Reduction of common-mode excitation on a differential transmission line bend by imbalance control

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Abstract: Asymmetry in a differential transmission line bend generates a large common mode, which leads to signal integrity issues. Herein two methods are proposed to improve the symmetry and reduce the common-mode at the line bend on a printed circuit board. Placing a guard trace near a narrowed inner signal line at the line bend results in a 15-dB reduction of the common mode. Alternatively, employing a stub connected to the inner signal at the bend section results in a more than 20-dB reduction.

Keywords: transmission line bend, common mode, imbalance

Classification: Energy in Electronics Communications

References


1 Introduction

High-speed signal devices generally use a differential signaling system because the signal voltage is lower than that of a single-ended transmission line system due to the high immunity of the differential transmission line to the coupling noise from an external field [1]. Additionally, when the total differential system with a driver and a receiver is completely symmetric, the radiated emission from a differential transmission line is lower than that from a single-ended transmission.

In order to avoid common-mode generation, a differential transmission line on a printed circuit board (PCB) should have symmetric layout. However, in an actual PCB, it is almost impossible to design a completely symmetric transmission line because a transmission line should have bends to connect the driver LSI and receiver LSI, which may be placed at various locations on a PCB. At a bent section, the common mode is excited from the differential mode propagates in the transmission line as a functional signal due to the lack of symmetry, leading to signal integrity issues [2].

Hence, isometric signal lines are used for differential transmission lines to improve actual PCBs. Often a transmission line must be bent to avoid several ICs or circuit components, and the asymmetric property excites the common-mode current [3]. The common-mode current flowing in a transmission line causes a large radiated emission [3] and increases the signal jitter. Therefore, the common-mode excitation or propagation must be reduced to improve the signal integrity.

Several designs have been proposed to reduce common-mode propagation in a PCB, including a periodically defected ground structure (DGF) [4, 5]. A periodic DGF can filter out common-mode noise without disturbing the differential signal transmission. Although the common mode current does not reach the receiver IC in this method, the common-mode flowing on part of the transmission line can result in radiated emission.

In this paper, methods to improve electric symmetry are proposed to reduce the common-mode excitation: placing a guard trace and a stub structure with narrowed the signal line. Because changing the signal line width is an effective mean to control the self inductance [6] and a guard trace connected to the ground plane [7] or a stub structure connected to the inside signal line near the bent section can control the self-capacitance, the electrical symmetry can be improved in the bent section.

2 Electrical symmetry of a transmission line bend

This section focuses on common-mode excitation at a transmission line corner bend shown in Fig. 1. If a lossless transmission line is assumed, an equivalent circuit model can be constructed using LC networks. In the straight sections, the trans-
mission lines are structurally and electrically symmetric. On the other hand, the transmission line at the bent section has structural and electrical asymmetric properties, which cause common-mode excitation from the differential mode propagating as the signal.

Designing an electrically symmetric transmission line at the bent section can eliminate the excitation of the common mode. At the bent section in Fig. 1, the inductance of the inside line, $L_{11}$, is smaller than that of the outside line, $L_{22}$, because the inside line is shorter than that of the outside line. Additionally, the capacitance between the inside line and the ground plane, $C_{11}$, is smaller than that of the outside line

$$C_{11} < C_{22}, \quad L_{11} < L_{22}. \tag{1}$$

Narrowing the inside line can also decrease the self capacitance. In this paper, two ideas are proposed to control the self capacitance. One is to place a guard trace connected to the ground plane near the inside line to conform $C_{11}$ to $C_{22}$. The other is to connect a stub to the inside line. Changing the length of the stub can control the self-capacitance, $C_{11}$. Along with altering the inside line width, adjusting the location of the guard trace or the length of the stub can improve the electrical symmetry of the bent section and eliminate the common-mode excitation.

3 Verification of common-mode reduction

A three-dimensional electromagnetic simulator, HFSS, is applied to verify that the proposed method reduces the common-mode excitation. In the test boards, the differential signal line, which is 60-mm long, is routed on the top layer and bent around the center of the transmission line as shown in Fig. 1. The ground plane on the bottom layer is sufficiently large to assume that it’s potential is equal to 0. The conductor patterns are composed of copper, while FR-4 (its relative permittivity is about 4.25 and thickness is 0.8 mm) is used as an insulating material in all test boards.
Test board (a) has only a differential transmission line on the top layer. To improve the electrical symmetry, test board (b) has a narrowing signal line and a guard trace at the bent section, while test board (c) has a stub connected to the inside signal line at the line bend. The width and length of the stub are $w_{\text{stub}}$ and $\ell_{\text{stub}}$, respectively. Here, the stub width is fixed at 0.5 mm and the length, $\ell_{\text{stub}}$, is varied.

### 3.1 Using a guard trace

Test boards (a) and (b) are compared to clarify the reduction effect of the common-mode conversion by narrowing signal line using a guard trace. Fig. 2(a) plots the calculated results of the conversion between the differential mode and common mode, $|S_{21}|$. Employing a guard trace in this configuration results in about 15-dB reduction in the common-mode excitation.

Table I shows the inductances and capacitances around the transmission line bend calculated by a three-dimensional electromagnetic solver with the quasi-static assumption and a 2.4-mm line length in the bent section. Narrowing the inside signal line and placing the guard trace increase the self inductance and self-capacitance of inside signal line, improving the electrical symmetry of the line bend. However, the characteristic impedance of the differential mode,

$$Z_{0D} = \sqrt{\frac{L_{11} + L_{22} - 2L_{12}}{C_{11} + C_{22}}},$$

which is listed in Table I, is negligibly influenced by the guard trace because the mutual capacitance and inductance are dominant in the characteristic impedance of the differential mode.

![Common-mode conversion from differential mode.](image)

(a) By guard trace and narrow signal line. (b) By stub and narrow signal line.

**Table I.** Variations of self capacitance and self inductance by narrowed signal line and guard trace or stub.

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
<th>(c) 0.6 mm</th>
<th>(c) 0.9 mm</th>
<th>(c) 1.2 mm</th>
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<td>$Z_{0D}$ [Ω]</td>
<td>105</td>
<td>108</td>
<td>106</td>
<td>104</td>
<td>103</td>
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<tr>
<td>$C_{11}$ [pF]</td>
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<td>0.115</td>
<td>0.094</td>
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<td>$C_{22}$ [pF]</td>
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<tr>
<td>$C_{12}$ [pF]</td>
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<td>1.03</td>
</tr>
</tbody>
</table>
3.2 Using a stub structure

Another method to increase the self capacitance of the inside signal line is to connect a stub to the inside signal line, which acts as an additional capacitor below a frequency range of $\lambda/4$ resonance and narrows the inside signal line width, increasing the self inductance.

The parameters of the equivalent circuit model at the line bend are extracted by the electromagnetic simulator with a quasi-static assumption. Table I lists the calculation results. Placing a stub improves the electrical symmetry of the line bend without changing the characteristic impedance of the differential mode, which is represent by Eq (2).

Fig. 2(b) shows the common-mode conversion ratios, $|S_{cd21}|$. The stub with a 0.9-mm length reduces the common-mode conversion by 20 dB.

4 Conclusion

We propose two methods to reduce the common-mode excitation at a differential transmission line bend. The common mode is converted from the differential due to the lack of symmetry of the transmission line. Narrowing the signal line to increase the self-inductance and placing a guard trace or a stub to increase the self-capacitance effectively reduces the common-mode conversion. The electromagnetic simulation showed more than a 20-dB reduction, but optimizing the conditions (e.g., signal line width, gap between the guard trace and signal line, or stub length) should result in further reductions.