Slot width</td>
</tr>
<tr>
<td>$L_s$</td>
<td>26 mm</td>
<td>Slot length</td>
</tr>
<tr>
<td>$h$</td>
<td>1.6 mm</td>
<td>PCB height</td>
</tr>
<tr>
<td>$\varepsilon_r$</td>
<td>4.8</td>
<td>Relative Permittivity</td>
</tr>
</tbody>
</table>

Figure 1: Proposed slot ground plane structure

Figure 2: Proposed Equivalent Circuits Model for Slotted Ground Plane
Figure 3: Comparison of S-parameters for a slotted ground plane (a) Return loss (b) Insertion loss

References


