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Wireless Interconnection on Si using Integrated Antenna

A.B.M.H. Rashid, S. Watanabe and T. Kikkawa

Research Center for Nanodevices and Systems, Hiroshima University
Phone: +81-824-24-6265, Fax:+81-824-22-7185, E-mail : harun@sxsys.hiroshima-u.ac.jp

1. Introduction

Parasitic resistance, capacitance and inductance of conventional wiring remain the primary obstacle to increase clock frequency in ULSI. Although tremendous works are going on to reduce resistivity of conductors and dielectric constant of interlayer dielectric materials, this approach may soon encounter fundamental material limits [1]. Recently a revolutionary approach of intra-chip wireless clock signal transmission using integrated antenna have been proposed [2]-[4]. However, detail study of wireless clock transmission in Si is still in its infancy. This paper examines the basic characteristics of integrated antenna on Si and the effect of interference generated by interconnect metal lines on their performance. The measured characteristics are compared with simulated results obtained by using a high frequency structure simulator employing 3-D finite element method.

2. Fabrications and Measurement

Figure 1 shows the conceptual diagram of the clock distribution system. Antenna test structures were fabricated on 260 μm thick Si wafer with a resistivity of 10 Ω-cm using 1 μm field oxide and a 1 μm thick aluminum layer for antenna formation as shown in Fig. 2. The setup for S-parameter measurement is shown in Fig. 3. It consists of HP8510C Vector Network Analyzer, 180° Hybrid Couplers (6.0-26.5 GHz), Signal-Signal probes and a probe station. Wafers were measured on a block of wood (2.6 mm thick) on the metal chuck of the probe station. The relative dielectric constant of wood was measured as 2.15 at 1 GHz.

3. Results and Discussion

Figure 4 shows the measured return loss (S_{11}) of dipole antenna versus antenna length (L). In Si a 3 mm long dipole should give a resonance peak at 14.5 GHz. However since a part of the electromagnetic wave travels through the air and the wood layer the resonance peak is shifted at about 22 GHz. The power transmitted to the receiving antenna is calculated from the scattering parameters using antenna transmission gain (G_a) as derived form *Frii's* transmission formula [2]. Figure 5 shows G_a versus frequency with antenna length as a parameter. At 20 GHz the 3 mm long dipole has 10 dB higher gain than the 2 mm dipole. Figure 6 shows that the phase delay has almost linear relationship with frequency, which illustrates that the signal coupling between the receiving and transmitting antenna occurs through wave propagation rather than simple RC coupling. Figure 7 shows the variation of G_a versus frequency with antenna separation distance (d) as a parameter. The gain decreases with d. For a distance of up to 7.5 mm antenna pair with a length of 2mm gives a gain which is above –50 dB at 20 GHz. This indicates the feasibility of using such dipole antenna pair in an area around a diameter of 1.5 cm. The variation of gain due to the rotation of the receiver with respect to the transmitter (θ) is an important factor for the practical implementation of the system. Figure 8 shows G_a versus frequency with θ as a parameter. As can be seen from the graph, for θ up to 60 degree both the simulated and the measured data shows no significant reduction in gain. However, when the rotation angle is 90 degree the measured result shows a 13 dB reduction in gain where as simulation shows a 57 dB reduction. This indicates that besides radiation (space wave) a part of power is also transmitted by other mechanism such as surface wave [2].

To study the effect of interference from interconnect metal lines systematically, transmission gain has been measured and simulated by placing metal lines between the transmitter and the receiver and by varying their numbers (n). Figure 9 shows that the transmission gain decreases by about 10 dB in presence of metal lines when the metals are placed normal to antenna radiation direction. However, as shown in Fig. 10, this reduction in gain depends on the maximum length of the individual metal lines and is negligible when the metal lengths are limited to one fourth of antenna length. Again, the measured data in Fig. 11 shows that the reduction in gain does not depend on the distance of the interconnect lines from the transmitter or receiver for up to 10 μm. On the other hand, as shown in Fig. 12 when the metal lines are placed parallel to the antenna radiation direction simulated results show that an improvement in gain occurs which is more prominent in the low frequency region.

4. Conclusion

Basic characteristics of integrated antenna on Si showed their feasibility to use for intra-chip wireless interconnections at frequencies ~20 GHz or higher. When interconnect metal lines are placed normal to the antenna radiation direction a reduction of transmission gain is observed. This reduction in gain is dependent on the maximum length of the individual metal lines and is negligible when the length of the metal lines are limited to one fourth of antenna length. On the other hand, when the metal lines are placed parallel to the radiation direction an increase in gain occurs. This gain improvement is particularly prominent in the low frequency region.

Acknowledgements
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References

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[2] Kihon Kim, Huyn Yoon and Kenneth K. O., IEDM Tech. Dig., pp. 485-488, December 2000.

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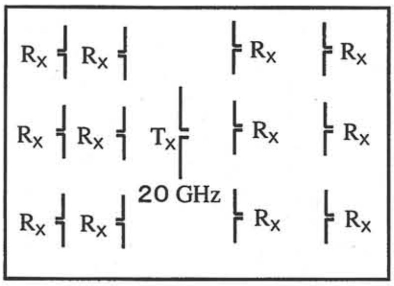

Fig. 1 Conceptual diagram of the wireless clock distribution system. Tx = Transmitter, Rx = Receiver.

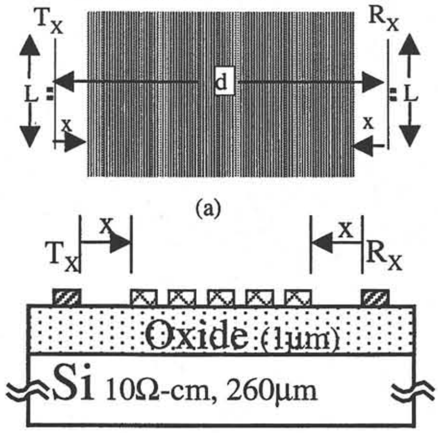

Fig. 2 (a) Layout and (b) Schematic cross-sectional diagram of dipole transmitter-receiver with interconnect metal lines in-between.

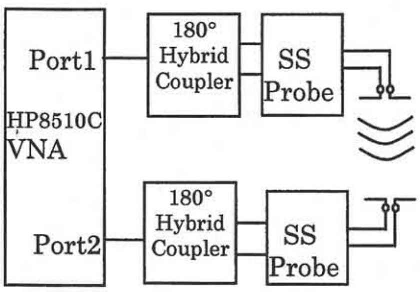

Fig. 3 Experimental set-up for on chip antenna characterization.

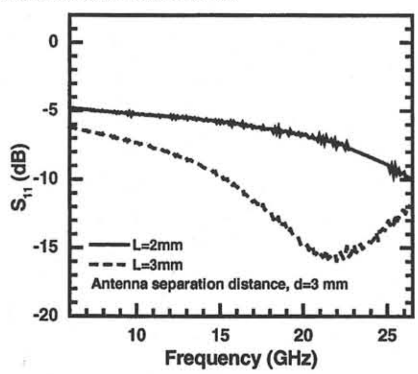

Fig. 4 Measured return loss (S_{11}) versus frequency with antenna length (L) as a parameter. The dipole transmitter to receiver distance was 3mm.

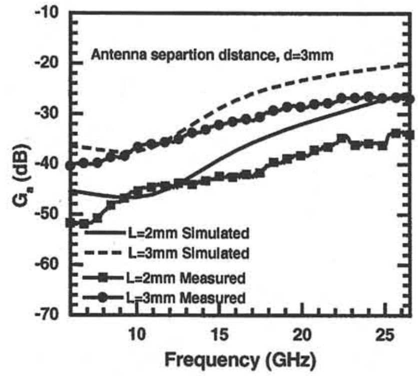

Fig. 5 Transmission gain (G_a) versus frequency with antenna length (L) as a parameter. Measured and Simulated data are compared.

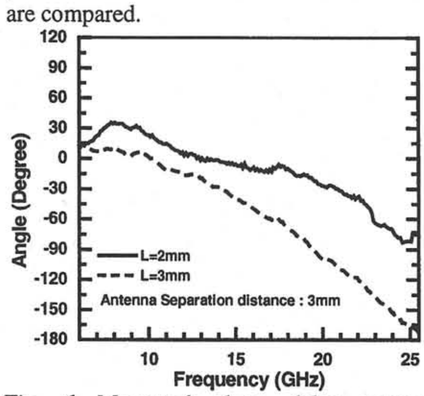

Fig. 6 Measured phase delay versus frequency with antenna length as parameter.

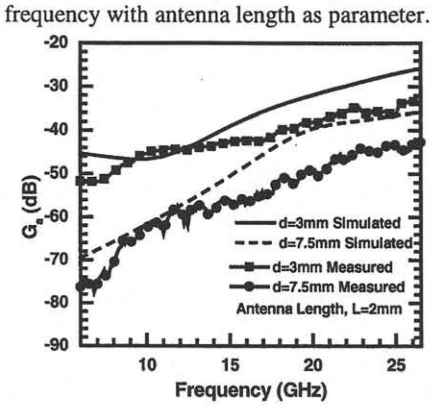

Fig. 7 G_a versus frequency with antenna separation distance (d) as a parameter. Measured and simulated data are compared.

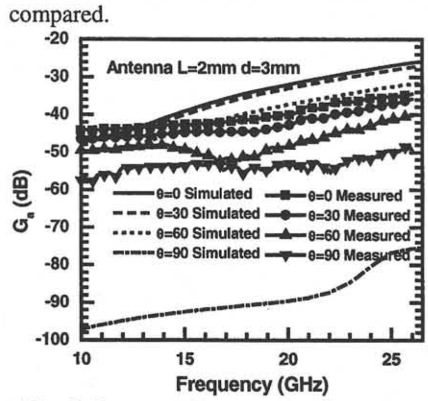

Fig. 8 G_a versus frequency with receiver rotation angle (θ) as a parameter.

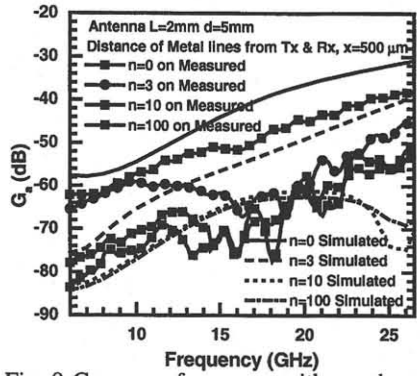

Fig. 9 G_a versus frequency with number of metal lines (n) placed normal to the antenna radiation direction as parameter.

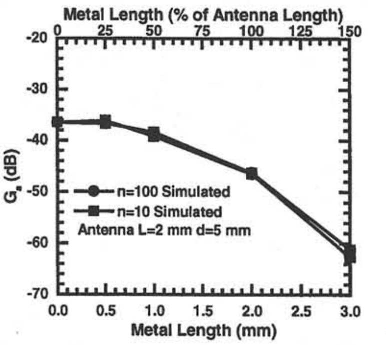

Fig. 10 G_a versus length of interconnect metal lines at frequency 20 GHz with number of metal lines (n) as a parameter.

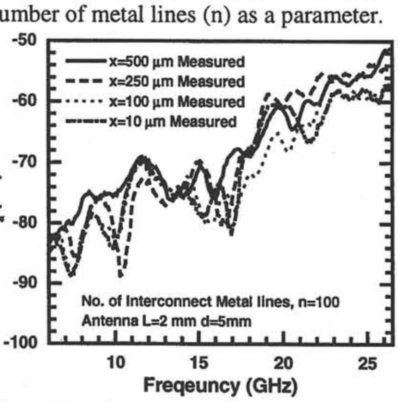

Fig. 11 G_a versus frequency with distance of metal lines from the transmitter-receiver (x) as a parameter.

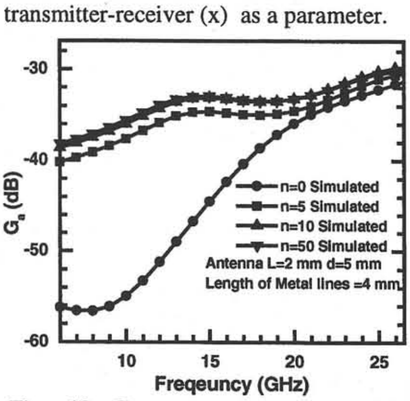

Fig. 12 G_a versus frequency with number of interconnect metal lines (n) placed parallel to the antenna radiation direction as a parameter.