Improved C_comp Model Case Study

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Outline

Improving the C_comp model

Case Study for a Lossy C_comp model
  ▪ Creating a Measurement Based Model
  ▪ Test Case Simulation with two C_comp Models

Conclusion
Improving the C_comp Model

IBIS-ISS based C_comp subcircuit model in development by the ATM and Interconnect task groups.

Model could represent a frequency dependent C_comp behavior.
Creating a Measurement Based C_comp model

8Gb DDR4 x8
- 25nm process
- 78-ball single layer FBGA

3-DUTs
- C_pkg (no die)
- L_pkg (shorted die)
- C_pkg, L_pkg, C_die (live die)

VNA Measurement:
- S11
- 50MHz – 8.5GHz
- 5.28125MHz steps

Modeled several Address inputs
Model Schematics – Address Inputs

C_pkg (no die)

\[ \text{Term Term 4 Num} = 4 \]
\[ \text{Z} = 50 \, \text{Ohm} \]
\[ \text{SRC SRC4} \]
\[ \text{R} = 7 \, \text{Ohm} \]
\[ \text{C} = 0.4 \, \text{pF} \]

L_pkg (shorted die)

\[ \text{Term Term 6 Num} = 6 \]
\[ \text{Z} = 50 \, \text{Ohm} \]
\[ \text{SRC SRC5} \]
\[ \text{R} = 7 \, \text{Ohm} \]
\[ \text{C} = 0.4 \, \text{pF} \]
\[ \text{INDQ2} \]
\[ \text{L} = 1.9 \, \text{nH} \]
\[ \text{Q} = 2 \]
\[ \text{F} = 30 \, \text{MHz} \]
\[ \text{Mode} = \text{proportional to sqrt(freq), constant L} \]
\[ \text{Rdc} = 0.145 \, \text{Ohm} \]

C_pkg, L_pkg, C_die (live die)

\[ \text{Term Term 2 Num} = 2 \]
\[ \text{Z} = 50 \, \text{Ohm} \]
\[ \text{INDQ2} \]
\[ \text{L} = 1.9 \, \text{nH} \]
\[ \text{Q} = 2 \]
\[ \text{F} = 30 \, \text{MHz} \]
\[ \text{Mode} = \text{proportional to sqrt(freq), constant L} \]
\[ \text{Rdc} = 0.145 \, \text{Ohm} \]

\[ \text{SRC SRC1} \]
\[ \text{R} = 19 \, \text{Ohm} \]
\[ \text{C} = 0.41 \, \text{pF} \]

\[ \text{SRC SRC6} \]
\[ \text{R} = 7 \, \text{Ohm} \]
\[ \text{C} = 0.4 \, \text{pF} \]
Step 1: C_pkg Simulation (S11, Mag/Phase)

Model
Measurement
Step 2: L_pkg Simulation (S11, Mag/Phase)

Model
Measurement
Step 3: C_pkg, L_pkg, C_die Simulation (S11, Mag/Phase)

Result:
ESR of C_comp is ~ 19 Ohms
Step 3: $C_{\text{pkg}}, L_{\text{pkg}}, C_{\text{die}}$ Simulation (S11, Mag)

ESR=0 Ohms (Original)  
ESR=19 Ohms (Lossy)
Test Case Simulation

**DDR4 LRDIMM**

- Uses previously measured DDR4 SDRAM die
- Simulated post-register Address net
  - DDP devices (2 die in package)
  - 40 loads total
  - DDR4-2400, 1.2Gbps for Address
  - 255-bit PRBS stimulus
  - Light and Strong drive Register driver settings
- Compared simple C_comp model to lossy C_comp model
LRDIMM Layout

Front side

Back side

Register
Net A09A Topology, Flower pattern

Outer Trace

Inner Trace
Non-Lossy C_comp, Strong Drive

U25
Jitter = 45ps  ApcACDC = 0.742ns  VMarginDC = 139mV
MinSlew = 2.58V/ns  ArrTime = 0.177ns

U29
Jitter = 52ps  ApcACDC = 0.659ns  VMarginDC = 173mV
MinSlew = 0.92V/ns  ArrTime = 0.505ns
Lossy $C_{comp}$, Strong Drive

U25
Jitter = 45ps  AptACDC = 0.742ns  VMarginDC = 155mV  MinSlew = 2.54V/ns  ArrTime = 0.177ns

U29
Jitter = 48ps  AptACDC = 0.657ns  VMarginDC = 182mV  MinSlew = 0.90V/ns  ArrTime = 0.503ns
Non-Lossy C_comp, Light drive

U25
Jitter = 53ps  AptACDC = 0.722ns  VMarginDC = 108mV
MinSlew = 2.12V/ns  ArrTime = 0.159ns

U29
Jitter = 62ps  AptACDC = 0.607ns  VMarginDC = 98mV
MinSlew = 0.62V/ns  ArrTime = 0.477ns
Lossy C_comp, Light drive

U25
Jitter = 54ps  AptACDC = 0.72ns  VMarginDC = 115mV
MinSlew = 2.08V/ns  ArrTime = 0.159ns

U29
Jitter = 56ps  AptACDC = 0.605ns  VMarginDC = 102mV
MinSlew = 0.62V/ns  ArrTime = 0.474ns
## Conclusions

<table>
<thead>
<tr>
<th>Driver Setting</th>
<th>C_comp Model</th>
<th>Vmargin DC - U25</th>
<th>Vmargin DC – U29</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong Drive</td>
<td>Non-lossy (original)</td>
<td>139mV</td>
<td>173mV</td>
</tr>
<tr>
<td>Strong Drive</td>
<td>Lossy (with ESR)</td>
<td>155mV</td>
<td>182mV</td>
</tr>
<tr>
<td>Light Drive</td>
<td>Non-lossy (original)</td>
<td>108mV</td>
<td>98mV</td>
</tr>
<tr>
<td>Light Drive</td>
<td>Lossy (with ESR)</td>
<td>115mV</td>
<td>102mV</td>
</tr>
</tbody>
</table>

Including ESR improves voltage margin by 16mV, 11.5% (best case)

ESR filters high frequency content at the die, which can improve SI

Improving the C_comp model is needed for improving the accuracy and usefulness of IBIS models.