On-Chip Wireless Signal Transmission using Silicon Integrated Antennas

K. Kimoto, M. Nitta, N. Sasaki 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

Background

Realization of 3D packaging of ULSI circuits for high integration and higher-speed operation.

Issue

Development of interconnect technology between chips.

Solution

Wireless interconnect using on-chip integrated dipole antennas.

Advantages

High speed data transmission by EM wave propagation.

Multiple access by use of UWB communication.

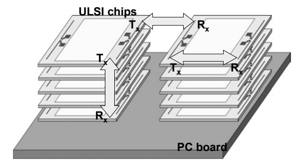
Fabrication by conventional LSI process.

Close range communication.

Si Integrated Antenna

Objective

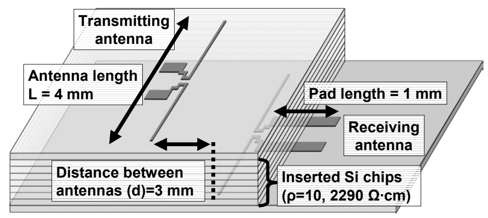
1. Transmission characteristics of integrated dipole antennas for stacked Si chips.
2. Interference and suppression by 5.2 GHz WLAN for UWB communication using integrated antennas.
3. Equivalent circuit model of Si integrated antennas.



T_x: Transmitter antenna, R_x: Receiving antenna

Conceptual diagram of intra-/inter-chip wireless interconnect, using dipole antennas integrated in multiple stacked Si ULSI chips on a PC board.

Signal Transmission through Stacked Si Chips



Antenna length (L) = 4 mm

Pad length = 1 mm

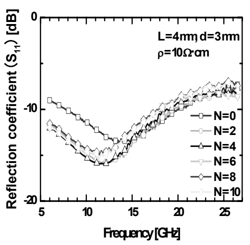
Horizontal distance between antennas (d) = 3 mm

Number of inserted Si chips (N) = 0-10

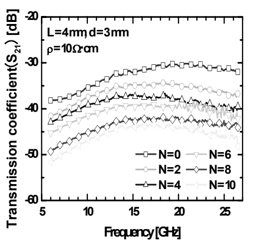
Resistivity of inserted Si chips (ρ) = 10 and 2290 Ω·cm

Transmission Characteristics in Frequency Domain

Reflection coefficient (S_{11})



Transmission coefficient (S_{21})

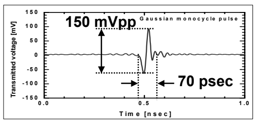


S_{11} did not changed when the number of inserted Si chips increased.

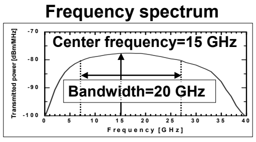
S_{21} decreased with increasing the number of inserted Si chips because of increasing lossy propagation channel through stacked Si chips.

Transmitted and Received Waveform of UWB Signal

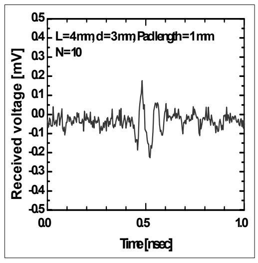
Transmitted waveform



Frequency spectrum



Received waveform

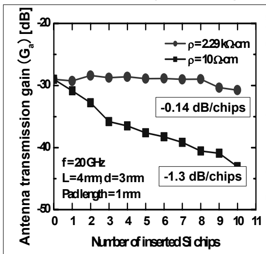


Gaussian monocycle pulse transmitted as UWB transmitting signal.

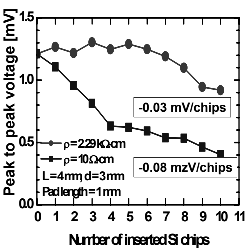
Gaussian monocycle pulse transmitted and received successfully through 10 Si chips with peak-to-peak voltage of 0.4 mV.

Dependences of Gain and Vpp on Number of Stacked Si Chips

Sinusoidal wave (f=20 GHz)

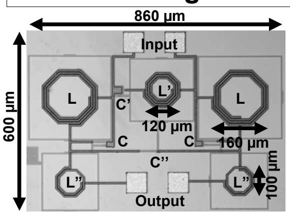


Gaussian monocycle pulse

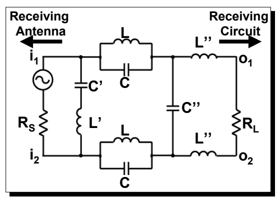


Attenuation rates improved by increasing the resistivity of inserted Si chips for transmission gain of sinusoidal wave propagation and peak-to-peak voltage of received Gaussian monocycle pulse, respectively.

Integrated Notch Filter



Chip photograph



Equivalent circuit of notch filter

Device parameter	
L	3.06 [nH]
L'	1.68 [nH]
L″	0.62 [nH]
C	280 [fF]
C'	520 [fF]
C″	20 [fF]

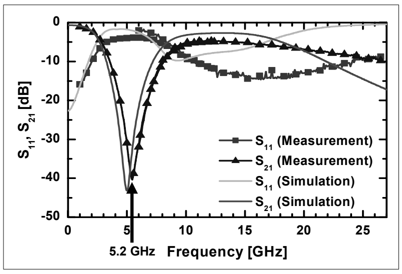
Integrated notch filter was fabricated by use of 0.18-μm CMOS technology.

This notch filter suppresses the influence of WLAN band at 5.2 GHz on UWB communication.

Two parallel L-C circuits resonate and make a notch at 5.2 GHz and a shunt series L'-C' resonance circuit enhances the notch.

L" and C" work for the impedance matching between receiving antenna and notch filter.

Transmission Characteristics of Integrated Notch Filter

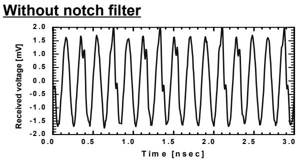


Measurement data showed good corresponding to the simulation results.

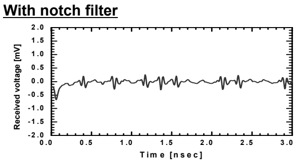
It was found that a notch was observed at 5.2 GHz and separation was approximately –40 dB.

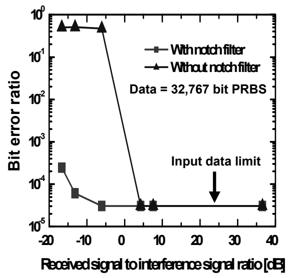
Suppression of Interference of WLAN at 5.2 GHz on UWB (Simulation)

Without notch filter



With notch filter



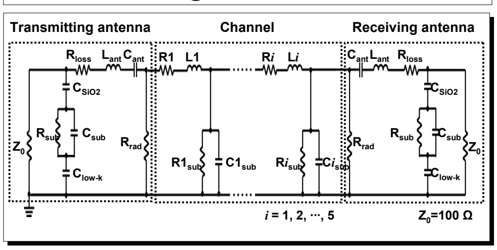


BER vs. Received signal to interference signal ratio

By use of the integrated notch filter, the interference of WLAN at 5.2 GHz was suppressed.

BER was below 3.05×10^{-5}, when received signal to interference signal ratio was over –6.05 dB.

Equivalent Circuit Model of Si Integrated Antenna



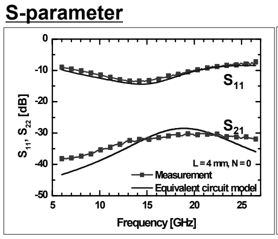
Transmitting and receiving antennas consisted of RLC (R_{rad}, C_{ant}, and L_{ant}) series resonant circuits.

Parasitic components (C_{SiO2}, R_{Si}, C_{Si}, and $C_{low\text{-}k}$) were added.

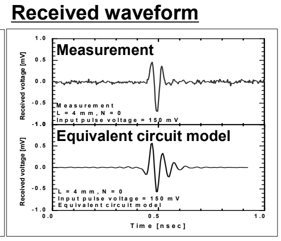
Signal propagation channel was modeled as a transmission line (Ri, Li, Ri_{sub}, and Ci_{sub}, i=1, 2, ···, 5).

Comparison Simulation Results of Equivalent Circuit with Measurement

S-parameter



Received waveform



The simulation results using the equivalent circuit model fitted well with the measurement data of S_{11} and S_{21}, respectively.

Using extracted RLC parameters and equivalent circuit model, received waveform of Gaussian monocycle pulse was simulated by HSPICE circuit simulator.

The simulation result could be reproduce the measurement data.

Conclusions

1. Gaussian monocycle pulse was transmitted and received successfully through 10 stacked Si chips with 0.4 mV peak-to-peak voltage. The attenuation was improved by inserting high resistivity Si chip.
2. Interference of WLAN at 5.2 GHz on UWB data transmission was investigated and suppressed by use of the designed notch filter integrated on Si chip.
3. Equivalent circuit model was developed for Si on-chip integrated antennas. Using the equivalent circuit model and extracted RLC parameters, received waveform could be reproduced by HSPICE simulator successfully.

Acknowledgment

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.