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An Inductively Coupled Wireless Bus for Inter-Chiplet Communication

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Abstract

We evaluate chiplet-to-chiplet wireless bus communication technology that achieves various mounting shapes by simulation and measurement of a test chip. The test chip prototyped in 0.18 µm CMOS confirms bus communication between horizontally arranged coils at 2.0 Gb/s.

1. Introduction

With the miniaturization of chips and the reduction of power consumption, embedded computer systems are becoming useful tools for various applications. We are focusing on small systems that require complex mounting shapes such as micro-robots [1] and wearable devices using fibers [2]. In order to build a system with various shapes and robustness for such applications, we are researching an implementation method to connect multiple chips wirelessly (Fig. 1). On-chip coils are formed along the outer periphery of each chip, and adjacent chips are wirelessly connected by utilizing inductive coupling between the coils. This enables making embedded systems with various shapes and replacing chips after mounting.

Here, data transmitted by one chip is carried to all adjacent chips. As shown in Fig. 1, when a rectangular chip (Chiplet0) is used, it is expected that data is transmitted to all adjacent square chips (Chiplet1, 2, 3 and 4). Previously, no detailed investigation was conducted on the horizontal inductive coupling characteristics of rectangular on-chip coil. Also, although vertical bus communication on stacked chips has been investigated [3], horizontal bus communication has not been verified. In this paper, we first present simulation results of horizontal inductive coupling between rectangular coils and experimental results of wireless bus communication in the horizontal direction using a rectangular coil.

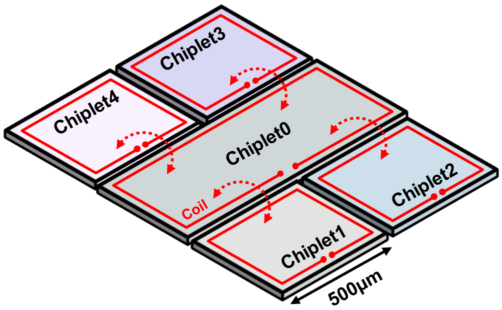

Fig. 1 Chiplet-based system using an inductively coupled wireless bus.

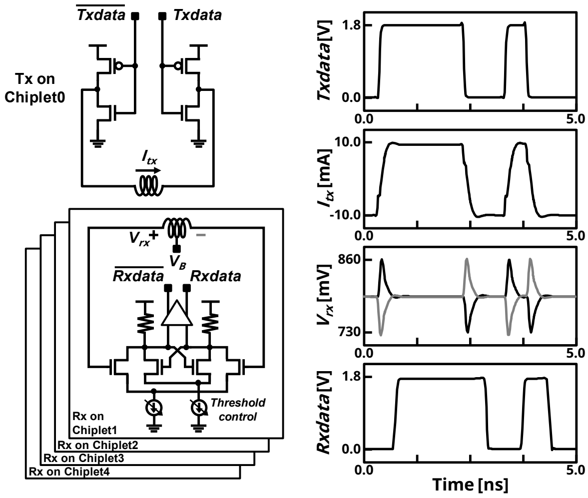

Fig. 2 Transceiver circuit diagram and operation waveforms.

2. Inductively Coupled Wireless Bus

Fig. 2 shows the transmitter and receiver circuits used for the wireless bus and their operation waveforms. NRZ (non-return-to-zero) data is transmitted without modulation. The transmitting coil is driven by an inverter circuit. At the time of data transition, the direction of the flowing current is switched, and accordingly, a pulse-like voltage is induced in receiving coils on peripheral chips. In a receiving circuit, the pulse-like voltage is amplified and restored to the original NRZ signal by a hysteresis comparator.

Fig. 3 shows the results of evaluating the change in mutual inductance according to the shape of the rectangular coil by electromagnetic field simulation. As a tool for electromagnetic field simulation, we used Momentum from Keysight. S-parameters are acquired by creating models of coils and silicon substrates on simulation tools and performing electromagnetic field simulations. The mutual inductance is determined by fitting the obtained S-parameters to a lumped-parameter equivalent circuit of coils.

The square coil using on the simulation has 1 mm of diameter and the number of turns of each coil is 2. The coil diameter and the communication distance between the coils satisfy the condition D/X = 8. The results in Fig. 3 (a) show the change in mutual inductance when the side D_w is shortened. As can be seen from the results, even when D_w is half of D_h, the mutual inductance is about 85% of that when $D_w/D_h = 1$, and the change of the mutual inductance is relatively small.

On the other hand, the results in Fig. 3 (b) show the

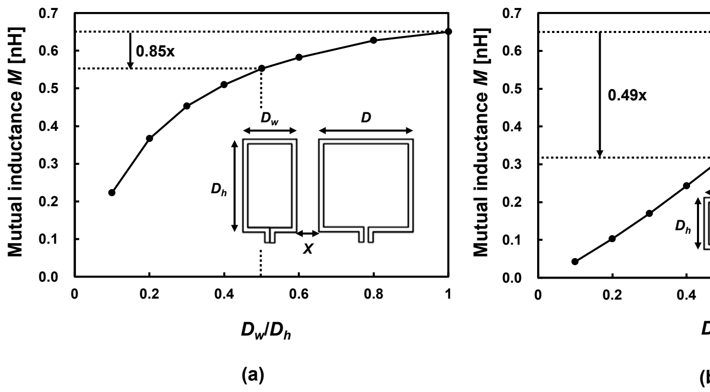

Fig. 3 Shape dependence of mutual inductance of rectangular coils (a) adjacent side is long, (b) adjacent side is short.

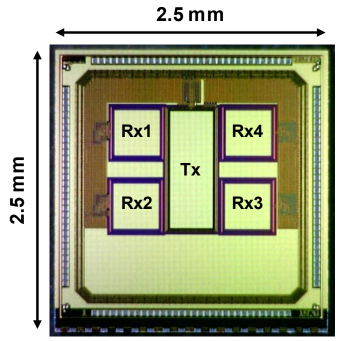

Fig. 4 Die photograph.

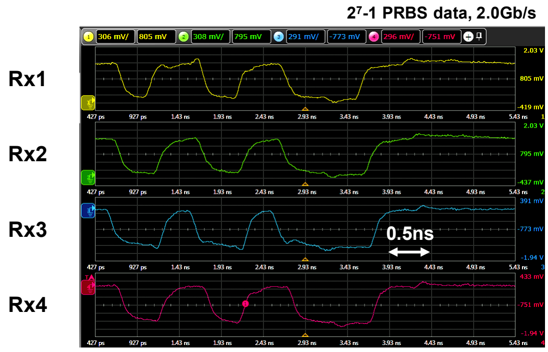

Fig. 5 Bus communication.

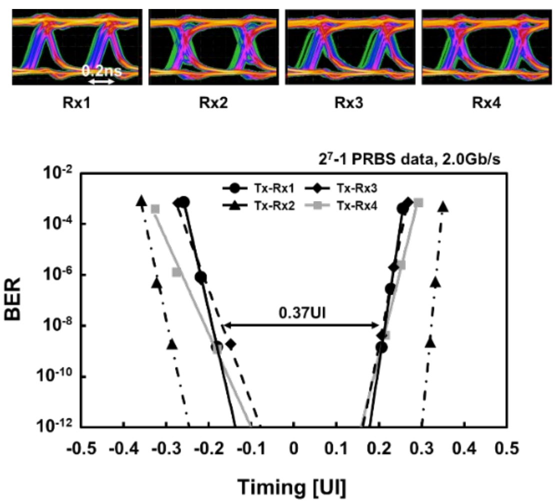

Fig. 6 Measured eye diagram and bathtub curve.

change in mutual inductance when the side closest to the adjacent coil (D_h) is shortened. The mutual inductance decreases linearly as the side ratio D_h/D_w decreases, and when D_h becomes half of D_w, the mutual inductance becomes about 49% of that when $D_h/D_w = 1$.

As can be seen from the results, since the adjacent sides strongly contribute to the coupling, the mutual inductance decreases gradually when the side perpendicular to the adjacent side is shortened. When the adjacent side itself is shortened, the mutual inductance is linear decreases.

3. Measurement Results

A test chip is designed and manufactured in 0.18 μm CMOS technology (Fig. 4). A 1.2 mm×500 μm transmitting coil and 500 μm×500 μm receiving coils are arranged on a 2.5 mm square chip. The number of turns of each coil is 2. The communication distances are 25 μm, 31.5 μm, 42 μm, and 50 μm, and the conditions are D/X = 10, 12, 16, and 20, respectively.

Fig. 5 shows the operation waveforms of bus communication. The transmitter circuit receives 2.0 Gb/s 2^7-1 PRBS (pseudo-random bit sequence) input data, and the data is transmitted to all the peripheral receiving coils via horizontal inductive coupling. The BER (bit error rate) is $<10^{-12}$. The power consumption is 18.6 mW for the transmitter circuit and 6.7 mW for the receiving circuit.

Fig. 6 shows the eye pattern and the bathtub curve obtained by the measurement. It is confirmed that the data is correctly transferred to each coil, and the timing margin is wide of 0.37 UI under the condition of BER = 10^{-8}.

4. Conclusions

In this work, wireless bus communication technology for chiplets is evaluated by simulation and measurement of a test chip. The test chip fabricated in 0.18 μm CMOS technology achieves 2.0 Gb/s high-speed bus communication with high reliability of BER$<10^{-12}$.

Acknowledgements

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