Power Integrity of Space Transformer on Probe Card

TAE-KYUN KIM, YONG-HO CHO
Microfriend
SANG-KYU YOO
Samsung Electronics
JONG-GWAN YOOK
Yonsei University

June 4-7, 2017
Overview

• Introduction of Probe Card Test
• Basic Study for Power Integrity
• Power Integrity on Probe Card
• Summary
• Future Works
Introduction of Probe Card Test

• Increased Noise Issue at Low Power and High Speed

✓ Supply Voltage decreases for Improving Device Reliability
✓ Low Power Consumption and Operation Requirement
✓ Noise Margin (Reducing of Supply Voltage)
✓ Timing Margin (Increasing of Clock Frequency)

➢ Highly Design Consideration for Power Integrity on Probe Card

Fig. Predicted Trends of the Supply Voltage and Clock Frequency
Introduction of Probe Card Test

- Memory Test Trends for Pad Pitch and Size

Fig. Predicted Trends of Pad Size and Pad Pitch

- Shrink VIA Pad
- Increase Circuit Density
- To be Fine Pitch

➢ Needs for High Density Circuit and Fine Pitch Design on Probe Card

Fig. Probe of Polyimide Circuit (STF)
Fig. Probe of Multilayer Ceramic (STF)
## Introduction of Probe Card Test

### Different Types of Circuit Design on Space Transformer

<table>
<thead>
<tr>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Layer Ceramic (Space Transformer)</td>
<td>Polyimide Thin Film With Ceramic (Space Transformer)</td>
</tr>
<tr>
<td>- Fine Pitch</td>
<td>- Fine Pitch</td>
</tr>
<tr>
<td>- Circuit Density</td>
<td>- Circuit Density</td>
</tr>
<tr>
<td>- Technology</td>
<td>- Technology</td>
</tr>
</tbody>
</table>

- Multi-Layer Ceramic (Space Transformer)
- Power Plane, Ground Plane, Signal Trace
- Normal Type (Limit of High Parallel Device/DUT)
- Available for using Polyimide Thin Film on STF (Called it ‘Hybrid’ Type)
- Polyimide Circuit + Ceramic (Space Transformer)
- Power (Mesh/Trace), Ground (Mesh), Signal Trace
- Signal/Power Re-distribution on Polyimide Thin Film
- Highly Denser Circuit and Small VIA PAD on Polyimide Thin Film (For Fine Pitch)
Introduction of Probe Card Test

• Power Delivery on Probe Card and Equivalent Circuit

- Low Impedance Path of Current flow at working Frequency
- Target Impedance using Decoupling Capacitor
- Low Inductance Capacitor on Space Transformer
- Design Consideration of Power and Ground
Basic Study for Power Integrity

- Power Impedance Characteristics on Space Transformer (w/o De-cap)

- STF Power Plane (Top/Bottom)
- Power Impedance without De-capacitor
- Similar Characteristics like De-capacitor
- Plane Capacitor and Plane Inductor

Resonance Mode Resonance

\[ Z = \frac{1}{j\omega C} \text{ (For Capacitance)} \]
\[ = j\omega L \text{ (For Inductance)} \]

Fig. Side View of PDN on Probe Card
Basic Study for Power Integrity

• Decoupling Capacitor and Target Impedance

Various of De-capacitors have own Characteristics at Frequency.
Target Impedance is the ratio of Voltage to Current.
Low Impedance implies Large Capacitance and Low Inductance.

Example) Vdd = 1V, ∆I = 50mA, Voltage Tolerance 5%

\[ Z_{\text{target}} = \frac{1 \times 0.05V}{50mA} = 1 \text{ Ω} \]

Fig. Target Impedance with Decoupling Capacitor

TK KIM/YH CHO/SK YOO/JG YOOK
### Power Integrity on Probe Card

- **Impedance Analysis for Different Size of Power Plane on Space Transformer**

#### Top Power Plane / Bottom Power Plane

<table>
<thead>
<tr>
<th>Type</th>
<th>Top Plane Size</th>
<th>Bottom Plane Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>16mm x 16mm</td>
<td>12 mm x 12 mm</td>
</tr>
<tr>
<td>Type B</td>
<td>16mm x 16mm</td>
<td>6 mm x 6 mm</td>
</tr>
<tr>
<td>Type C</td>
<td>16mm x 16mm</td>
<td>6 mm x 12 mm</td>
</tr>
</tbody>
</table>

- **Impedance Analysis for Different Size of Bottom Power Plane**
- **Analysis for Plane Capacitance and Plane Inductance**
Power Integrity on Probe Card

• Impedance Analysis for Different Size of Power Plane on Space Transformer (w/o De-cap)

- As Power Plane Size is large, the Plane Capacitance is increasing.
- As Power Plane Size is small, the Plane Inductance is decreasing.
- As Power Plane Size is small, the Resonance is increasing.
Power Integrity on Probe Card

• Impedance Analysis for Different Size of Power Plane on Space Transformer (with De-cap)

[The Effect of Decoupling Capacitor]

✓ Lower Impedance between Power and Ground Reference Planes.
✓ Reduce/Eliminate Plane resonances.
✓ The Power Impedance depends on the Position.
✓ Top side of De-cap is much more Effective than Bottom side of De-cap.

✓ De-cap can make Low impedance at Working Frequency Regardless of Plane Size.
Power Integrity on Probe Card

- Impedance Analysis for Different Shape of Power Plane on Space Transformer

<table>
<thead>
<tr>
<th>Top Power Plane / Bottom Power Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type A</strong></td>
</tr>
<tr>
<td>- Power Top Plane Area : 64 mm²</td>
</tr>
<tr>
<td>- Power Bottom Plane Area : 230 mm²</td>
</tr>
<tr>
<td><strong>Type B</strong></td>
</tr>
<tr>
<td>- Power Top Plane Area : 64 mm²</td>
</tr>
<tr>
<td>- Power Bottom Plane Area : 230 mm²</td>
</tr>
</tbody>
</table>

- Impedance Analysis for Different Shape of Bottom Power Plane
- Analysis for Plane Capacitance and Plane Inductance
Power Integrity on Probe Card

- Impedance Analysis for Different Shape of Power Plane on Space Transformer (w/o De-cap)

- For Different Shape of Power Plane, these have similar Plane Capacitance.

- Plane Inductance have a little differences between these 2 cases.

- The Resonance is Increasing slightly.
Power Integrity on Probe Card

- **Impedance Analysis for Different Shape of Power Plane on Space Transformer (with De-cap)**

[The Effect of Decoupling Capacitor]

- Lower Impedance between Power and Ground Reference Planes.
- Reduce/Eliminate Plane resonances.
- The Power Impedance depends on the Position.
- Top side of De-cap is much more Effective than Bottom side of De-cap.

- De-cap can make Low Impedance at working Frequency Regardless of Plane Shape.
Power Integrity on Probe Card

- Decoupling Capacitor Effect of SSN Voltage on Space Transformer

[Simulation Conditions]
- DRAM DDR2 IBIS Model
- Time Domain Analysis
- Decoupling Capacitor Effect depends on Position.
  - De-cap decreased Voltage Fluctuation and Noise as changing De-cap Position.

- Simultaneous Switching Noise (SSN)
  \[
  \Delta V = L \frac{\Delta I}{\Delta t} \\
  \Delta I : Increase of Maximum Power (Current) \\
  \Delta t : Increase of Clock Frequency
  \]

- SSN cause by Simultaneous Switching Output Buffers
Power Integrity on Probe Card

• Space Transformer Circuit Design Concept on Polyimide Thin Film

- STF Consists of Universal Multi-Layer Ceramic and Polyimide Thin Film.
- Circuit Design on Polyimide Thin Film is made by MEMS Process.
- Probe Structure is built up by 3D MEMS (Layer by Layer)

TK KIM/YH CHO/SK YOO/JG YOOK

SW Test Workshop | June 4-7, 2017
Power Integrity on Probe Card

• PDN Impedance characteristics on Space Transformer (with Polyimide)

[The Effect of Decoupling Capacitor]

✓ Low Impedance between Power and Ground Reference Planes
✓ Reduce / Eliminate Plane Resonances
✓ The Power Impedance depends on the Position.
✓ Top side of De-cap is much more Effective than Bottom side of De-cap.

➢ De-cap can make Low Impedance at working Frequency Regardless of Plane Shape or Size.
Power Integrity on Probe Card

• Decoupling Capacitor Effect of SSN Voltage on Space Transformer (with Polyimide)

[Simulation Conditions]
- DRAM DDR2 IBIS Model
- Time Domain Analysis
- Decoupling Capacitor Effect depends on Position.

- De-cap decreased Voltage Fluctuation and Noise as changing De-cap Position.

Simultaneous Switching Noise (SSN)

\[
\Delta V = L \frac{\Delta I}{\Delta t} : \Delta I : \text{Increase of Maximum Power (Current)}
\]

\[
\Delta t : \text{Increase of Clock Frequency}
\]

- To Reduce SSN, Inductance needs to be Controlled.
Power Integrity on Probe Card

• Measurement Setup to Analyze Power Impedance on Probe Card

  ✓ Vector Network Analyzer (≤8GHz)
  ✓ RF Probe (≤15GHz)
  ✓ Probe Station (2-Dimension)
  ✓ Microscope (x20)
  ✓ Probe Card (PCB+STF Assembly)

  ➢ S-parameter → Z-parameter (Z11)
Power Integrity on Probe Card

- Relationship between S-parameter and Z-parameter

* Reverse Pattern of 2 parameters between Resonance and Impedance
* Resonance makes High Impedance
* S-parameter ($S_{11}$) $\rightarrow$ Z-parameter ($Z_{11}$)

- Self Impedance (Input Impedance)
  - $Z_{11} \rightarrow$ Dominant

\[ Z_{11} = \frac{[(1 + S_{11})(1 - S_{22}) + S_{12}S_{21}]}{[(1 - S_{11})(1 - S_{22}) - S_{12}S_{21}]} Z_0 \]
**Power Integrity on Probe Card**

- **[Measurement] Power Impedance Analysis on Space Transformer (w/o Polyimide)**

- De-cap can make Low Impedance at working Frequency Regardless of Plane Size or Shape.

- Large number of De-caps affect Resonance and Impedance.

- Matching Target Impedance is available for placing De-cap on Top and Bottom side.

---

TK KIM/YH CHO/SK YOO/JG YOOK

SW Test Workshop | June 4-7, 2017
Power Integrity on Probe Card

• [Measurement] Power Impedance Analysis on Space Transformer (with Polyimide)

- De-cap can make Low Impedance at working Frequency Regardless of Plane Size or Shape.
- Large number of De-caps affect Resonance and Impedance.
- Matching Target Impedance is available for placing De-cap on Top and Bottom side.
SUMMARY

✓ Basic Study for **Power Impedance** on **Space Transformer** has been performed.

✓ **Power Integrity** has been analyzed both Normal Space Transformer and Polyimide Space Transformer using method of **Simulation** and **Measurement**.

✓ Satisfaction for **Target Impedance** with Decoupling Capacitors which Impedance depends on position and **Top Size of De-cap** is much more effective for **Lowering Impedance**.
FUTURE WORKS

✓ The Electrical Characteristics for Probe Card Circuit designed by Polyimide + Multi-Layer Ceramic (Called it ‘Hybrid type space transformer’).

➢ Could have many Issues because of large number of discontinuity points from Multi-Layer Ceramic to Polyimide Circuit.

- Analysis of **Signal Integrity** (Impedance, Eye-Diagram, Crosstalk...)
- Analysis of **Power Integrity** (Power Impedance, Target Impedance, SSN...)

TK KIM/YH CHO/SK YOO/JG YOOK

24

SW Test Workshop | June 4-7, 2017
Acknowledgements

- SANG-KYU YOO
- JOON-YOON KIM
- YONG-HO CHO
- SUNG-MO KANG
- HUN-SOO KIM
- SUNG-WOONG LEE
- JONG-GWAN YOOK
- HO-SUNG LEE
Thanks for Your Attention!