A Transmission Line Coupler Component for direct B2B communications

Reiji Miura
The University of Tokyo
Tokyo, Japan
miura@kuroda.t.u-tokyo.ac.jp

Tadahiro Kuroda
The University of Tokyo
Tokyo, Japan
kuroda@kuroda.t.u-tokyo.ac.jp

Mototsugu Hamada
The University of Tokyo
Tokyo, Japan
Hamada@kuroda.t.u-tokyo.ac.jp

***Abstract*— A contactless connector by using a transmission line coupler (TLC) in direct board-to-board (B2B) communications is described. We propose a TLC block component, and a new structure of side vias for impedance matching. In this method, error-free communication up to 3 Gbps is possible with a B2B distance of 15 mm.**

Keywords*— *contactless connector, transmission line coupler, impedance matching

I. INTRODUCTION

A practical system consists of multiple module boards, which are connected by a backplane. Signals on a module board are carried to its edge connector for their inter-module communications, which brings power, delay, area penalties.

We develop a transmission line coupler (TLC) technology enabling a direct board-to-board(B2B) high-speed communications, in which transmission lines on two separate printed circuit boards are electromagnetically coupled. In this paper, we present a new TLC applicable for the replacement of the current backplane communication.

The TLC utilizes crosstalk between transmission lines for the communication. This means that the signal is transferred with both electric and magnetic fields distributed along with the transmission lines. With this nature, the impedance matching at the TLC is manageable as we do in the transmission line design. Therefore, a high-speed B2B communication as high as 12Gbps is achieved while the conventional magnetic coupling B2B communication is limited to about 1Gbps. Besides, since it is tolerant to the coupler's misalignment, a conventional backplane connector can be used for the mechanical connection and power supply combined with the TLC to integrate a system with multiple modules. The contactless signal connection is free from the reliability problem of the insertion-extraction of module boards. However, a general backplane has a board pitch of about 15mm, while the conventional TLC was desirable to be used with the gap of up to 5 mm. It is difficult to increase the communication distance.

In this paper, we propose a TLC block component for the direct B2B communication, in which a TLC is elevated in the block component. The component is mounted on a PCB so that the gap of the TLC is decreased. A prototype was fabricated with a TLC capable of communication up to 3.5 Gbps. The height of the prototype component is 5 mm, with which the communication distance is decreased to 5mm (15 mm (board pitch) – 2 x 5 mm (height of two TLC block components)). When a conventional side via is used to lift the signal up, the communication up to 1Gbps is error free. A simulation analysis shows that the impedance mismatch at the side via that lifts the signal limits the data rate. Therefore, we propose a new TLC block component with a new structure of side vias, which is error-free up to 3Gbps by improving the signal lifting part while maintaining manufacturing feasibility and achieving impedance matching.

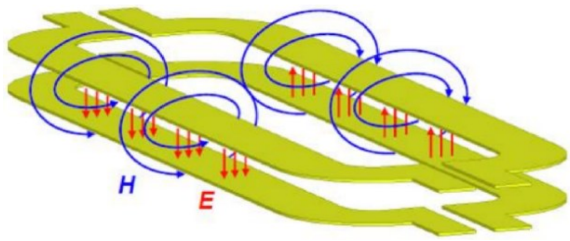

Fig. 1 Basic structure of TLC.

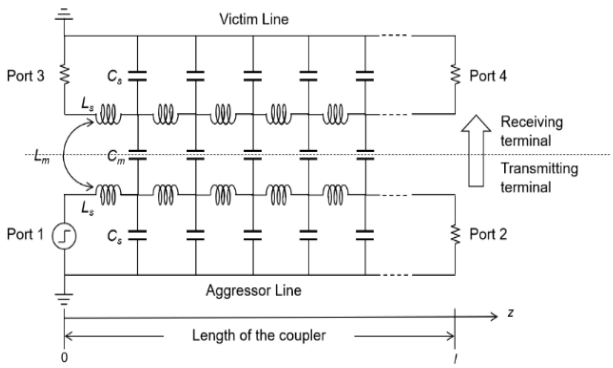

Fig. 2 Equivalent circuit model of two coupled transmission lines.

II. TLC FUNDAMENTALS

A. *Electrical Characteristics and Design Parameters*

Fig. 1 depicts the basic structure of TLC. It consists of two pairs of differential transmission lines, with each pair implemented on the surface layer of a different PCB, and with the two pairs coupled across a gap. Each pair of differential transmission lines is laid out in the shape of a horseshoe. The horseshoe shape enables strong inter-pair coupling across the gap by increasing intra-pair spacing to 1) reduce intra-pair coupling, and 2) accommodate wider traces for better inter-pair coupling.

Based on the circuit model in Fig. 2, the voltage and current of a signal at any particular point z along the transmission line and at any particular time t can be represented by the following set of equations:

$$\frac{\partial}{\partial z}\begin{bmatrix}V_1\\V_2\end{bmatrix} = -\frac{\partial}{\partial t}\begin{bmatrix}L_{11} & L_{21}\\L_{21} & L_{22}\end{bmatrix}\begin{bmatrix}I_1\\I_2\end{bmatrix}$$
$$\frac{\partial}{\partial z}\begin{bmatrix}I_1\\I_2\end{bmatrix} = -\frac{\partial}{\partial t}\begin{bmatrix}C_{11} & C_{21}\\C_{21} & C_{22}\end{bmatrix}\begin{bmatrix}V_1\\V_2\end{bmatrix} \quad (1)$$

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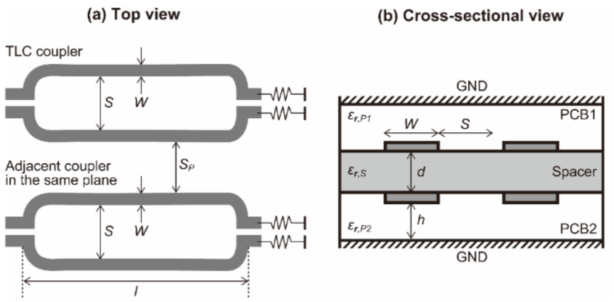

Fig. 3 Physical design parameters of a standard TLC.

where $V_1(z,t)$ and $I_1(z,t)$ are the voltage and current for the transmitting terminal, $V_2(z,t)$ and $I_2(z,t)$ the voltage and current for the receiving terminal, L_{11},L_{22}=L_s are the self inductances of the individual transmission lines, C_{11},C_{22}=C_s+C_m are the total capacitances of the individual transmission lines, L_{12},L_{21}=L_m, and C_{12},C_{21}=-Cm. (Note that the definition of the inductance matrix is not completely analogous to that of the capacitance matrix in that L_{11},$L_{22}\neq L_s+L_m$.) The transmitter voltage at Port 1 is $V_{TX}(t)$=$V_1(0,t)$, and the received voltage at Port 3 is $V_{RX}(t)$=$V_2(0,t)$.

Since signal transmission in TLC is achieved through capacitive and inductive coupling, its effectiveness is quantified by the capacitive and inductive coupling coefficients, K_C and K_L, given by

$$K_C = \left|\sqrt{\frac{C_{21}}{C_{11}C_{22}}}\right|,\ K_L = \left|\sqrt{\frac{L_{21}}{L_{11}L_{22}}}\right| \qquad (2)$$

Fig. 3 defines the physical design parameters of the standard TLC. The assumption of homogeneous dielectric medium means that both PCBs and the spacer have the same dielectric constant, in other words, $\varepsilon_{r,P1} = \varepsilon_{r,P2} = \varepsilon_{r,S} = \varepsilon_r$. Since $K_C = K_L = K$, the coupling coefficient K can be computed by considering electric field distribution only, by modeling the coupled traces as parallel-plate capacitors plus fringe effects. Specifically, for identical transmission lines where C_{11}=C_{22}, K is given by

$$K = \frac{\varepsilon_0\varepsilon_r\frac{W}{d} + C_{m,fr}}{\varepsilon_0\varepsilon_r\frac{W}{d} + C_{m,fr} + 2C_{s,fr} + \varepsilon_0\varepsilon_r\frac{W}{h}} \qquad (3)$$

When the ratio of the line width W to the communication distance d and the ratio of the line width W to the distance h to GND are increased, the coupling force K also increases. However, in order to achieve a communication distance of about 15 mm, we need to set the line width W to 15mm , and the TLC size becomes 75mm×10mm. This is not practical nor acceptable.

B. Communication evaluation method

Figure. 4 shows the communication evaluation method in this study. The transmitter IC is inserted in front of the TLC to work as a buffer and stabilize the amplitude and rise time. After passing through the TLC, the low-frequency component is cut off and the waveform is received as a return-to-zero waveform. A hysteresis comparator is used as a receiver IC to restore this received waveform. The BERT generates PRBS signal, and each waveform is confirmed using an oscilloscope. The transmitter is MAX3842 of MAXIM. The receiver is ADCMP580 of ANALOG DEVICES.

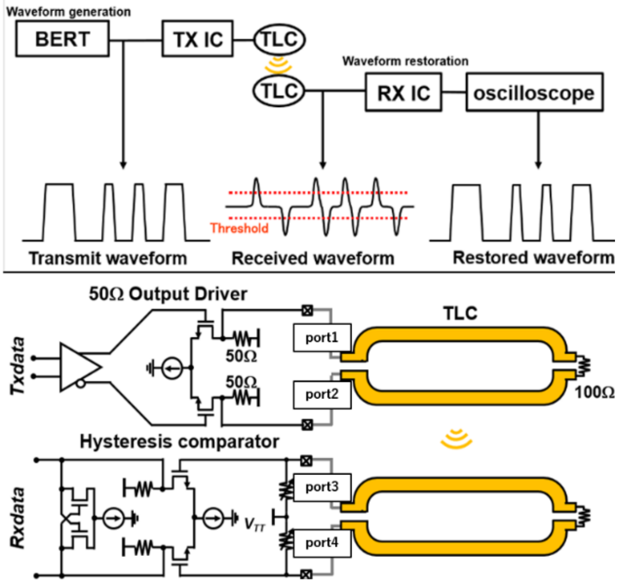

Fig. 4 Communication evaluation method.

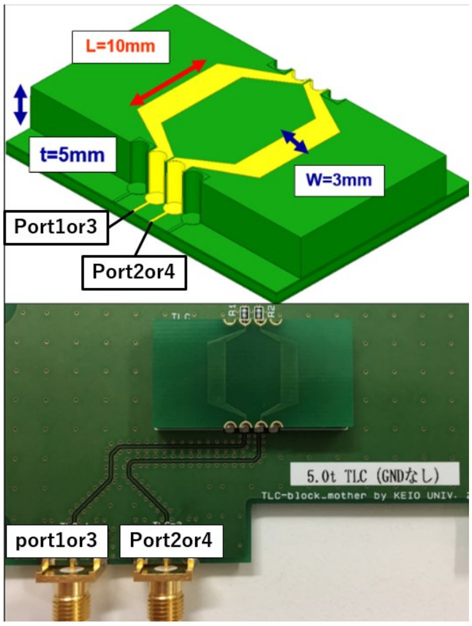

Fig. 5 details of TLC block component.

III. PROPOSED METHOD

This section describes the TLC block component (Fig. 5) proposed in this paper. This TLC is elevated in the block component. The component is mounted on a PCB so that the gap of the TLC is decreased. Further, coupling coefficients K shown in equation (3) can be increased since the distance h to GND becomes large. A prototype was fabricated with line width W=3mm, line length L=10mm and the TLC capable of communication up to 3.5 Gbps.

A. Block height determination

This subsection describes the height t of the block component which lifts the TLC up. We perform simulation by changing the value of the height t, measure the S/N ratio (Signal amplitude / Noise amplitude in Fig.6), and compare them. The results are shown in Fig. 6. We chose t=5mm with the best S/N ratio as the block height.

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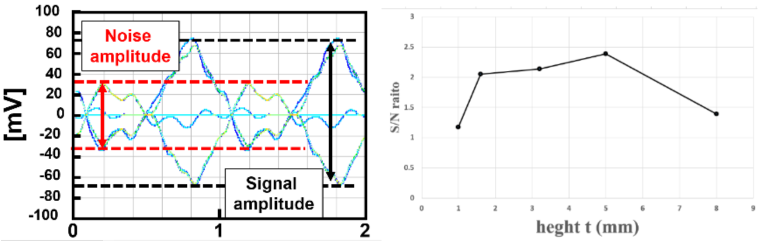

Fig. 6 S/N ratio comparison.

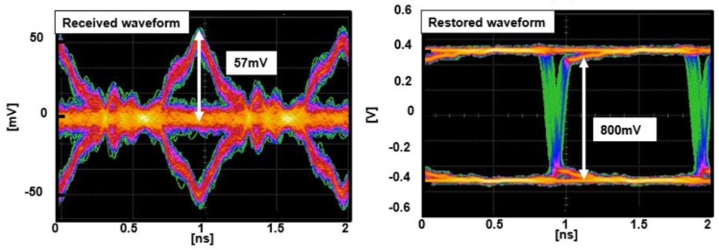

Fig. 7 Waveform obtained in the experiment.

B. *Experimental results*

We create an experimental system as shown in Fig. 4, and set the input waveform communication speed from BERT to 1 Gbps. The communication distance between TLC couplers is 5 mm, and the distance between boards is 15 mm. Fig.7 shows the received waveform through the TLC, and restored waveform observed with an oscilloscope.

In the received waveform in Fig. 7, the signal amplitude is 57 mV, which is larger than the receiver IC threshold, and the noise amplitude is within the threshold. It is possible to confirm the restoration of the waveform by passing it through the receiver IC.

C. *Impedance matching of edge vias*

As mentioned above, the TLC used in this paper can communicate at up to 3.5Gbps. The simulation is performed at a board-to-board distance of 1.5 cm and a communication speed of 3 Gbps. However, the noise amplitude becomes too large (Fig.8 normal block-type TLC), and receiver IC can't restore the waveform. The cause of the noise is that the edge via which used to lift the signal up does not have impedance matching.

To match the impedance of the side vias to transmission lines, the insertion of a return path is required along with the side vias. However, having a metal layer perpendicular to the substrate is very difficult from a manufacturing feasibility point of view.

We have propose a new TLC block component in which GND mesh is added along with the edge vias as shown in Fig. 8 for impedance matching. This GND mesh consists of vias and wiring layers commonly used for PCBs. In the received waveform obtained with the new TLC block component , the signal amplitude is about 70 mV, which is larger than the threshold of the receiver IC, and the noise amplitude is within the threshold. Therefore, proposed a new TLC block component with a new structure of the edge via is error-free up to 3Gbps. The cost increase of a new TLC block component is only for the PCB of the block part. Assuming the size of a typical PCB is 20 cm x 20 cm, the cost increase is only a few percent.

IV. CONCLUSION

In this paper, we propose a contactless method by using a transmission line coupler in direct B2B communications. Since it was difficult for TLC to communicate at a distance of 15 mm, we propose the new TLC block component that lifts the TLC from the substrate. Furthermore, error-free communication up to 3 Gbps is possible with a board-to-board distance of 15 mm by improving the impedance of the edge vias that lifts the signal while maintaining manufacturing feasibility.

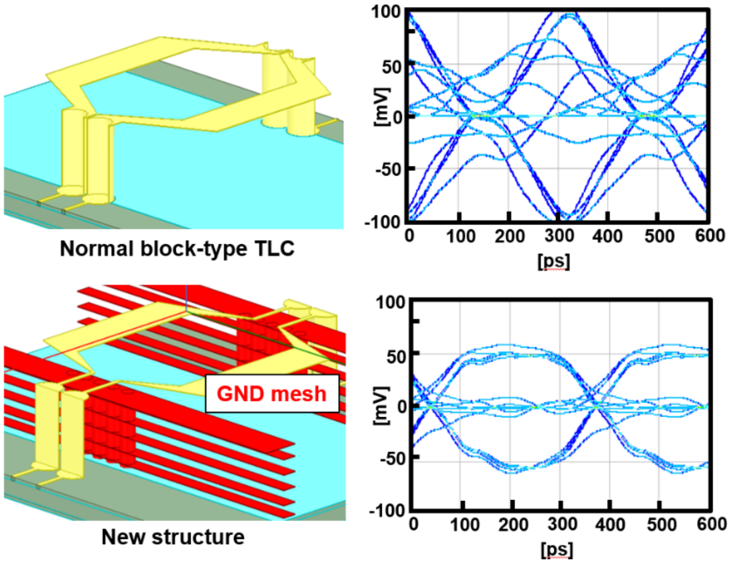

Fig. 8 Receive waveform comparison (3Gbps).

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