An Inductively Coupled Wireless Bus for Chiplet-Based Systems

Junichiro Kadomoto, Satoshi Mitsuno, Hidetsugu Irie, and Shuichi Sakai

The University of Tokyo, Tokyo, Japan
E-mail : kadomoto@mtl.t.u-tokyo.ac.jp

Abstract - A wireless bus for inter-chiplet communication is presented. Utilizing horizontal inductive coupling of on-chip coils, wireless connection between chiplets are established. A test chip prototyped in 0.18 µm CMOS confirms 2.0 Gb/s bus communication between horizontally arranged coils with BER of less than 10^{-12}.

I. Introduction

Embedded computer systems are becoming embedded into all our lives with the miniaturization and reduction of the power consumption. Among many 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 present a chiplet-based system utilizing wireless bus (Fig. 1). On-chip coils are formed along the outer periphery of each chip, and adjacent chips are wirelessly connected. This enables to construct embedded systems with various chip configurations, various shapes at low cost.

On the proposed system, data transmitted by one chip is broadcast 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. Although vertical bus communication between stacked chips has been investigated [3], horizontal bus communication has not been verified. In this paper, we show electromagnetic field simulation results of inductive coupling between rectangular coils. Furthermore, experimental results of wireless bus communication in the horizontal direction using a test chip are shown.

II. Inductively Coupled Wireless Bus for Chiplets

Fig. 2 illustrates the transmitter and receiver circuit diagram and operating waveforms. NRZ (non-return-to-zero) data is transmitted without modulation. The transmitting coil is driven by an inverter circuit. The transmitter makes a current flow in the transmitting coil in a direction according to the data. A pulse-like voltage is induced in the 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 the evaluation of the mutual inductance change as a function of the shape of the rectangular coil by electromagnetic field simulation. As a software for electromagnetic field simulation, we used Momentum from Keysight. S-parameters are acquired by creating models of coils and silicon substrates on the software and performing electromagnetic field simulations. The mutual inductance is calculated by fitting the obtained S-parameters to a lumped-parameter equivalent circuit of coils.

The size of the square coil using in the simulation is 1 mm and the number of turns of each coil is 2. The coil size and the communication distance between the coils satisfy the condition D/X = 8. The results in Fig. 3 (a) show the mutual inductance dependence on the side D_w. 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.

Besides, the results in Fig. 3 (b) show the mutual inductance dependence on the side D_h. 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 is about 49% of that when D_h/D_w = 1.

Since the adjacent sides D_h strongly contribute to the horizontal inductive coupling, the mutual inductance decreases gradually when the side D_w is shortened. When the adjacent side D_h is shortened, the mutual inductance is linear decreases.

III. Experimental Results

A test chip is designed and fabricated in 0.18 µm CMOS technology. Fig. 4 shows the test chip microphotograph. A 1.2 mm×500 µm transmitting coil (Tx coil) and 500 µm×500 µm receiving coils (Rx coil 1, 2, 3, and 4) 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 transceiver. 2.0 Gb/s 2^7-1 PRBS (pseudo-random bit sequence) data are used as a test data pattern. The data is transmitted to all the receiving coils via horizontal inductive coupling. The BER (bit error rate) of less than 10^{-12} is confirmed. The power consumption is 18.6 mW for the transmitter circuit and 6.7 mW for the receiving circuit.

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

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IV. Summary and Conclusions

Wireless bus communication technology for chiplet-based computers is evaluated by simulation and measurement of a test chip. Experimental results confirm 2.0 Gb/s high-speed bus communication with high reliability of BER<10^{-12}.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Numbers JP19H04076 and JP19J13974.

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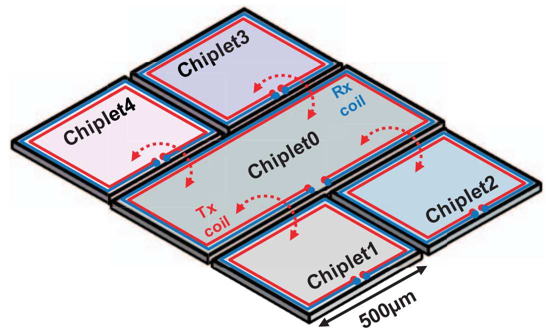

Fig. 1. Chiplet-based computer using an inductively coupled wireless bus.

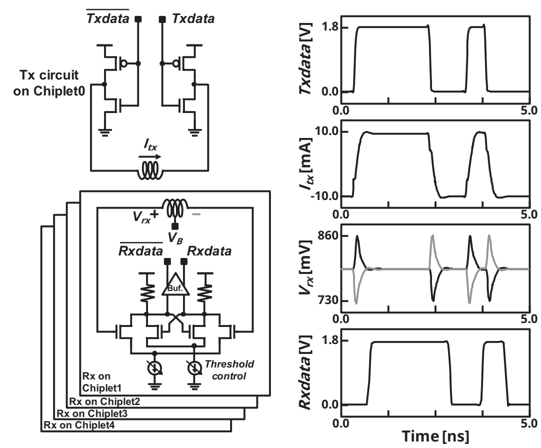

Fig. 2. Transceiver circuit and operating waveforms.

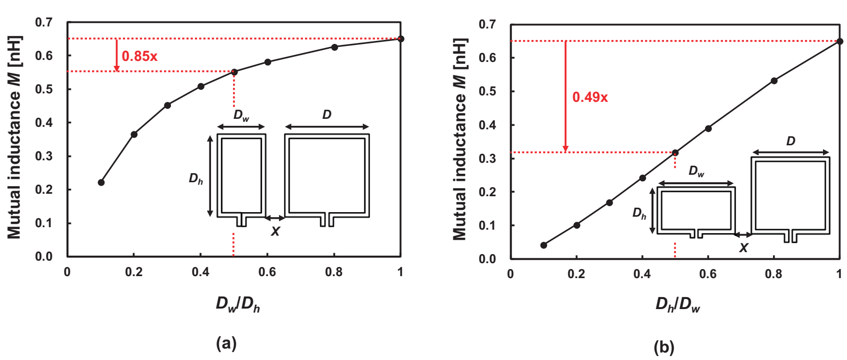

Fig. 3. Mutual inductance of rectangular coils (a) adjacent side is long, (b) adjacent side is short.

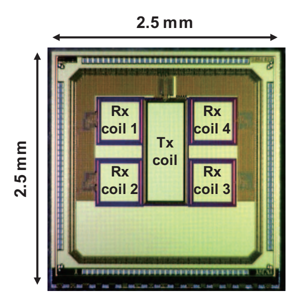

Fig. 4. Chip micrograph.

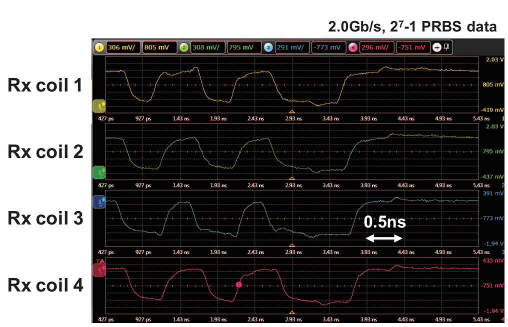

Fig. 5. Bus communication between coils.

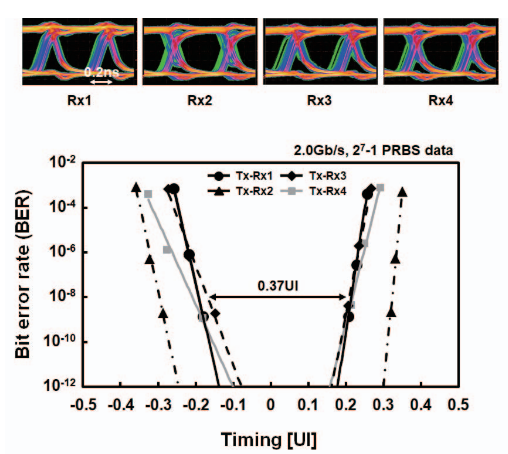

Fig. 6. Measured eye and bathtub curve.