Data Transmission Characteristics of Integrated Linear Dipole Antennas for UWB Communication in Si ULSI

K. Kimoto, N. Sasaki, M. Nitta and T. Kikkawa

Research Center for Nanodevices and Systems, Hiroshima University
Phone: +81-082-424-6265, Fax: +81-082-424-3499,
E-mail: kimoto@sxsys.hiroshima-u.ac.jp, kikkawa@sxsys.hiroshima-u.ac.jp

1. Introduction

According to the scaling rule of silicon ultra-large scale integrated circuits (ULSI)[1], metal-oxide semiconductor transistor performance can be improved in terms of operation frequency and power consumption by reducing the feature sizes[2]. However, global clock frequency of ULSI will be limited at 4 GHz because of parasitic RC (resistance:capacitance) delay due to the increase of interconnects and interlayer dielectrics with reducing the feature sizes[3].

In order to overcome this problem, a new concept of wireless interconnection using Si integrated antennas operating at microwave frequency has been proposed[4-7]. Figure 1 shows a concept of wireless interconnects using integrated antennas fabricated in Si ULSIs. Recently, ultra-wideband (UWB) communication has been received more attention for short distance signal transmission[8]. However, one of the issues for on-chip Si integrated antennas is transient response of the transmitting and receiving antennas fabricated on Si substrates. In this paper the transient response and the bit error rate (BER) in UWB communication using Si integrated antenna was investigated.

2. Fabrication method and Measurement

P-type (100) Si wafers with resistivities from 10 to 2290 Ω·cm and thickness of 260 μm were prepared for substrates. The surface of Si was oxidized to form 0.3 μm thick field SiO_2. 1.0 μm thick aluminum was deposited on the SiO_2 layer by DC magnetron sputtering and the antenna patterns were formed by electron beam lithography. 10 μm wide and 6 mm long linear dipole antennas were fabricated on SiO_2 as shown in Fig. 2. Antenna length (L) was fixed as 6 mm and the distance between transmitter and receiver antennas (d) changed from 1 to 10 mm.

Figure 3 showed measurement set-up for BER of UWB signal transmission by integrated linear dipole antennas. It consists of Agilent 4902B Serial Bit Error Rate Tester (BERT), Picosecond impulse forming networks (IFN), Agilent 86100C sampling oscilloscope and a microwave probe station. The BER measurement was carried out as follows. Pseudo random binary signals generated by Serial BERT were transformed to Gaussian monocycle pulse trains by two IFNs. 180º hybrid couplers were inserted between the dipole antenna and the IFN. The Gaussian monocycle pulses were transmitted and received by linear dipole antennas and recorded by the sampling oscilloscope. The received signals were recovered as binary data and compared with the generated signal to obtain the BER.

3. Results and Discussion

Gaussian monocycle pulse as a transmitting signal was shown in Fig. 4. Its pulse width was approximately 70 ps and its center frequency and its bandwidth were approximately 15 GHz and 20 GHz, respectively. Figures 5 and 6 showed transmitted pseudo random binary pulse trains and the received pulse trains, respectively.

The procedures for obtaining BER were shown as follows. Figure 7 shows that received Gaussian monocycle pulses were synchronized with clock signal and integrated. Then, the computation of sample-hold to integrated signals was shown in Fig. 8. When integrated signals come in, the binary signal rise for positive pulse and fall for negative pulse. The peak values are held for 1 clock cycle till next pulse comes in. After carrying out the operation of comparator, binary signals were recovered. Figure 9 shows the generated and recovered signals. Figure 10 shows the effect of horizontal distance on the BER. The BER of 32,767 bit pseudo random binary sequence (PRBS) was 3.1×10^{-5} for 1 mm distance between antennas on 10 Ω·cm resistivity Si substrate, when data rate was 7 Gbps. Figures 11(a) and 11(b) show the effect of Si substrate resistivity on the BER for 5 Gbps and 13.5 Gbps, respectively. The lowest BERs were achieved as 4×10^{-3} and 1.6×10^{-2} for data rates of 5 Gbps and 13.5 Gbps, respectively. The BER increased with increasing the distance between transmitting and receiving antennas.

4. Conclusion

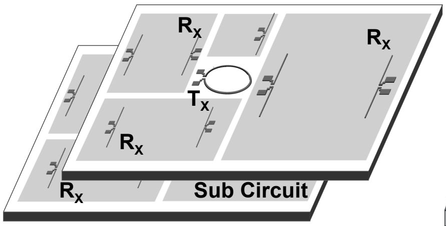
Bit error rates of UWB signals transmitted and received by Si integrated antennas for ULSI on-chip wireless interconnection were investigated. The BER of 3.1×10^{-5} was achieved for 6 mm long dipole antennas which were fabricated on 10 Ω·cm Si substrate when data rate was 7 Gbps.

Acknowledgements

This work is supported by the Ministry of Education, Culture, Sports, Science and Technology under the 21st Century COE program and the Grant-in-Aid for Scientific Research.

References

[1] R. H. Dennard et al, IEEE J. Solid-State Circuits, SC-9, 256 (1974).
[2] Y. Oku et al, Technical Digest of IEEE International Electron Devices Meeting, Dec. 2003, pp. 139-142.
[3] H. B. Bakoglu et al, IEEE Trans. Electron Devices vol. 32, pp. 903-909, May 1985.
[4] B.A. Floyd et al, IEEE J. Solid-State Circuits, Vol. 37, May 2002, pp. 543-552.
[5] A.B.M. H. Rashid et al, IEEE Electron Devices Lett. Vol. 23, Dec. 2002, pp.731-733.
[6] A.B.M. H. Rashid et al, Japanese Journal of Applied Physics, Vol. 42, No. 4B, April 2003, pp. 2204-2209.
[7] T. Kikkawa et al, Abstracts of IEEE Topical Conference on Wireless Communication Technology, Honolulu, Oct. 15-17, 2003.
[8] Norbert Daniele, Technical Tutorial, Ultra Wideband Summit 2003, 2-5 Dec. 2003.



T_x : Transmitting antenna, R_x : Receiving antenna

Fig. 1. Concept of wireless interconnect using integrated antennas in multiple Si ULSI chips.

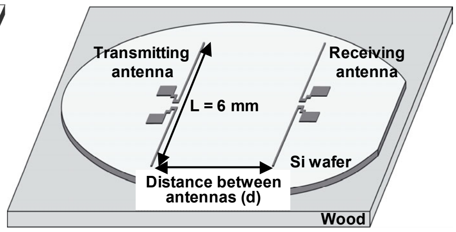


Fig. 2. Schematic diagram of Si integrated linear dipole antenna measurement sample structure.

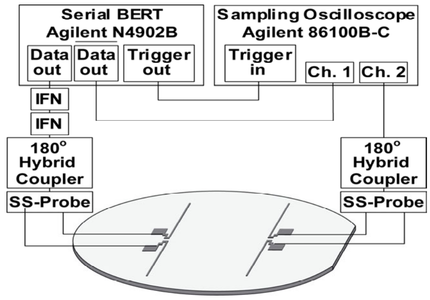


Fig. 3. Measurement set-up for bit error rate of ultra-wideband signal transmission in time domain.

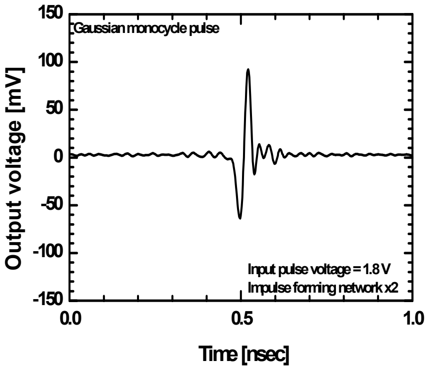


Fig. 4. A transmitting Gaussian monocycle pulse for a transmitter dipole antenna.

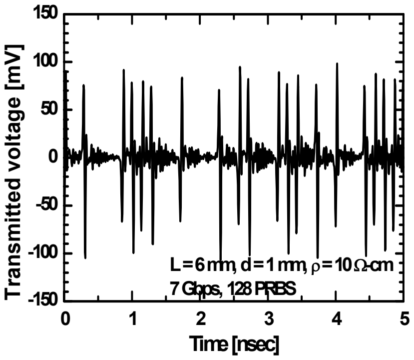


Fig. 5. Transmitted Gaussian monocycle pseudo random binary pulse trains.

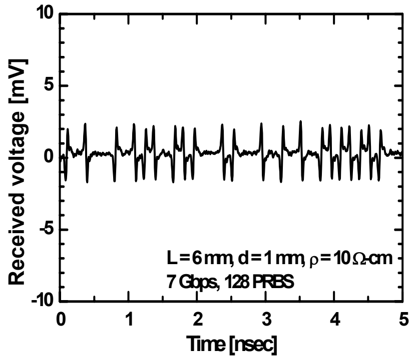


Fig. 6. Received Gaussian monocycle pulse trains by linear dipole antennas (L=6 mm, d=1 mm, ρ=10 Ω·cm).

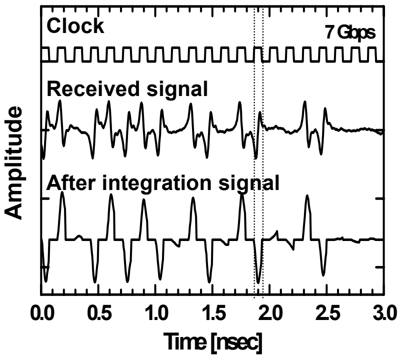


Fig. 7. Computation of integration.(Clock, received and after integration signals)

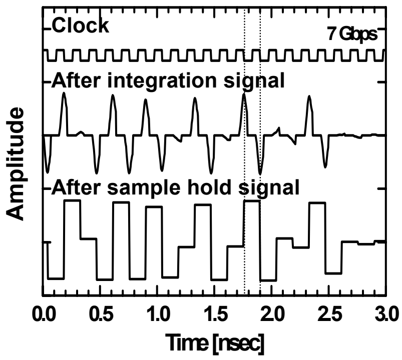


Fig. 8. Computation of sample hold and comparator. (Clock, after integration and after sample hold signals)

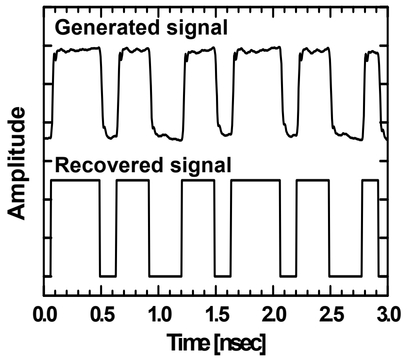


Fig. 9. Generated and recovered pseudo random signals.

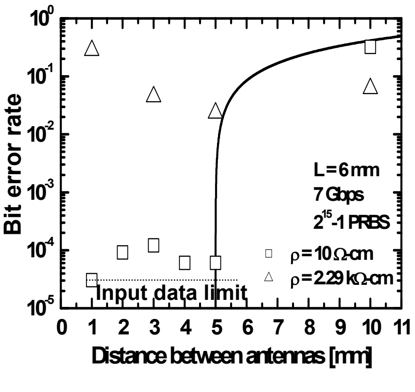


Fig. 10. Effect of distance between antennas on bit error rates of 32,767 bit pseudo random binary signals.

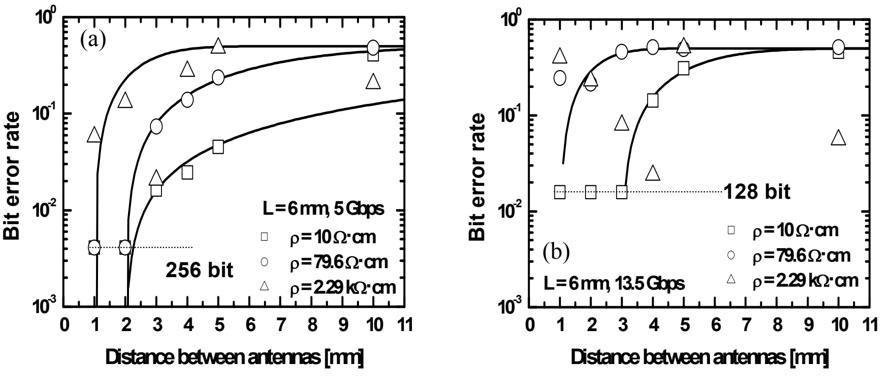


Fig. 11. Effect of Si substrate resistivities on bit error rates of 128 bit pseudo random binary signals. ((a) Bit rate = 5 Gbps, (b) Bit rate = 13.5 Gbps.)

Data Transmission Characteristics of Integrated Linear Dipole Antenna for UWB Communication in Si ULSI

K. Kimoto, N. Sasaki, M. Nitta and T. Kikkawa

Research Center for Nanodevices and Systems, Hiroshima University

1-4-2 Kagamiyama, Higashi-Hiroshima 739-8527, Japan

E-mail : {kimoto, kikkawa}@sxsys.hiroshima-u.ac.jp

Motivation

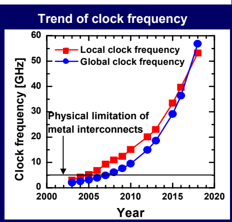
According to the scaling rule of LSI, conventional metal interconnects will limit high-speed operation of ULSI due to RC delay.

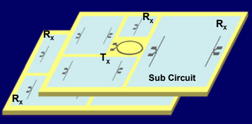
ULSI global clock frequency will be limited below 4 GHz due to RC time constants of interconnects.

⬇

Wireless interconnection could be a breakthrough technology for higher-speed operation of ULSI using Si integrated antennas.

Trend of clock frequency

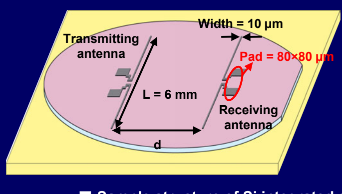




T_x :Transmitting antenna, R_x :Receiving antenna

Concept of Wireless Interconnects on ULSI - Chip

Si Integrated Dipole Antenna Structure and Fabrication Process



: SiO_2 = 0.3 μm
: Si = 260 μm
: Wood = 2.6±0.1 mm
L : Antenna length
d : Horizontal distance between antennas
ρ : Si substrate resistivity

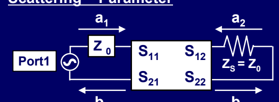
■ Sample structure of Si integrated dipole antenna

■ Fabrication process flow

1. Oxidation	Thermal oxide (thickness : 0.3 μm)
2. Aluminum sputtering	DC magnetron sputtering (thickness : 1.0 μm)
3. Lithography	Electron beam lithography (HL700)
4. Patterning	Wet etching
5. Photoresist stripping	Remover

Measurement Set-up (Frequency Domain)

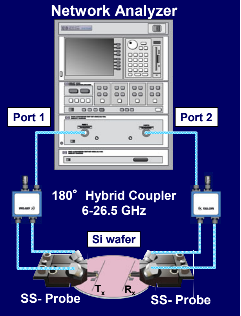
Scattering – Parameter



$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

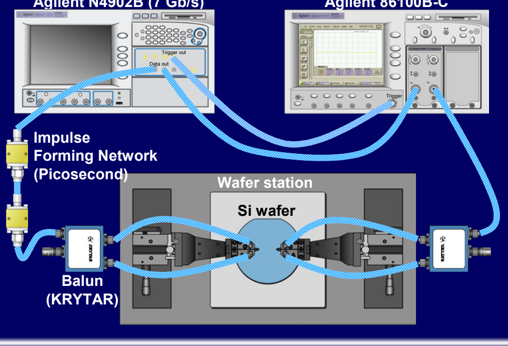
a_i - Incident wave
b_j - Reflected wave

$$S_{ii} = \frac{b_i}{a_i}\Big|_{a_j=0} \qquad S_{ij} = \frac{b_i}{a_j}\Big|_{a_i=0}$$



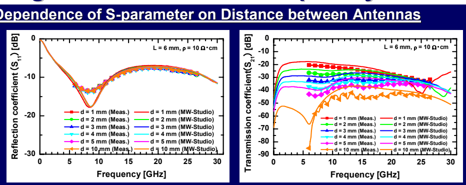
T_x:Transmitting antenna
R_x:Receiving antenna

Measurement Set-up (Time Domain)

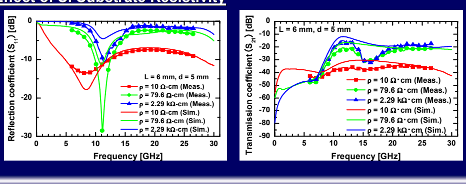


Transmission Characteristics of Si Integrated Antenna in Frequency Domain

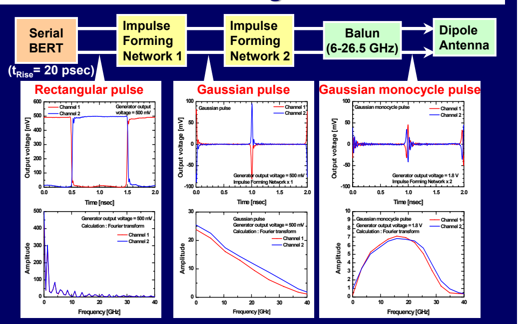
■ Dependence of S-parameter on Distance between Antennas



■ Effect of Si Substrate Resistivity



Characteristics of Transmitting UWB signal

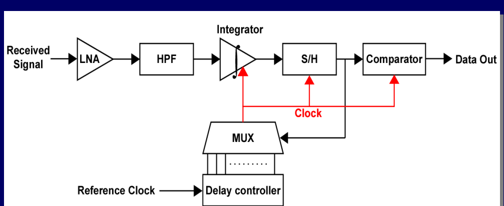


■ Characteristics of Gaussian monocycle pulse

Pulse width = 70 psec, Center frequency = 15 GHz, Bandwidth = 20 GHz

Bit Error Rate in UWB Signal Transmission

■ Proposed Circuits for Bit Error Rate Computation

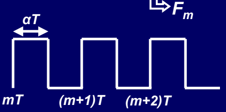


Process Steps for Bit Error Rate Computation

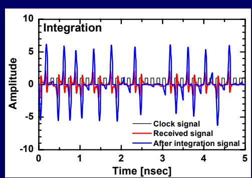
1. Integration

Received Gaussian monocycle pulse ($r(t)$) is synchronized with clock signal and integrated.

$$\langle F \rangle = \frac{1}{n}\sum_{m=0}^{n-1}\int_{mT}^{(m+\alpha)T}|r(t-\Delta t)|dt \Rightarrow F_m$$



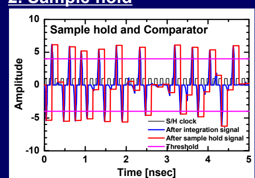
Clock signal



$r(t)$: Received signal
T : Chip rate
α : Duty cycle ($0<\alpha\leq0.5$)
n : Number of bit

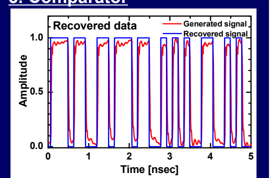
Δt is defined as synchronization timing between received and clock signals. Average value of integration $\langle F \rangle$ becomes the maximum when synchronization is accomplished.

2. Sample hold



When Gaussian pulse F_m comes in, the binary signal rises for positive pulse and falls for negative pulse. The peak values are held for 1 clock cycle and change when next pulse comes in.

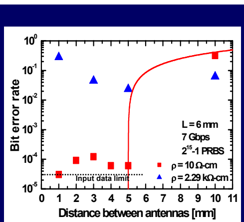
3. Comparator



When $F_m > V_{th}$, the binary data 1 is recovered.
When $F_m < -V_{th}$, the binary data 0 is recovered.
When $|F_m| < V_{th}$, the previous data are held.

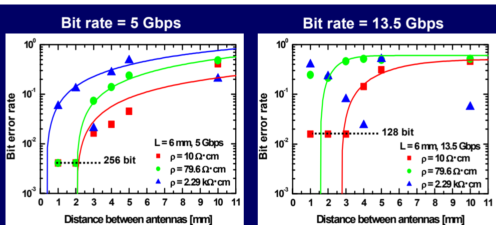
Non return zero binary signals are recovered.

Effects of Distance between Antennas on Bit Error Rate



■ The bit error rate of 32,767 bit pseudo random binary sequence (PRBS) was 3.1×10^{-5} for 1 mm distance between antennas on 10 Ω·cm resistivity Si substrate, when data rate was 7 Gbps.

Effect of Si Substrate Resistivity on Bit Error Rate



■ The lowest bit error rates of 128 bit PRBS were achieved as 4×10^{-3} and 1.6×10^{-2} for data rates of 5 Gbps and 13.5 Gbps, respectively.

■ The bit error rate increased with increasing the distance between transmitting and receiving antennas.

Conclusions

1. Bit error rates of UWB signals transmitted and received by Si integrated antennas for ULSI on-chip wireless interconnection were measured and calculated.
2. UWB pulse trains of 32,767 bit pseudo random binary signals with data rate of 7 Gbps were recovered with bit error rate of 3.1×10^{-5} successfully.

Acknowledgement

This work is supported by the Ministry of Education, Culture, Sports, Science and Technology under the 21st Century COE program and the Grant-in-Aid for Scientific Research.