Dependable Wireless Solid-State Drive (SSD)

Ken Takeuchi, Chuo University
Tadahiro Kuroda, Keio University
Hiroki Ishikuro, Keio University
Objectives of Research

- Wireless SSD/Memory card and its host system
- Robust against memory cell error, contact error, ESD, EMI and waterproof
- High-speed near field wireless communication
  - Target: 10-50Gbps at 1mm distance
- Wireless power delivery with MHz load variability
  - Target: 1-3W
11 ISSCC Presentations

ISSCC 2014
- Takeuchi “Hybrid Storage of ReRAM/TLC Flash for Cloud Data Centers”
- Kuroda, Ishikuro “Electromagnetic Clip Connector for In-vehicle LAN”

ISSCC 2013
- Takeuchi “Unified Solid-State Storage”
- Kuroda, Ishikuro “A 0.15-mm-Thick Non-Contact Connector for MIPI”
- Kuroda “Inductive-Coupling Wake-Up Transceiver for Non-Contact Memory Card”
- Kuroda “Retrodirective Transponder Array with Universal On-Sheet Reference for Wireless Mobile Sensor Networks”

ISSCC 2012
- Takeuchi “Error-Prediction LDPC”
- Kuroda, Ishikuro “7Gb/s/Link Non-Contact Memory Module”
- Ishikuro “Voltage-Boosting Wireless Power Delivery System”

ISSCC 2011
- Takeuchi “Asymmetric Coding for SSD”
- Kuroda, Ishikuro “12Gb/s non-contact interface”
Dependable Memory System

- Data retention error and program disturb error become worse as the memory cell is scaled.
- ECC should be improved with the device scaling.

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Highly Dependable Memory System

- In total, >1000X reliability improvement

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Adaptively change ECC correctability (IMW2010: Dynamic Codeword Transition ECC)</td>
<td>17X</td>
</tr>
<tr>
<td>2010</td>
<td>Correct the asymmetric memory error (ISSCC2011: Asymmetric Coding)</td>
<td>20X</td>
</tr>
<tr>
<td>2011</td>
<td>Fast and Extremely Reliable LDPC (ISSCC2012: Error Predicting LDPC)</td>
<td>11X</td>
</tr>
<tr>
<td>2012</td>
<td>Unified Storage System (ISSCC2013: Riverse Mirroring)</td>
<td>32X</td>
</tr>
<tr>
<td>2013</td>
<td>Integrated Error Correction of ReRAM and Flash Memory (ISSCC 2014)</td>
<td>22X</td>
</tr>
</tbody>
</table>
Asymmetric Coding (ISSCC 2011)

- Increase “0” for Upper page and “1” for Lower page
- X20 Better Reliability

Data retention error: $V_{\text{TH}}$ decrease due to the charge leakage

Modified data1: 0 0 1 0
Modified data2: 1 1 0 1

Bit flip
Do NOT flip

Flag

Asymmetric Coding

Overhead

Modified data1: 0 0 1 0
Modified data2: 1 1 0 1

e.g. Code length: 4

(NAND Flash memories)

SSD controller

Daughter board
Error Predicting LDPC (ISSCC 2012)

- Compensate the capacitive interference by using the neighboring cell data
- Compensate the Vth decrease during data retention by write/erase cycles and data retention time data
- X11 Better Reliability

FG-FG interference

Conventional $V_{ref1}$ $V_{ref21}$

Proposed $V_{ref}$ $V_{ref}$ $V_{ref}$ $V_{ref}$

Vth decrease during data retention

&=# of cells

11 01 00 10
Unified Solid-State Storage (ISSCC 2013)

- Unified Storage Controller integrating SSD controller and RAID controller.
- Use ReRAM as NV-Cache.
- X32 Better Reliability
Reverse-mirroring (ISSCC 2013)

Assign data to primary and mirror Storage to minimize errors.
### Page RAID (ISSCC 2013)

<table>
<thead>
<tr>
<th>Storage</th>
<th>HDD</th>
<th>NAND (USSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure</td>
<td>Disk (Mechanical)</td>
<td>Page (Bit-errors)</td>
</tr>
</tbody>
</table>

#### Redundancy Scheme

- **RAID**:
  - No disk exchange
  - Low cost

- **Page-RAID**
  - Replace

![Diagram](image)
Page RAID (ISSCC 2013)

- RAID optimized for flash memory, Repair failed word-line
- Store parity in ReRAM
- >X10 Better Reliability

- XOR (Page-RAID)
- ECC (Conv.)
- ECC (for ReRAM)

ReRAM is suitable for parity buffer due to large endurance cycle.

N_{\text{page}}: Page number in a block (e.g. 256)

Write block-parity to NAND
ReRAM (Parity buffer)
Non-contact Connector

Conventional Connector  
Mechanical contacts

Issues and challenges
- dependability (non-waterproof)
- signal integrity (crosstalk, reflection)
- farm factor (big, thick, heavy)
- assembly (manual labor, large force)

Non-contact Connector  
Near-field coupling

+ non-contact
+ no mechanical structure
+ impedance controlled
+ easy to put on and take off
Transmission Line Coupler (TLC)

![Diagram of TLC](image)

- **Port1**
- **Port2**

**Dimensions**
- **Length (L)**
- **Width (W)**

**Parameters**
- **Offset (h)**
- **Substrate**

**Graphs**
- **Coupling Gain [dB]** vs **Frequency [GHz]**
  - **L=3mm**
  - **L=5mm**
  - **L=7mm**

- **Coupling Gain [dB]** vs **Misalignment (h) [mm]**
  - **W=0.4mm**
Applications

SD

Memory Card
High speed: 50x (12Gb/s)
Low power: 1/500
Sealing: waterproof
ISSCC2011, ISSCC2013

LCD

Display
Thin: 1/10 (0.15mm)
High speed: 10x (6Gb/s)
Low energy: 1/10 (16pJ/b)
ISSCC2013

Transmission Line Coupler (TLC)

DIMM

High speed: 5x (12.5Gb/s)
Multi-drop bus
ISSCC2012, CICC2012

In-vehicle LAN
Reduced weight: 30%
EMC
ISSCC2014

Mobile Terminal
Small size & Low cost

Dependable Assembly

Automotive, Computer
High speed & Low error
Memory Card (ISSCC2011)

Wireless Memory Card
NAND Flash Memory Chip
Nested Clover Coils for Simultaneous Power/Data Transmission
Host Chip

Wireless Memory Card Host

20mm x 20mm Power Link Coil

Power Link ON
Power Link OFF
Timing Margin = 0.5 UI

10^{-7} 10^{-9} 10^{-11} 10^{-13}
BER

Data rate [Gb/s]

10^{-12} 10^{-13} 10^{-14}
BER

Delay Time [ps]

2^{31}-1 PRBS @ 12Gb/s

75mA_{rms} 13.56MHz

Power Link Coil

Data
Wireless Memory Card Host

Memory Chip

Nested Clover Coils

for Simultaneous Power/Data Transmission

Power Link Coil

75mA_{rms} 13.56MHz

TLC

1mm

2^{31}-1 PRBS @ 12Gb/s
LCD Module (ISSCC2013)

- TLC 0.15mm-Thick
- Host Board
- LCD Module

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Coupling Gain [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-10</td>
</tr>
<tr>
<td>6</td>
<td>-20</td>
</tr>
<tr>
<td>8</td>
<td>-30</td>
</tr>
<tr>
<td>10</td>
<td>-40</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>-10</td>
</tr>
</tbody>
</table>

Port 1
Port 2
Port 3
Port 4

20dB
S_{31}
S_{41}

2Links in one TLC
2Gb/s x 2Links = 4Gb/s/coupler

0.15mm-Thick

305 ps
Memory Bus (ISSCC2012, CICC2012)

- TLC: 12.5Gb/s 5Drops
- ISSCC’12  CICC’12
- DDR4
- JSSC’12
- ISSCC’11
- ISSCC’13
- TLC: 12.5Gb/s 5Drops

Number of Modules vs. Data Rate [Gb/s/lane]

Controller #1 #2 #3 #4 #5

DRAM TLC

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In-vehicle LAN (ISSCC2014)

“An Electromagnetic Clip Connector for In-vehicle LAN to Reduce Wire Harness Weight by 30%”
(Paper 30.6)
Summary: Non-Contact Connector

- **SD Memory Card**
  - High speed: 50x (12Gb/s)
  - Low power: 1/500
  - Sealing: waterproof
  - ISSCC2011, ISSCC2013

- **DIMM**
  - High speed: 5x (12.5Gb/s)
  - Multi-drop bus
  - ISSCC2012, CICC2012

- **Display**
  - Thin: 1/10 (0.15mm)
  - High speed: 10x (6Gb/s)
  - Low energy: 1/10 (16pJ/b)
  - ISSCC2013

- **Transmission Line Coupler (TLC)**

- **LCD**
  - Display
  - Thin: 1/10 (0.15mm)
  - High speed: 10x (6Gb/s)
  - Low energy: 1/10 (16pJ/b)
  - ISSCC2013

- **In-vehicle LAN**
  - Reduced weight: 30%
  - EMC
  - ISSCC2014

- **Mobile Terminal**
  - Small size & Low cost

- **Dependable Assembly**

- **Automotive, Computer**
  - High speed & Low error

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Dependable Wireless Power Delivery System

Small size, battery-less application
Requirement:
Fast load tracking and low EMI

Switch between $f_{res}$ and $f_{res}/3$
Single-Channel Dual-Output WPD System

$\Delta \Sigma$ Controller

Amp Buffer

Diode Driver

PRS-PWM Module

Duty Controller

Power Controller
Test Chip and WPD Module

Coil size
2cm x 2cm

Resonance capacitor: 5
Smoothing capacitor: 2
Power Efficiency and Output Regulation

- Output voltage regulated at 16V and 8V
- Power efficiency: 40%
Fast Load Tracking and EMI Reduction

\[
P_{OH} = 0.341 \text{W}
\]
\[
P_{OL} = 0.085 \text{W}
\]

Mode control

\[
V_{OH}(16\text{V})
\]
\[
V_{OL}(8\text{V})
\]

Load transition point

\[
+3%
\]
\[
-6%
\]
\[
200\mu\text{s}
\]

Spurious emission (dBμA/m@10m)

-8dBμA/m

Regulation

8dB improvement

Power setting code

0.045W to 0.52W