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Electromagnetic Interference and Susceptibility in Inductive-Coupling Link

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1. Introduction

This paper proves the Electro Magnetic Compatibility of an inductive-coupling link which provides one of the solutions for System in a Package (SiP). The inductive-coupling link is a chip to chip communication system using magnetic field generated by on-chip inductor. Thus we have to ensure that the magnetic field doesn't interfere with peripheral circuit or environment (EMI: Electromagnetic Interference) and that inductive-coupling link doesn't have a susceptibility of electromagnetic noise (EMS: Electromagnetic Susceptibility). In this work, we verify Electromagnetic Compatibility (EMC) of inductive-coupling link with experiment using test chips and prove that the inductive-coupling link has sufficient EMC.

2. Inductive-Coupling Link

Inductive-coupling link is a communication method using magnetic field [1]. As shown in Fig. 1, there are coils manufactured by metal wires on the chips. We can transmit and receive digital data "0" and "1" by switching the direction of current I_{TX} to the coils, which also switch the direction of magnetic field H and received voltage V_{RX}. Because inductive-coupling link generates and detects magnetic field, we have to consider the influence of magnetic field on surrounding environment and the tolerance to the influence of the surrounding electromagnetic noise.

3. EMI Measurement

Fig. 2 shows the method and the picture of EMI measurement respectively. As shown in Fig. 2, there are arrays which are consisted of 8x8 coils on the chip and we can drive the 1-4 arrays arbitrarily [1]. The diameter of the coils which construct arrays is 29μm and the pitch of the coils is 30μm. All the input data are "0", thus the current direction passing the coils is same and the magnetic field strength becomes strongest. So we can equivalently consider an array as the coil which has 240μm diameter. N arrays are equivalently a 240μm x 240N μm coil. Operating frequency of the chip is 900MHz and Energy consumption is 2.28pJ/bit. The magnetic field probe detects the magnetic field generated by equivalent coils and outputs received voltage to the spectrum analyzer.

Because of the measurement environment, the probe could only detect the magnetic field near the chip. So we evaluated the measurement results as following.

Let us define the diameter of the coil d, the distance from the coil r, and the wave length of magnetic field λ as shown in Fig. 3. The field is constant where $r << d$ (near field), proportional to $1/r^3$ where $d < r < \lambda/2\pi$ (Fig. 3 (a), proportional to $1/r$ where $\lambda/2\pi < r$ (far field, Fig.3 (b)) [2]. In $d < r < \lambda/2\pi$, we confirmed the correspondence of measured and calculated result, and predicted the magnetic field in $\lambda/2\pi < r$.

Fig. 4 shows calculated and measured electric field strength generated by one array and four arrays when the height above the chip z_0 is changed. The magnetic field is converted to the electric field to compare with regulated electric field strength. The measured magnetic field is conformed with calculated one near the chip. And at the distance 10m, at which the electric field strength is regulated by CISPR22 or VCCI [3], calculated electric field is 21dBμV/m/$\sqrt{\text{MHz}}$ smaller than regulated field when 256 channels are operated.

Let us discuss how large we can extend the diameter of the equivalent coil. In this work, we measured the strongest case of magnetic field. But the probability of the strongest case rarely occurs. The probability that channels transmit "1" or "0", in other words "+H" or "-H", is following binomial distribution. The standard deviation of magnetic field is proportional to the square root of channel number. So the standard deviation of 256 channels is $8\sqrt{2}$ channels. Thus the statistical magnetic field strength of 256 channels is 21 dBμV/m/$\sqrt{\text{MHz}}$ lower than the worst case. So we have 42dB margin from regulated field strength in total. If we design coils with 30μm of channel pitch, we can increase the number of coils up to 4064256 channels keeping on the right side of the law. This number of coils is equivalently 2.02cm of diameter coil.

4. EMS Measurement

Fig. 5 shows the method and the setup of EMS measurement. The measurement is carried out in anechoic chamber. We radiated electromagnetic wave to the chips during the inductive-coupling link are communicating. The direction of magnetic field is conformed to the direction of communication direction. The data rate is 1Gb/s, so the frequency of electromagnetic wave is 1GHz. The operating voltage of the chips is 1.8V. But in this voltage, we achieved BER<10^{-12} under the 120V/m of electric field strength, which is the maximum strength in this measurement facility can radiate. And it is about 4 times stronger than that car antenna radiates [4]. As shown in Fig. 6, the effect of electromagnetic wave can only be seen in much lower voltage than operating voltage. So we confirmed that inductive-coupling link has sufficient tolerance to EMS.

5. Conclusion

We can design 4 millions of coils or equivalently 2cm of coil for inductive-coupling link without worrying about EMI. The tolerance of inductive-coupling link to EMS is sufficient. So we can use inductive-coupling link without worrying Electromagnetic Compatibility.

Acknowledgements

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References

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[2] H. Ishikuro et al." Wideband Inductive-coupling Interface for High-performance Portable System", *IEEE* 2007 *Custom Integrated Circuits Conference* (*CICC*) pp.2-3-1~2-3-8

[3] VCCI Council "V-3/2009.04 Normative Annex 1 Technical Requirements", pp. TECH1, TECH7

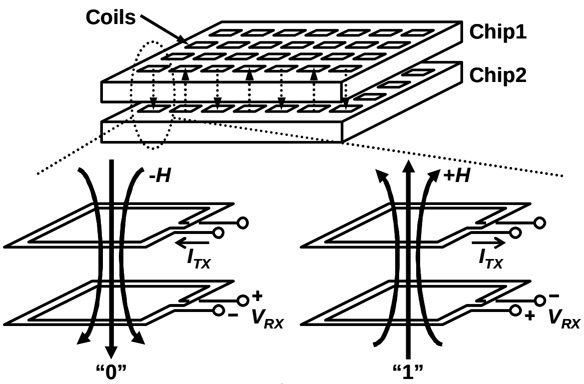


Fig. 1. Principle of Inductive Coupling.

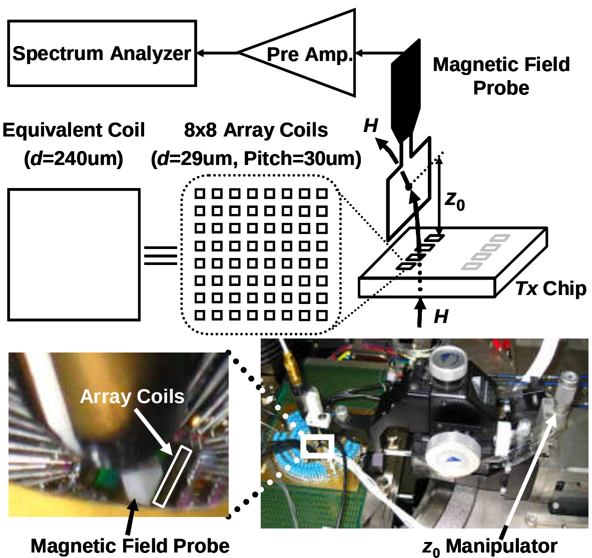
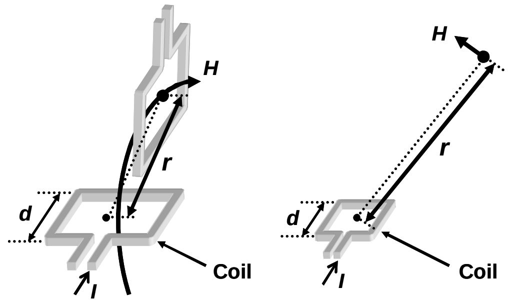


Fig. 2. Measurement of EMI.



(a) $r < \lambda/2\pi$ (b) $\lambda/2\pi < r$

Fig. 3. Analysis of Magnetic Field.

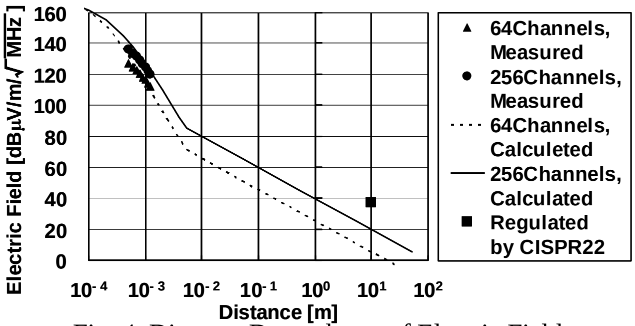


Fig. 4. Distance Dependency of Electric Field

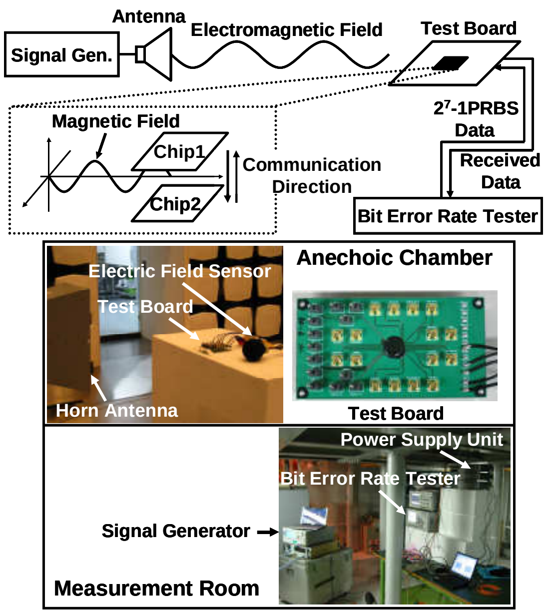


Fig . 5. Measurement of EMS.

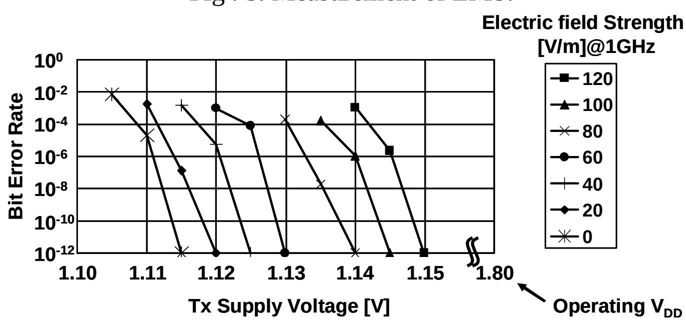


Fig. 6. Measured BER under radiation.