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# Analysis of positioning error and its impact on high frequency properties of differential signal coupler

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**Abstract.** This paper presents the analysis of the effect of differential signal coupler positioning accuracy on its high frequency performance parameters for contact-less high speed chip-to-chip data transmission on PCB application. Our considerations are continuation of the previous works on differential signal coupler concept, design methodology and analysis for high speed data transmission monitoring. The theoretical analysis of possible coupler positioning innaccuracies is extended for representative design cases by simulations carried out using EM simulator. The results reported here confirm that the concept of contactless monitoring of high speed chip-to-chip data transmission in a pair of coupled microstrip lines is of practically usefulness without applying the expensive and precise positioning system.

**Key words:** high speed data transmission monitoring, coupler positioning accuracy, manufacturing of coupling structures.

## 1. Introduction

The data exchange speed between systems has been growing rapidly over the recent years [1–6], greatly accelerating the development of high speed interconnect technology [7–12]. Due to the growth of transmission rate in interconnections on PCB, the signal integrity issues are more and more important [13]. High speed interconnections between subsystems become critical for the entire system performance [14, 15]. This situation urges for research and development of techniques of high speed interconnections. The goals include ensuring the required bandwidth, electromagnetic compatibility (EMC), as well as the ease of manufacturing with desired transmission quality [16–20]. The growth of transmission rate has direct impact of the interconnect bandwidth inside the device. On PCB, connections between active circuits and connectors became critical for the performance of the entire device and system [21]. The number of devices produced every day reached unprecedented levels [22]. The popularity and accessibility of new multimedia devices such as smartphones, tablets and ultrabooks, indicate that – in the near future – manufacturing cost reduction will become critical. Assuming that the price of a product is at the level acceptable by a customer, potential savings on materials, technology and manufacturing process directly increase the profit for the manufacturer. These factors indicate that research on high speed interconnections and manufacturing cost optimization still is and will be important in the years to come.

Motivated by the aforementioned needs, the new contactless approach to high-speed data transmission monitoring for chip-to-chip communication monitoring on Printed Circuit Board (PCB) has been introduced [1, 2]. The proposed methodology is based on a concept where a dedicated differential signal coupler [3–5], implemented on a separate piece of laminate, is overlaid on PCB containing the transmission line under the test. The monitored signal from the main transmission line is decoupled by two branches of the coupler without significantly influencing the transmission in the monitored line. This solution is beneficial from both the functional and the cost points of view: it is possible to overlay the coupler on the transmission line without any prior preparation at the PCB design stage, and no dedicated measurement connectors are required. The complete analysis and design methodology of the differential signal coupler which can be used for high speed data transmission monitoring on PCB can be found in [3–5].

From application point of view, the accuracy of differential signal coupler positioning on the board with transmission line under test can be critical for monitoring performance and the impact of the coupler on the transmission conditions in the main line. The considerations conducted in this paper aim at investigating the influence of the coupler positioning accuracy on its high frequency parameters. The main goal of this analysis is to define the requirements for differential signal coupler positioning so that the monitoring satisfies given performance requirements without disturbing transmission in the monitored line.

## 2. Analysis

The differential signal coupler design considerations presented in [3–5] were carried out assuming that the coupler's branches are positioned symmetrically around the monitored transmission line (the distances between each branch and transmission line are equal) and the branch axes are parallel to the main line. Any positioning errors will affect the key coupler parameters, disturb the symetry, and change the impact of the differential signal coupler on the main transmission line.

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Quantifying the relationship between such errors and coupler performance parameters, carried out in this section, is particularly important from the practical point of view. In particular, the need for troublesome and extremely precise coupler positioning could significantly reduce the area of potential practical applications for the proposed technology.

Possible positioning errors can be decomposed into the parallel shift (Fig. 1a) and rotation (Fig. 1b). As mentioned in [3–5], the modification of $s_C$ (Fig. 1a) parameter will change the coupler's branch coupling $C_B$. Let's consider the relations which describes the coupler parameters. The even ($Z_{0e}$) and odd mode ($Z_{0o}$) impedances of coupled lines have the values as follow:

$$Z_{0e} = \sqrt{\frac{1+10^{(C_B/20)}}{1-10^{(C_B/20)}}}, \qquad (1)$$

$$Z_{0o} = \sqrt{\frac{1-10^{(C_B/20)}}{1+10^{(C_B/20)}}}.$$

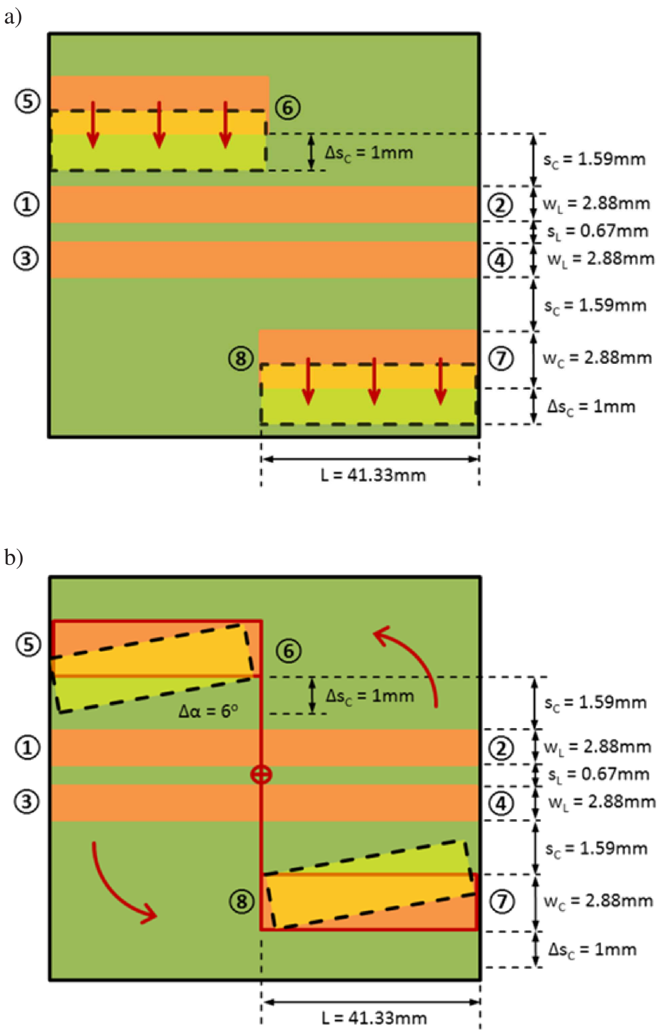

Fig. 1. Two basic coupler positioning errors: (a) parallel shift, (b) rotation

The quotient $(s_c/h)$, where $h$ is the thickness of PCB substrate is:

$$\left(\frac{s_c}{h}\right) = \frac{2}{\pi}\cosh^{-1}$$
$$\cdot\left\{\frac{\cosh\left[\frac{pi}{2}\left(\frac{w_c}{h}\right)'_{so}\right] + \cosh\left[\frac{pi}{2}\left(\frac{w_c}{h}\right)_{se}\right] - 2}{\cosh\left[\frac{pi}{2}\left(\frac{w_c}{h}\right)'_{so}\right] - \cosh\left[\frac{pi}{2}\left(\frac{w_c}{h}\right)_{se}\right]}\right\}. \qquad (2)$$

The $(w_c/h)$ quotients for even and odd modes can be calculated using the equation:

$$\left(\frac{w_c}{h}\right)_{se,so}$$
$$= \frac{8\sqrt{\left[\exp\left(\frac{R}{42.4}\sqrt{\varepsilon_r+1}\right)-1\right]\frac{7+(4/\varepsilon_r)}{11}+\frac{1+(1/\varepsilon_r)}{0.81}}}{\left[\exp\left(\frac{R}{42.4}\sqrt{(\varepsilon_r+1)}-1\right)\right]}, \qquad (3)$$

where

$$\left(\frac{w}{h}\right)'_{so} = 0.78\left(\frac{w}{h}\right)_{so} + 0.1\left(\frac{w}{h}\right)_{se}. \qquad (4)$$

Finally, the $(w_c/h)$ ratio is:

$$\frac{w_c}{h} = \frac{1}{2\pi}\cosh^{-1}(d) - \frac{1}{2}\left(\frac{s_c}{h}\right), \qquad (5)$$

$$d = \frac{\cosh\left[\frac{\pi}{2}\left(\frac{w_c}{h}\right)_{se}\right](g+1)+g-1}{2}, \qquad (6)$$

$$g = \cosh\left(\frac{\pi}{2}\left(\frac{s_c}{h}\right)\right). \qquad (7)$$

Taking into account the analytical relations presented above, we can expect that the coupler positioning error presented in Fig. 1a, can result in increasing the coupling factor for the branch 5–6 and decreasing for 8–7. Consequently, the symmetry of the coupling factors in structure will be disturbed. It is expected that the second type of elementary positioning error (Fig. 1b) introduces the coupling factor error but its quantitative assessment in the frequency domain is not straightforward.

## 3. Simulation results

The considerations presented in the previous section are confirmed by simulations in the frequency domain performed using ADS Momentum for 1 GHz differential signal coupler implemented on FR4 laminate ($\varepsilon_r = 44$, $h = 155$ mm, $tan(\delta) = 0.018$, copper with thickness – 35 $\mu$m), which were described [3]. The initial dimensions of the coupling structure are presented in Fig. 1. The positioning error due to a parallel shift was analyzed in the range 0.1 mm to 1.0 mm (63% of $s_C = 1.59$ mm) with 0.1 mm step for 100 MHz – 4 GHz bandwidth. The simulation results are presented in Fig. 2.

We can observe that for the frequencies lower than 1400 MHz, the worst-case match is obtained for 700 MHz (Fig. 2a). For this frequency, the impact of the positioning error is not critical (3.5 dB for the shift error of $\Delta s = 1$ mm). The impact of positioning inaccuracy is the most visible at 1.15 GHz and 3.27 GHz but this is not critical because of good matching ($< -25$ dB) of the circuit for these subbands. The impact on the main transmission line loss characteristic (Fig. 2b) is lower than 0.2 dB for the frequencies lower than

3 GHz. The main transmission line self coupling characteristic (Fig. 2c) is not affected. As it was expected, the coupler's branch coupling $C_B$ characteristic (Fig. 2d) is shifted due to the coupler positioning error. The characteristic is directly shifted without significant changes of its shape. This type of distortion is not a serious issue from practical point of view: it can be easily compensated by simple equalizer with an active gain control module (AGC).

The coupler rotation positioning error was analyzed in the range 2° to 6° with 2° step for 100 MHz – 4 GHz bandwidth. The simulation results are presented in Fig. 3.

The results obtained for the coupler rotation indicate that for the frequencies lower than 2 GHz, the impact of coupler rotation on the main transmission line characteristic is lower than 2 dB (Fig. 2a). Above 700 MHz, we observe the shift of the resonant points towards higher frequencies (70 MHz for 6° at 1.2 GHz). The impact of coupler rotation on the main transmission line loss characteristic (Fig. 3b) and the main transmsision line self-coupling (Fig. 3c) is negligible. The coupling factor of the single branch $C_B$ has similar characteristic as for the parallel shift but the level of impact is lower.

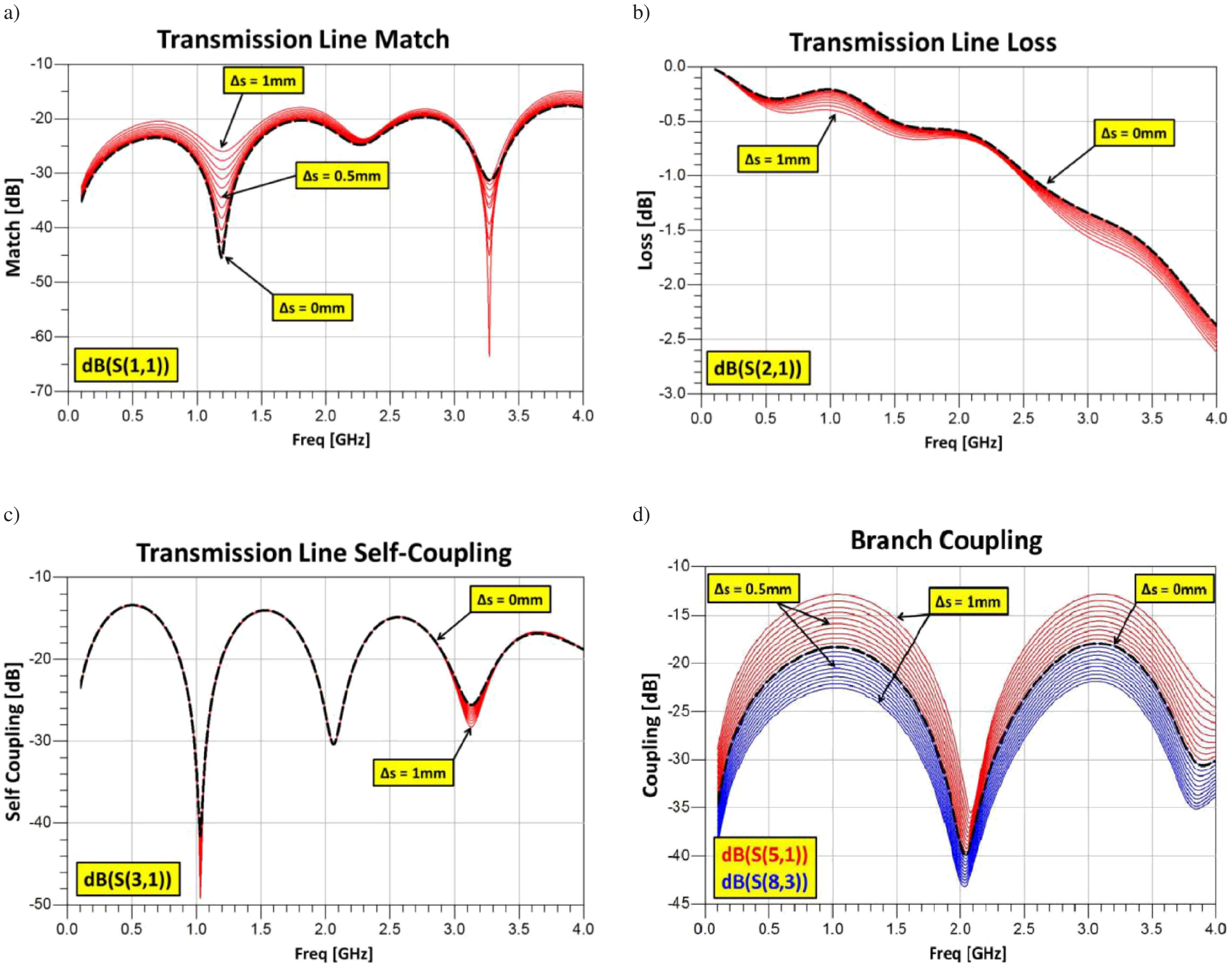

Fig. 2. Simulation results for parallel positioning shift error: a) main transmission line match, b) main transmission line loss, c) main transmission line self-coupling, d) coupler's branch coupling $C_B$

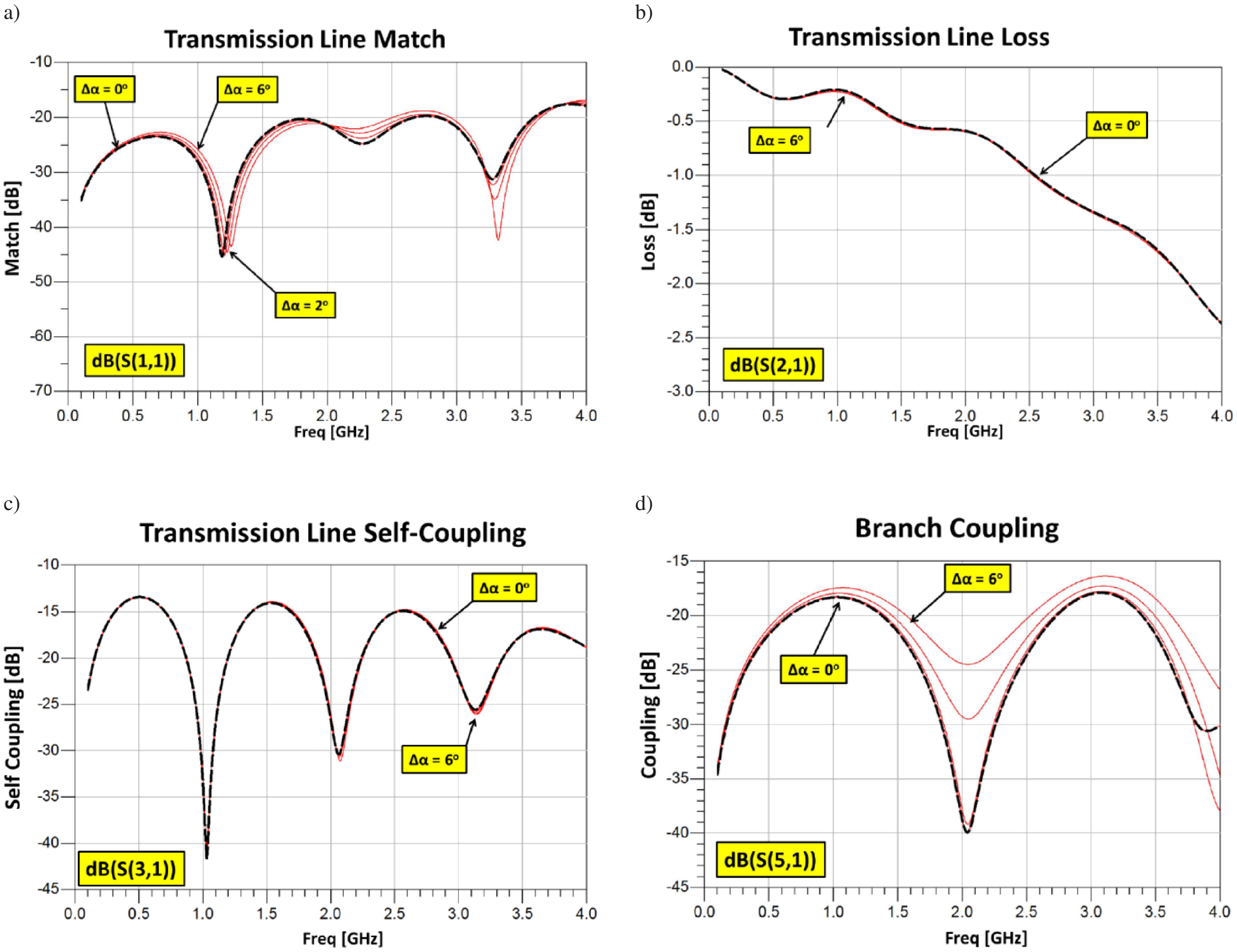

Fig. 3. Simulation results for rotation positioning error: a) main transmission line match, b) main transmission line loss, c) main transmission line self-coupling, d) coupler's branch coupling $C_B$

## 4. Conclusions

In this paper, the impact of differential signal coupler positioning error on its high frequency performance parameters was analyzed. The correctness of theoretical considerations was confirmed by simulations. Our results indicate that the positioning error is not critical for its practical applications. It was observed that the coupler's rotation has significantly lower impact than the parallel shift on both the high frequency parameters of the coupler and the operating conditions of the main transmission line. The changes of high frequency parameters are not significant and can be compensated by an external active equalizer. Additionally, the impact of the differential signal coupler on the main line was not significantly increased. This allows us to confirm that the concept of contactless monitoring of high speed chip-to-chip data transmission in a pair of coupled microstrip lines presented in [1, 2] can be applied in practice without using an expensive, precise positioning system.

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