KEY CHALLENGES AND TECHNOLOGY TRENDS IN SOCKET DESIGN

“Automated Topside and Bottomside Testing of POP Packages on a Robotic Handler”
Eric Pensa, Willie Jerrels
Texas Instruments

“High Speed Contactor Interconnect”
David Mahoney
Xilinx, Inc.
Hongjun Yao
Antares Advanced Test Technologies

“Particle Interconnect: Simple and Effective Socket Solution”
Robert Howell
Exatron

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Automated Topside and Bottomside Testing of POP Packages on a Robotic Handler

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Texas Instruments MAKE Test Handler-Interface Engineering
March 12, 2008

Outline

• Why is topside testing needed
• History of topside testing
• What is topside vs. bottom side testing
• Current status of topside testing
• Future requirements for topside testing
Why is Topside Testing Needed?

- Customer demand for POP packaging is strong and only expected to grow
- POP packages need to be contacted on both the bottom (BGA) and top side (Pads) simultaneously
- Current approach on existing robotic handlers is for bottom side testing only

What is a POP package?

- POP = Package on Package Technology
- A memory package is stacked directly onto the above POP package
- Customer chooses their own POP Package memory configurations/densities & preferred POP memory vendor (Cont’d)
Why is topside testing needed?

- Offering a production worthy solution for testing POP packages that is not currently available. Without this test capability the large cost savings achievable with POP packages will not be realized.

- “Top Test capability is expected to reduce TI costs on selected POP packages considerably. This is a direct result of not having to bring the full memory interface to the bottom BGA, thus decreasing ball count, decreasing substrate complexity, decreasing substrate layer count, and finally decreasing cost.” (Cont’d)

Current POP design and test methods require 100% access to the memory device from the bottom BGA solder balls (paths A, B & D below). This practice increases the package pin count, reduces BGA pitch and in turn increases our customer’s assembly complexity, adds to system PWB cost and lowers reliability. The goal is to eliminate path B and only have paths A, C & D. (Cont’d)

(A): Bottom BGA only; (B): Top & Bottom BGA; (C): Top PAD only
History of Topside Testing

- First customer request ~ 2.5 years ago for 14x14 POP package
- TI MAKE Test and Delta Contactor teams began development of topside test solution for 14x14 POP package
- Challenge was finding 2 pogopins for bringing signal up to topside
- Unexpected challenge was building non-flat nest PCB board - handler vendor declined!
- Kit and socket were verified Summer 2005 with O/S testing using daisy chains only due to device being cancelled - no production testing ever done w/ 14x14 POP

What is Top Side vs. Bottom Side Testing?

- Requirement: No PAD damage (No Ni, Cu exposure)/ Good contact for DC test

Topside Socket

Nest PCB

Topside Nest Pogos

BGA Pogos

IDI Pogos

Spear Point Pin

Crown Pin

Radius Pin

Au 0.75um
Ni 10um
Cu 22um

Au 0.50um
Ni 0.8um

0.28mm
Current Status of Topside Testing

- Topside testing resurrected ~ 1 year ago for a 12x12 POP package by a TI customer

- To meet aggressive 3 month kit/socket request, decision was made to leverage off of 14x14 topside kit as much as possible

- Customer’s 2 key requirements: 1) **NO** Ni or Cu exposure; 2) “gentle mark” to topside pad will only be accepted

- Topside pogopin from 14x14 kit was single point/spear type: SEM analysis of tested units showed **failure to meet both requirements**.

- Only 3 “drop-in replacement” pogopins were available for consideration: 2 w/ radiused tips & 1 w/ 3 point crown tip

(Cont’d)
Current Status of Topside Testing

- 14x14 units were run thru the handler with all 3 “drop-in” pogos: SEM testing showed all 3 would meet customer requirements with radiused tip markings being slightly more gentle than 3 point crowns. (Note: No electrical testing; same mechanical settings as used w/ 14x14 kit.)

- Topside Handler Kit, Socket, and O/S Testboards were ordered for the 12x12 POP package

- Both radiused and 3 point crown type pogos were ordered

- Customer preferred the radiused tip (Cont’d)

SEM results from Initial Mechanical Assessment of Probe Pins:
- Evaluation varied 1) Probe type 2) Force, 3) # of probe attempts
- Radial pins exhibited minimal “marking” and no Ni detection
- Alternate pin styles showed ~2x “mark size” over radial pin

Radial Pin Results – 20g Force:

Figure 1 – J tip, 20 grams
Radial Pin SEM Results on 20g Force / 10 hits (insertions): NOTE: No Ni exposed up to 30 hits

<table>
<thead>
<tr>
<th>Line scan of device pad</th>
<th>No nickel exposure</th>
</tr>
</thead>
</table>

![Image of SEM results](image)

Figure 4 – J-tip, 20 grams, 10 hits

---

12x12 POP Contactor Module Adjustable Hard Stop

| Illustration courtesy of Delta Design |

![Image of POP Contactor Module](image)

Recommend leaving the 2.50 frame shims on at least to begin with.

New Module Adjustable Hard Stop with 2-56 Phillips Head Screws.
**Current Status of Topside Testing**

- To reduce risk, handler vendor was requested to run kit continuity check at all 3 temp’s w/ daisy chained 12x12 POP units: good results from both pogo types at all 3 temps!
- Kit arrives in TI Dallas: however live 12x12 POP units proved to be more sensitive than the daisy chained ones: Mis-contact(Bin 8) rates were significantly worse! Fortunately customer received required units throughout troubleshooting phase.
- A multi-month effort began to fine-tune the setup to eliminate mis-contact (Bin 8) with the nest being the focus:

(Cont’d)

---

**Current Status of Topside Testing**

a) “Retainers” were added to the handler nest for pogopin to pad alignment

b) Nest "ceiling" was lowered to counter any package warpage

c) Single ended BGA pogopins replaced w/ double ended as used on 14x14 kit

d) Adding hardstop height with Kapton tape helped; therefore variable hardstops on the contactor were offered [5.30 thru 5.45mm in .05 steps] to deal with package thickness variances

e) Variable hardstops also added to the contactor modules to replicate the success of hand test lids w/ hardstops closer to the POP unit under test by reducing package flexing possibility – finally both chucks for the 1st time recorded 0% Bin 8 for 1st pass test!

f) Same chuck/nest assemblies were transferred to TI Asia; 0% Bin 8 was achieved with same units tested in Dallas

(Cont’d)
Future Requirements of Topside Testing

Where are we/what have we learned:

- Performing both top and bottomside testing is a “very fine balancing act”
- Nest issues contributed to miscontact in the following ways:
  a) new nest material was needed to avoid expansion due to moisture
  b) nest pogopin tip shape, size & XY movement required much attention
  c) nest pocket design & QC process required enhancements over existing approaches that have served bottomside nests well for years
- POP package issues contributed to miscontact in the following ways:
  a) using daisy chained devices were not as helpful in kit design for topside test
  b) package warpage caused offsets to topside pads
  c) sawing process was changed to reduce offsets to topside pads
  d) dimensions and warpage need to be better controlled than for packages only needing bottomside test; topside nests are less tolerant of package variations than typical nests

Future Requirements of Topside Testing

- Will new nest designs be needed for thinner POP packages that are more prone to warpage?
- Topside nests and hand test lid assemblies are very expensive with long lead times; they need to have maximum flexibility to accommodate package thickness differences
- Will new nest designs be needed for POP packages with bare die on topside?
- Current testing is for single site; what challenges will multi-site testing present?

(Cont’d)
Future Requirements of Topside

- Having our strategic socket vendors producing turnkey topside sockets and hand test lids [nest PCB and new pogo designs will be needed]

- Developing topside testing solutions for other strategic handlers

- Current topside pogopins are very expensive with lead times up to 6 to 8 weeks; both need to be reduced
High Speed Contactor Interconnect

2008 Burn-in and Test Socket Workshop
March 9 - 12, 2008

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Signal Integrity Manager

High Speed Contactor Interconnect Background

• Traditional external loop back circuitry consists of two contact elements in a socket and a loop back trace on the Printed Circuit Board (PCB).
• As the length of Pogo Pins are reduced the contact force and the overall travel of the Pogo Pin are also reduced.
• This paper looks at the performance of using long electrical contacts in conjunction with a interconnect that is placed inside the socket body of a traditional Automated Test Socket for a BGA package.
• We have also compared the electrical performance to a High Performance Contactor using the standard loop back trace on the PCB.
Key Challenges and Technology Trends in Socket Design

**Standard Pogo Pin**

- **Contact Resistance vs. Displacement**
  - Average CR $<50$ mOhm at displacement of 1.3 mm.
  - Spring force of $-330$ gF at 1.3 mm of displacement.

**High Performance Pogo Pin**

- **Contact Resistance vs. Displacement**
  - Average CR $<31$ mOhm at displacement of 0.5 mm.
  - Spring force of $-313$ gF at displacement of 0.5 mm.
• The traditional external loop back circuitry in our model consists of Micro-Strip traces on the top layer of our Printed Circuit Board (PCB).
  – This model is based on an actual Virtex-5 package pin out.
  – The BGA package pitch is 1mm.

### Standard Micro-Strip Loopback

<table>
<thead>
<tr>
<th>PCB Geometries</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PAD Diameter</td>
<td>25 Mil</td>
</tr>
<tr>
<td>Via Diameter</td>
<td>12 Mil</td>
</tr>
<tr>
<td>Trace Width</td>
<td>8 Mil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER</th>
<th>Dielectric Thickness</th>
<th>Dielectric Constant</th>
<th>Cu Thickness</th>
<th>Layer Name</th>
<th>Signal Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FR4 (Er 4.4)</td>
<td>4.5</td>
<td>1.4</td>
<td>TOP</td>
<td>Loopback Traces</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>1.4</td>
<td>DGnd1</td>
<td>GND PLANE</td>
</tr>
</tbody>
</table>
### Standard Micro-Strip Loopback PCB Design

- Top View of High Speed Contactor Interconnect Simulation Model.
- 4 terminals were used in our simulation model.
- GND locations were based on an actual pin out.

![Top View of High Speed Contactor Interconnect Simulation Model](image)

### Package Substrate Model

**PCB Geometries**
- PAD Diameter: 0.5 mm
- Via Diameter: 14 Mil
- Trace Width: 4 Mil

<table>
<thead>
<tr>
<th>Layer</th>
<th>Dielectric Thickness</th>
<th>Dielectric Constant</th>
<th>Cu Thickness</th>
<th>Layer Name</th>
<th>Signal Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAYER 1</td>
<td>FR4</td>
<td>6.3</td>
<td>1.4</td>
<td>TOP</td>
<td>GND PLANE</td>
</tr>
<tr>
<td>LAYER 2</td>
<td>FR4</td>
<td>FR4 (Er 4.4)</td>
<td>1.4</td>
<td>INNR 1</td>
<td>SIGNAL</td>
</tr>
<tr>
<td>LAYER 3</td>
<td>FR4</td>
<td>FR4 (Er 4.4)</td>
<td>1.4</td>
<td>INNR 1</td>
<td>GND PLANE</td>
</tr>
<tr>
<td>LAYER 4</td>
<td>FR4</td>
<td>4.5</td>
<td>1.4</td>
<td>TOP</td>
<td>BALL PAD</td>
</tr>
</tbody>
</table>

![Package Substrate Model](image)
Standard Contactor

- Standard Contactor:
  - Pogo Length: 7.33mm
  - Pogo Pin Diameter: 0.75mm

(Differential) S-Parameters of Standard Contactor
High Performance Contactor with Standard Loopback

- High Performance Contactor
  - Pogo Length: 2.15mm
  - Pogo Pin Diameter: 0.5mm

GND GND
**Key Challenges and Technology Trends in Socket Design**

**High Speed Contactor Interconnect**

- **GND Pogo Length**: 7.33mm
- **GND Pogo Pin Diameter**: 0.75mm
- Interconnect above non conductive Elastomer.

**Differential S-Parameters of High Performance Contactor**

![Graph showing S-parameters of high performance contactor](image)

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High Speed Contactor Interconnect

- The High Speed Contactor Interconnect Dimensions:
  - Trace Width: 8 Mil
  - Trace Thickness: 1.4 Mil
  - Trace Length: 1.4mm
(Differential) S-Parameters of High Speed Contactor Interconnect

Contactor Comparisons

- Differential Insertion Loss
- Differential Return Loss
- Differential TDR
Differential (S21) of all Contactors

- Differential Insertion Loss

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Differential (S11) of all Contactors

- Differential Return Loss

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Differential TDR of All Contactors

- Differential TDR

Eye Diagrams

- PRBS Parameters:
  - 80pS rise time
  - 80pS fall time
  - 6.5Gbps
Combined Eye Diagrams

Eye Diagrams

- Although the Eye Diagram results are based on ideal elements, the High Speed Contactor Interconnect provided greater bandwidth for external Loopback testing.

Eye Diagrams

- PRBS Parameters:
  - 60pS rise time
  - 60pS fall time
  - 8Gbps
Combined Eye Diagrams

- Although the Eye Diagram results are based on ideal elements the High Speed Contactor Interconnect provided greater bandwidth for external Loopback testing.

High Speed Contactor Interconnect Summary

- The High Speed Contactor Interconnect demonstrated greater Bandwidth than a High Performance Contactor with standard loopback traces on the PCB.
- The High Speed Contactor Interconnect maintained both greater working range and higher bandwidth than the High Performance Pogo Pin Contactor.
- The addition of an interconnect in the socket provides greater bandwidth for loop back testing purposes without having to change the entire socket to high performance pogo pins.
The goal of our presentation will be to convey practical information to allow for in-house self design of “Simple & Effective” test sockets using Particle Interconnect “PI”
Particle Interconnect uses metallized diamond particles to form a micro “bed of nails” contact. The rough surface created by PI allows for zero lead length interconnect of DUT leads and test board circuits. PI pierces any contaminants on either the DUT leads or test contacts. The resulting contact has a resistance of under 3 milliOhms.
## PI Electrical Properties

- Contact resistance under 3 milliOhms
- Capacitance approaches zero
- Inductance approaches zero
- Tested to 40 GHz
- Artwork-controlled 50 ohm impedance
- Excellent TDR results

## PI Mechanical Properties

- Contact pressure 10 to 12 grams / contact
- Contact height typically 0.001”
- -70°C to +200°C temperature range
- Long life:
  - over 1,000,000 contacts on rigid material
  - over 100,000 contacts on flex material
- No “wiping action” required
All Particle Interconnect Test Sockets are RoHS Compliant

Decide on contact base material

- Rigid PCB
- Flex circuit
- Etched Beryllium Copper and other metal materials
Rigid PCB Applications

- Typically 0.010” or thicker
- Standard FR-4 is the most popular material
- Ceramic, Teflon, G-10 and other special base materials are available
- Works best for devices with flexible leads
  SOIC, SSOIC, TSOP, SOT, PLCC, Power Transistors

Selective Particle Interconnect plating
“Universal” Test Socket

Any lead pitch
.050" / 1.27 mm
1.00 mm / .80 mm / .65 mm
.625 mm / .50 mm / .40 mm

RF “Zero” Test Sockets
Customer generated PCB artwork
Just add a PI Layer to the Gerber file

Zero Socket required
Ground Slug Options

- Cut out for ground slug metal plunger
- Plated up ground slug pedestal
- Lots of tightly drilled plated-thru vias
- Contact to DUT PCB (add a drop of DI water)

Bent pin test for no extra cost

- Device leads within +/-0.002" / 0.05mm
  - Good contact (Leads bend slightly on contact but then spring back)
  - Device with leads bent down
  - Good contact (Leads “bent” back to flat by just pushing against the contact)
- Device with leads bent up
  - Bad contact (Free coplanaritity test)
Flex circuit Interposers

- As thin as 0.001” core material
- Standard Kapton is the most popular material
- FR-4 and Teflon materials are available
- Works for all devices*, with some simple help

* For QFN–MLP-LGA and other devices with no leads, some compliance will need to be added to or built-in to the flexible interposer
Which materials?

**Teflon:** Best electrical properties (best for RF / 40 GHz)
- Most flexible
- Shortest mechanical life

**Kapton:** Good electrical properties (includes most RF)
- Most popular to date
- 100K contacts minimum mechanical life

**FR-4:** Basic electrical properties
- Allows for best mechanical compliance
- 100K contacts minimum mechanical life

Interposers are manufactured in sheet form

Size of sheet determined by smallest pitch feature on the sheet

And then cut out as needed by your application
Kapton Interposers

Simple 2 sided Gerber File

Easily adapted to ANY existing socket footprint

Multiple socket patterns on one sheet

Pitch to 0.3mm

Conductive Elastomers

Adds compliance “under” the interposer

Socket top

Handler-ready socket base

PI coated interposer

Z axis conductive elastomer

Many choices

Customer-supplied test PCB

Paper #3
**“Flexee”**

Teflon Interposers

This material is very flexible. This fact alone solves compliance problems in some applications.

**BGA Interposers**

Add compliance by interposer design.

Top side pad

Bottom side pad
CSP “Chip Scale Package”
Add compliance with very thin FR-4

- Manual test socket
- Top-loader
- Hardened tool steel socket guide
- Multiple sizes of die
- Multiple pad patterns
- Multiple interposers
- Only one size base
- DUT test PCB

CSP Diced Die
Chip Scale Package

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CSP “Chip Scale Package”
Interposer Close-up

Mini Diving Boards
Scale in 0.01 inches

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DUO-Compliant Interposers

Add compliance “within” the interposer

• Allows up to 0.004”/0.1mm of compliance
• Brings otherwise ruined DUT test boards back to life!
• There are additional ways to add compliance “in the works”

LENGTHEN THE TOP SIDE CONTACT PADS
SHORTEN THE BOTTOM SIDE CONTACT PADS

"PLATE UP" ONLY THE TOP SIDE CONTACT PADS

TOP SIDE CONTACT PADS TYPICALLY PLATED UP TO 3 oz COPPER

TOP SIDE GROUND PADS AND ALL OF THE BOTTOM SIDE PADS TYPICALLY PLATED TO 2 oz COPPER

PLATE UP .001" TO .0015"

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Paper #3

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Key Challenges and Technology Trends in Socket Design

DUO Interposer Cross Section

- Top side lead contact plated to 3 oz.
- Top side ground slug contact plated to 2 oz.
- Bottom side lead contact plated to 2 oz.
- Air space
- Bottom side ground slug contact plated to 2 oz.

INITIAL MLF DEVICE - DUO INTERPOSER - DUT BOARD CONTACT
APPLY ADDITIONAL PRESSURE TO THE MLF DEVICE - DUO INTERPOSER - DUT BOARD CONTACT

NEED TO ADD EVEN MORE COMPLIANCE

DUT BOARD "NO TRACE" FREE SPACE

INTERPOSER FOOT PRINT ON DUT BOARD

MLF FOOT PRINT ON DUT BOARD
Pillow Contact Assembly

- Air fitting
- Add compliance with a puff of air
- Base PCB
- Clamp bolts
- Base block with pusher pads
- O-ring air seal

Pillow Socket Assembly

- 3/2008 Particle Interconnect: Simple and Effective Socket Solution
Etched Beryllium Copper
and other metal materials

- Plate on to the tops of flat spring probes
  (Great for “fuzz button” applications)
- BeCu etched fingers
- Copper strips used for EMI shielding
- The tips of copper bars for very high current switches
- Grounding lug washers

Close-Up of PI coated BeCu Fingers
Universal Size PLCC Test Socket

Thank You