iNEMI

International Electronics Manufacturing Initiative

Lead-Free Rework Optimization Project

Project Co-Chairs:
Jasbir Bath,
Flextronics International

Craig Hamilton,
Celestica

IPC APEX 2008

Advancing manufacturing technology

Background

- Reliability tests in the previous iNEMI lead-free assembly and rework project indicated a need to initiate a follow on iNEMI Rework Optimization Project.
- Thermal fatigue life of certain components on the iNEMI Payette board such as the CBGA937 was reduced after rework.
- This project would evaluate and recommend best practices, rework equipment requirements, impact of adjacent component temperatures and procedures for best practice lead-free rework processing.

iNEMI Rework Optimization Project Participants

Members

- Solectron, Jabil, Celestica, Sanmina-SCI, Plexus, Foxconn
- Cisco, Alcatel-Lucent, SUN, HP
- TI, Tyco, Intel, IBM
- Indium, Kester, Senju, Nihon Superior
- O.K. Industries, ERSA

Non-members participating in certain parts of project

- SRT/VJ Technologies
- AirVac
- Finetech
- ECD
- Spencor Technic

Lead-Free Rework Optimization Project

Main group Co-chairs: Jasbir Bath (Flextronics), Craig Hamilton (Celestica)

Sub-group Chairs

- Rework Repeatability: Jasbir Bath (Flextronics)
- Adjacent Component Group: Holly Rubin (Alcatel-Lucent)
- BGA socket/ QFN group: Alan Donaldson (Intel)
- Mini-pot rework group: Denis Jean (Plexus)/ Jenny Porter (Flextronics)/ Craig Hamilton (Celestica)

1) BGA//CSP Rework Machine Repeatability and Tolerance Study Background

Currently we have little or no data on temperature repeatability of BGA/CSP rework equipment.

This is an issue for lead-free as the temperatures during lead-free BGA/CSP rework are likely to be higher than lead-free reflow soldering giving potential component/board temperature issues.

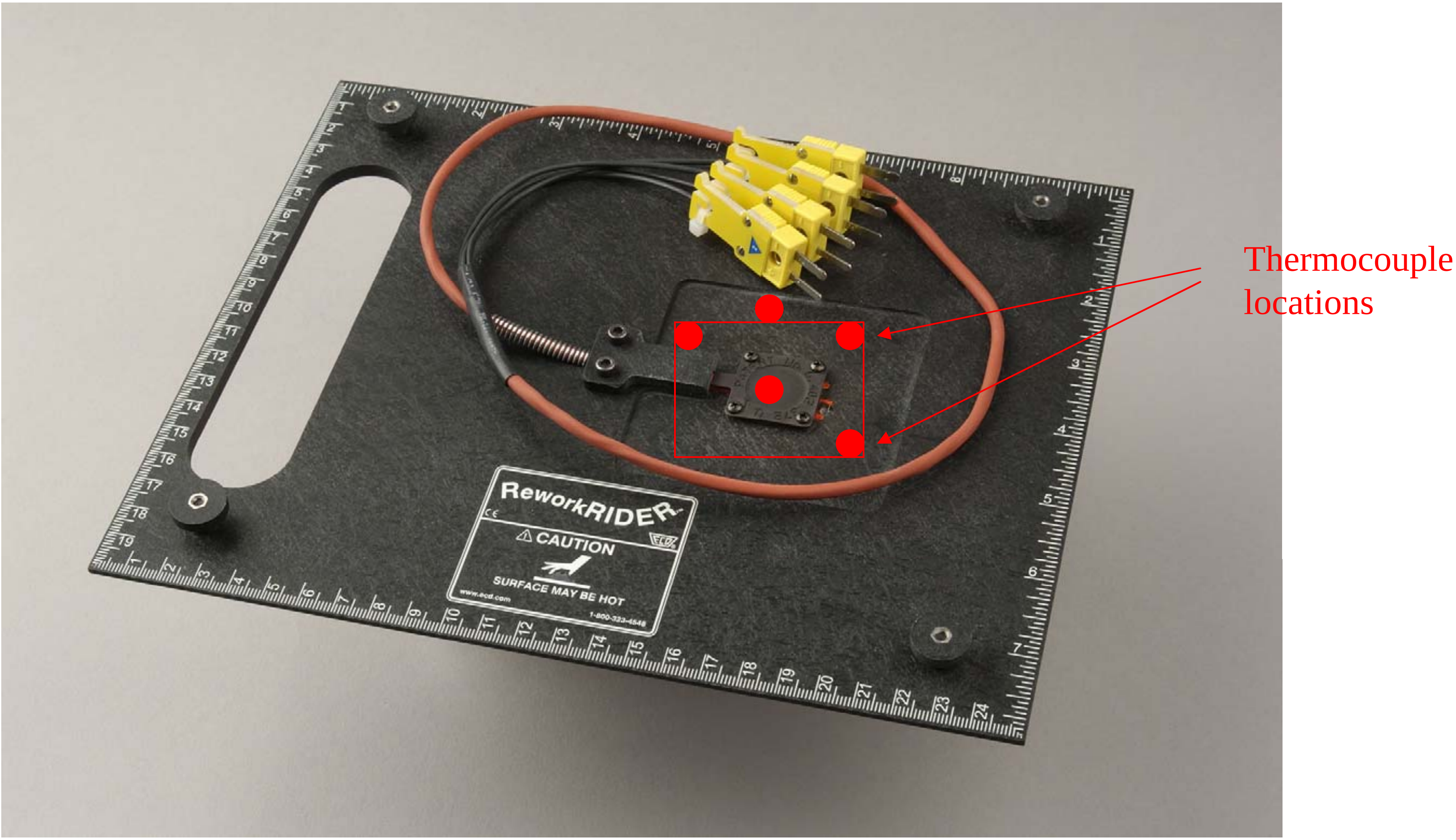
1) BGA/CSP Rework machine repeatability and Tolerance Temperature Study (Fixed Temperature Input: Measure Temperature Output)

Stage 1: Rework manufacturer to use retrofit ECD rework rider to record temperatures using defined lead-free rework temperature set-points and rework time durations with a specific rework machine

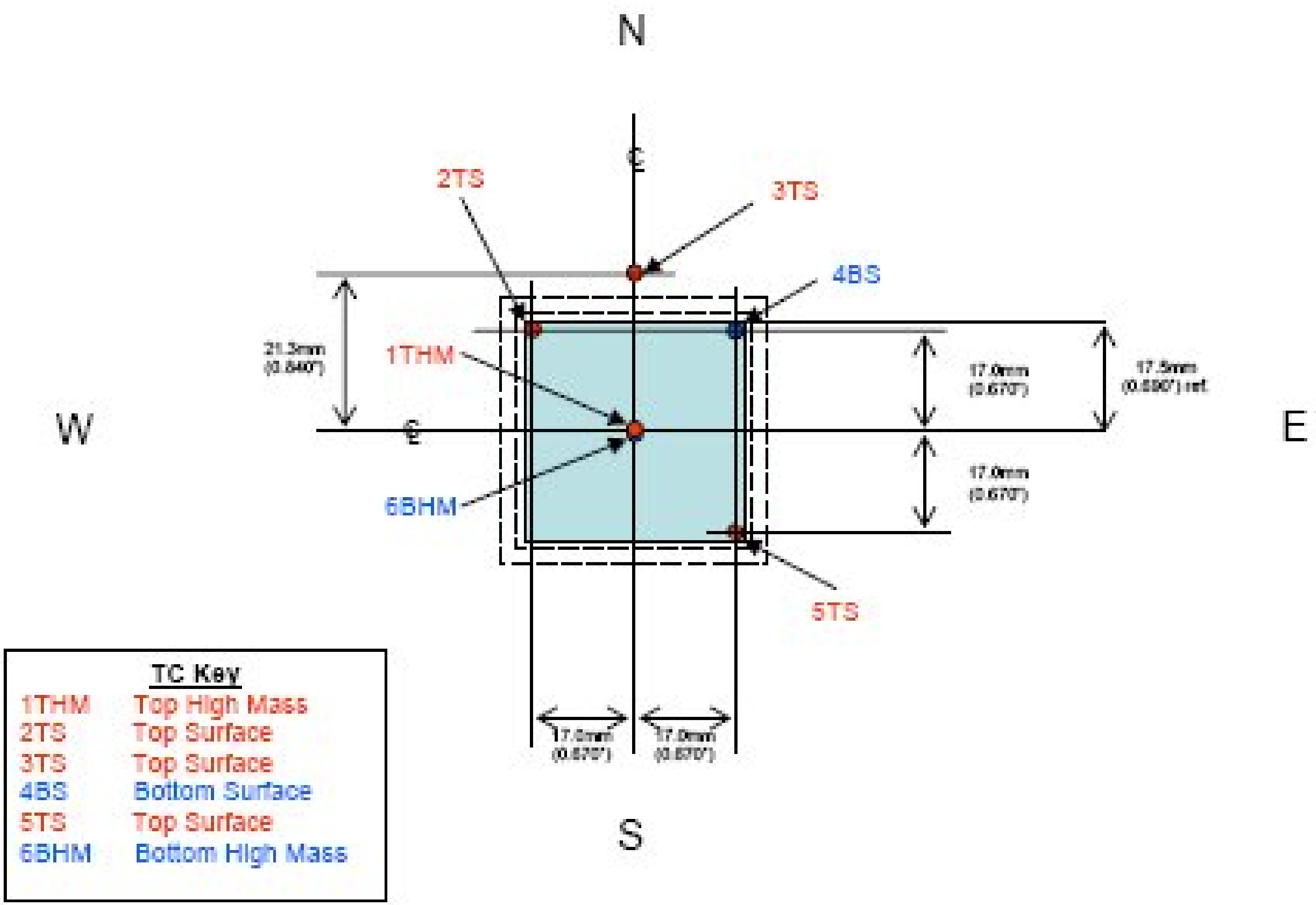
Stage 2: Same test at rework manufacturer with retrofit ECD rework rider with same machine model but with different rework machine, using same rework temperature set-points and time durations as Stage 1

Compare data from these stages to determine and improve rework machine temperature repeatability and tolerances

Retrofit ECD ReworkRIDER™ Thermocouple locations



Rework Rider TC locations



Rework Machine Supplier A Temperature Results Phase 1

Single Rework Machine Temperature Repeatability Results(with 99% Confidence Level in Repeatability of Temperature Measurements)

- **TC1 Top Center Average Peak Temperature = 274ºC +/- 4ºC**
- **TC2 Top North West Component Corner = 309ºC +/- 6ºC**
- **TC3 150mils away from Component on Topside = 264ºC +/- 5ºC**
- **TC4 North East Corner on Bottomside = 318ºC +/- 5ºC**
- **TC5 Top South East Component Corner = 279ºC +/- 5ºC**
- **TC6 Bottomside Center = 272ºC +/- 5ºC**

- **99% of the all readings are within +/-5ºC around the recorded peak temperature at each thermocouple location**

- **For example: If the recorded lead-free top component body peak temperature reading on a board was actually 250ºC, 99% of the time, the actual reading could be 5ºC lower (245ºC) or 5ºC higher (255ºC) than this value based on the temperature repeatability of this single rework machine**

Phase 1 and 2 Results (See IPC/APEX 2008 Conf. Paper)

Machine Repeatability	Typical	Worst Case
Machine A, Phase 1	+/- 5ºC	TBD
Machine B, Phase 1	+/- 3ºC	TBD
Machine C, Phase 1	+/- 7ºC	TBD
Machine D, Phase 1	+/- 1ºC	TBD
Machine A, Phase 2	+/- 6ºC	TBD
Machine B, Phase 2	+/- 4ºC	TBD
Machine C, Phase 2	+/- 6ºC	TBD
Machine D, Phase 2	+/- 2ºC	TBD
Thermocouple Repeatability	+/- 1ºC	+/- 2ºC

- Variations in temperature repeatability across rework machines of the same model from 4 different machine suppliers.
- Average repeatability across the four machines in the two phases to be +/- 5ºC.

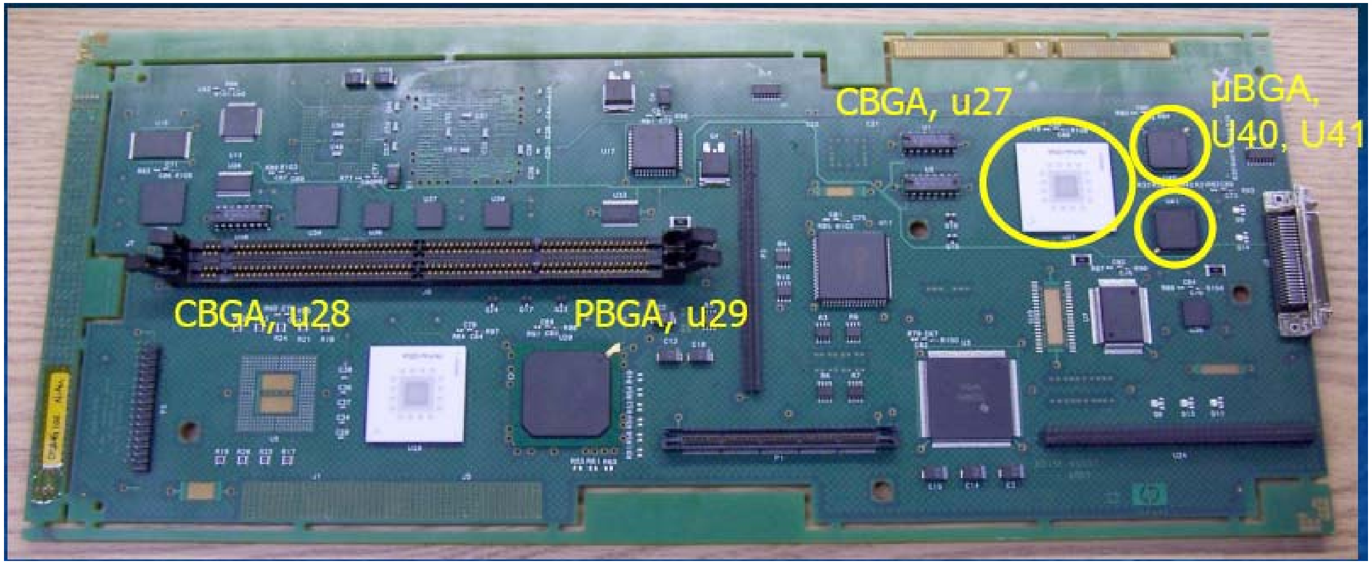
Conclusions

- The repeatability tests for rework machines from four rework machine suppliers indicated an average repeatability of +/- 5ºC.
- The rework machine temperature profiler was found to be fairly effective in measuring temperature repeatability of the rework machine equipment.
- Work highlighted need to keep tighter tolerances in the form of periodic machine calibrations and temperature profiling to prevent component temperature issues during lead-free rework.

Future Work

- Phase 3 to assess the rework temperature repeatability of the same model of machine at an OEM/EMS manufacturing site.
- Assessments to include variations in airflow used for the rework machine/ rework nozzle heights and the effect on temperature repeatability.
- Other areas which may influence temperature repeatability would be pre-heater settings, power supply settings, nozzle design which may be considered in future testing.

Adjacent Component Group (Holly-Dee Rubin)



INEMI Payette board: Spacing between components is 0.5 inch (13mm)

Previous Findings

Based on previous J-STD-020 reflow parameters

- **To maintain peak package temperature <250°C required increased bottom heater temperatures**
- **Reworking the µBGAs with increased bottom heater temperatures caused secondary reflow of the CBGA joints, and adversely impacted thermal fatigue life**

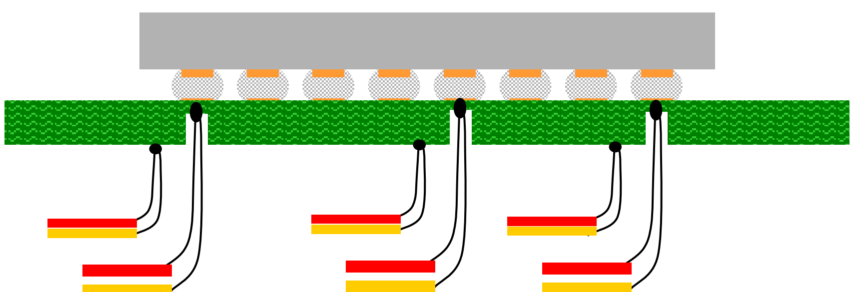
CBGA-uBGA Interaction Study

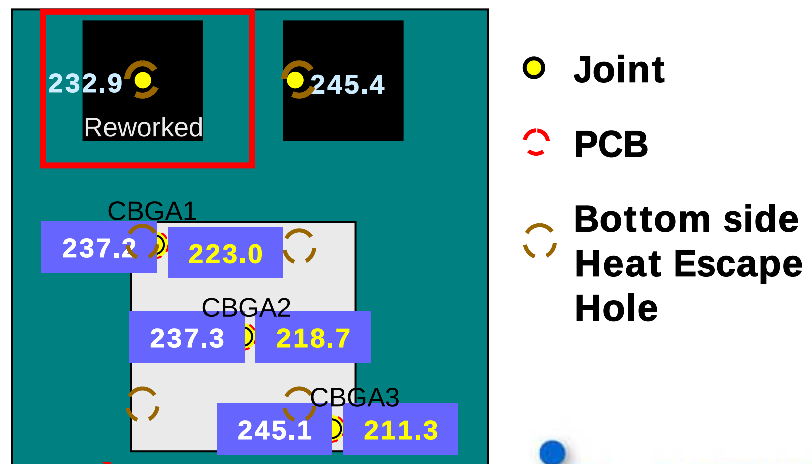
- **Observations:**
  - **Adjacent CBGA had liquidus temperatures (0.5 inch (13mm) away)**
  - **Thermal gradient across the CBGA package**

  (see table)

Joint and Package Temp Monitored Values

TC Location	Peak Temp (C)
Reworked uBGA Joint	232.9
Adjacent uBGA Joint	245.5
CBGA 1 Joint	223.0
CBGA 1 Bottom PCB	237.2
CBGA 2 Joint	218.7
CBGA 2 Bottom PCB	237.3
CBGA 3 Joint	211.3
CBGA 3 Bottom PCB	245.1





CBGA solder joints below and some above liquidous temperature

Adjacent Component Group

Objectives

- Stay within J-STD-020D (260°C peak) parameters when reworking components
- Ensure adjacent component joint temperatures remain below liquidus

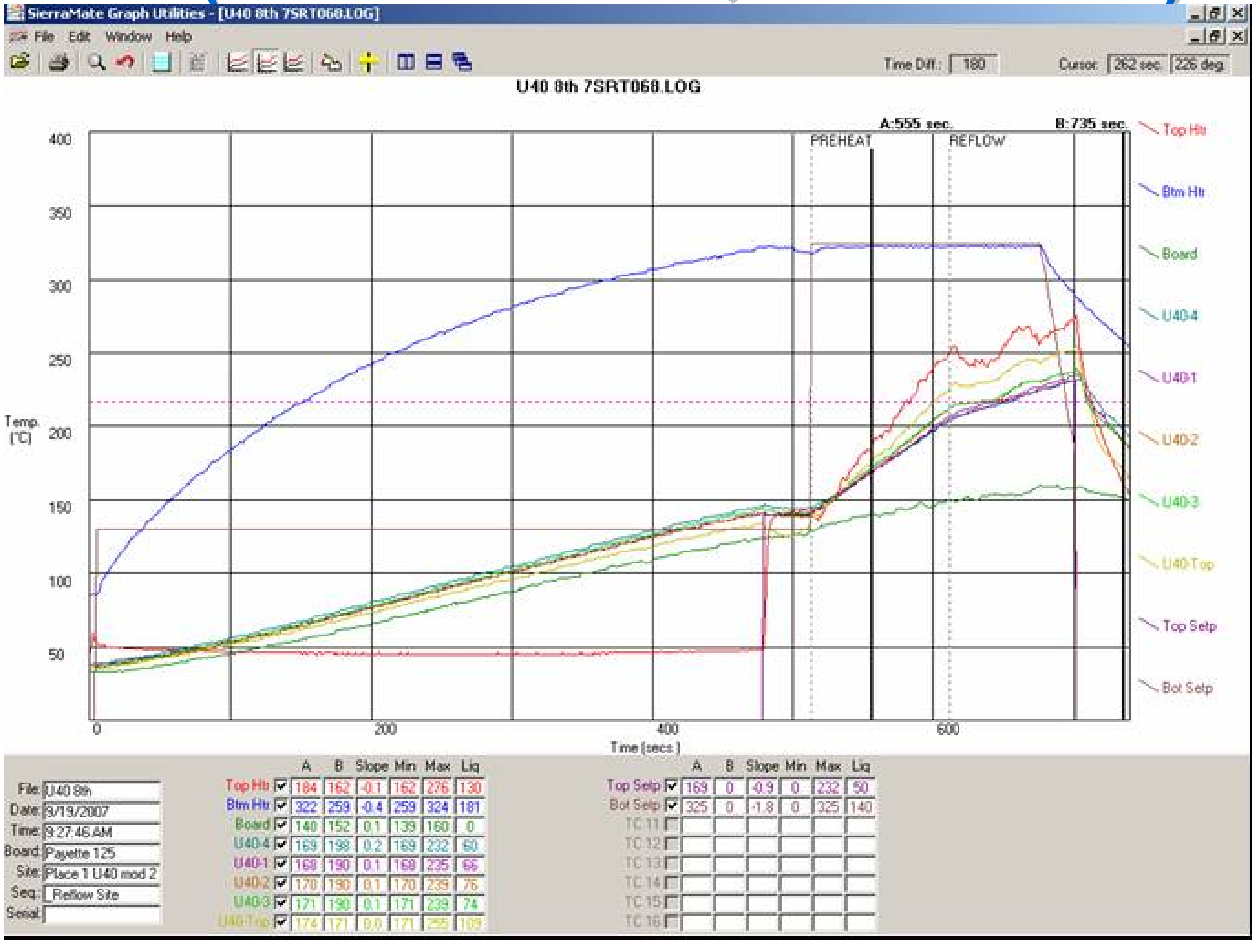
Solutions Explored

- Heat shields
- Rework profile re-optimization

Adjacent Component Temperature Results

- Using the increased maximum allowed package temperature in J-STD-20D, a rework profile was developed that kept the adjacent CBGA joints below the Sn3Ag0.5Cu liquidus temperature (217°C) in all cases.
- During rework of the U40 uBGA component, the peak solder joint temperature of the CBGA (U27) was 204°C.
- Use of either an Aluminum or Ceramic heat shield (over the CBGA) lowered the joint temperatures on the CBGA by about 2°C to 4°C.

Representative Lead-free UBGA Rework Profile (Leo Anderson, Flextronics)



U40 Solder Joint peak temp.: 232 to 239 °C. Time over 217C= 60 to 74 sec

U40 Component top peak temp.: 255 °C. Time over 217C= 109 seconds

Conclusions

- **A lead-free rework profile was developed which kept the adjacent CBGA solder joints below liquidus (217°C) whilst keeping the reworked uBGA component within J-STD-020D limits.**
- **Found that heat shields (Al and Ceramic) helped to reduce the temperature of the adjacent CBGA but not to a large extent (2°C to 4°C)**

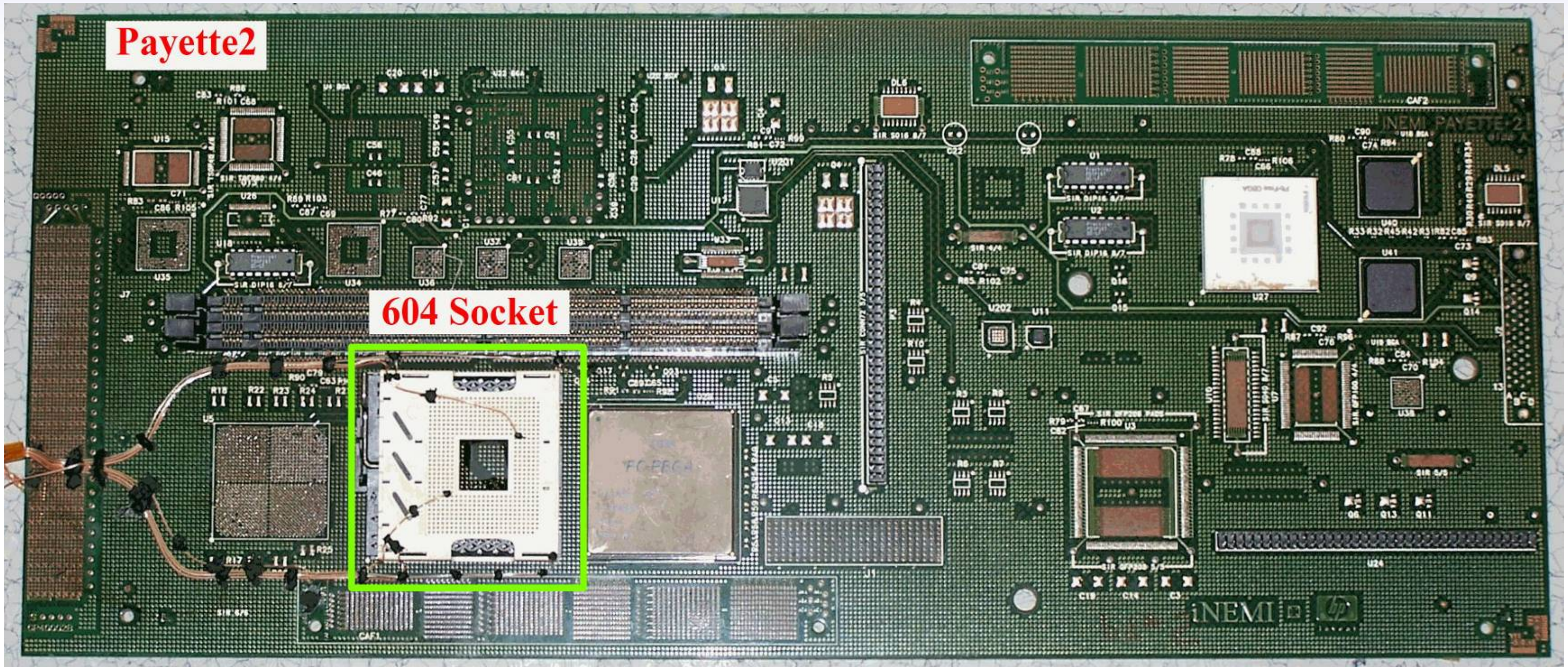
Next Steps

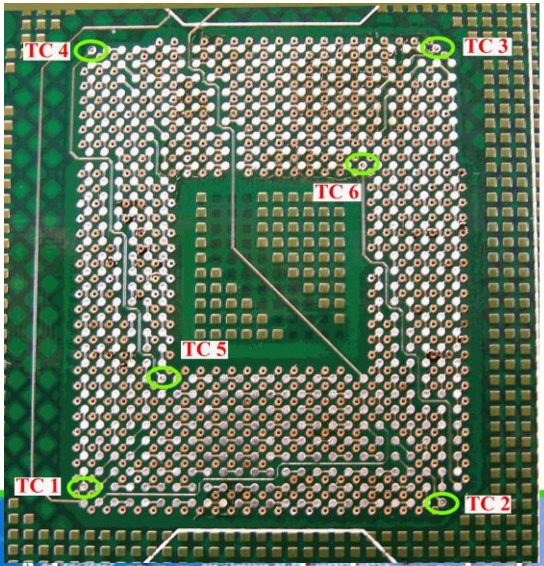
- Rework more boards for cross-sectional analysis and electrical testing to confirm that the adjacent CBGA components have not undergone partial melting/reflow.
- Further optimize rework process ready for reworking boards for ATC testing.

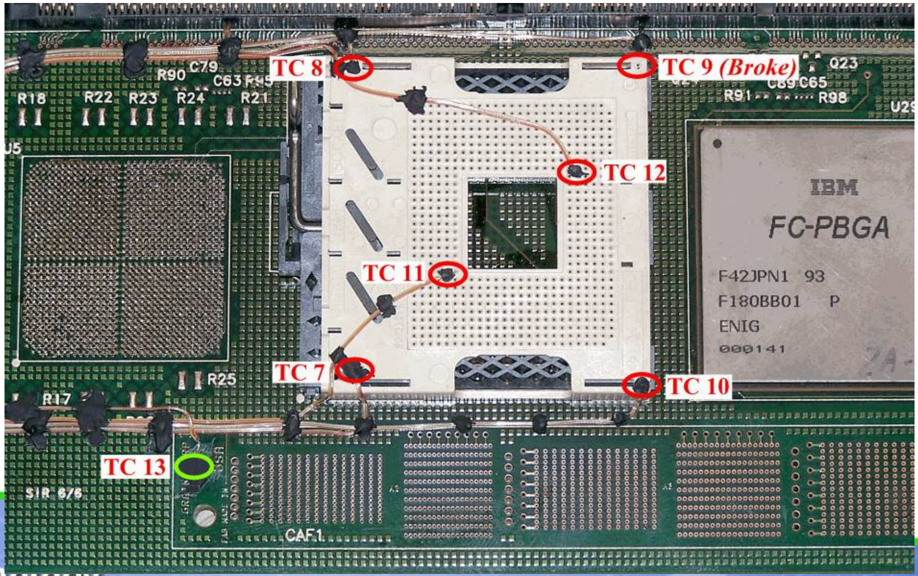
Lead-free BGA604 Socket Rework (Alan Donaldson)

- Create a lead-free board rework profile for the BGA 604 socket on the INEMI Payette board
- Rework the sockets and verify they pass electrical test
- Measurement of stand-off height

INEMI Payette BGA604 Socket Profile Board Setup







TC1-4 Socket Outer Corner Solder Joints

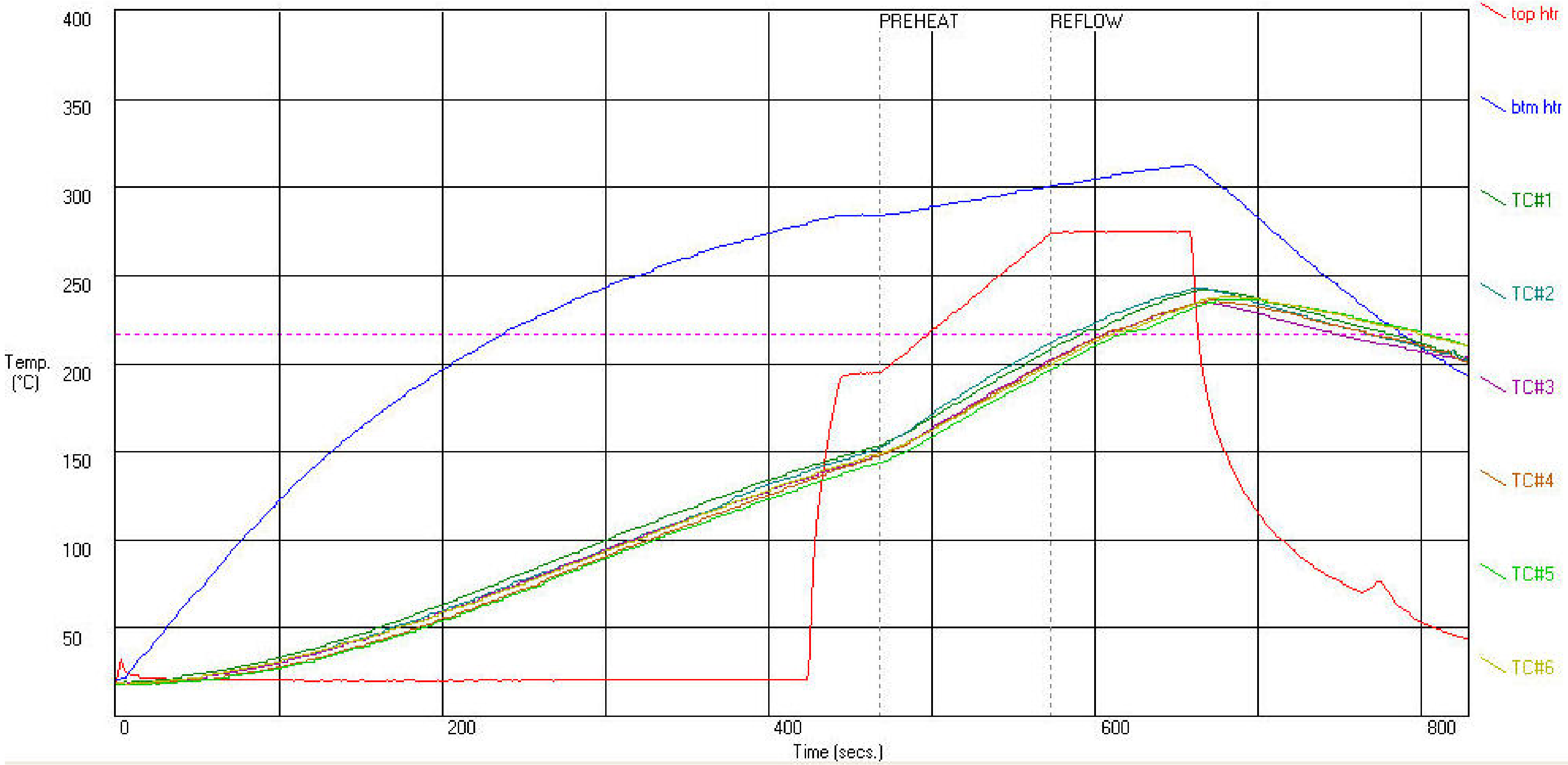
TC5-6 Socket Center Solder Joints

TC7-10 Socket Top Body

TC11-12 Socket Body Top Pin Holes

TC13 CAF1 Board Location

BGA 604 Socket Rework Temperature Profile



- **Soak Time (150- 217°C) = 124 to 139 sec**
- **Time above liquidus (217°C) for solder joints = 137sec to 185 sec**

BGA 604 Socket Rework Temperature Profile

Thermocouple Solder Joint Description	Rising Ramp Rate/ **°C/sec**	Flux Activation Time (150°C to 217°C)	Critical Ramp Rate (205°C to 215°C) **°C/sec**	Socket Peak Temperature (230°C to 250°C)	Socket Time Above Liquidus (40-200sec)	Falling Ramp Rate/ **°C/sec**
TC1 Pin 1 Outer Corner	**0.5**	139sec	**0.5**	**242°C**	**186sec**	**- 0.2**
TC2 Outer Corner	**0.6**	124sec	**0.5**	**243°C**	**180sec**	**- 0.3**
TC3 Outer Corner	**0.5**	132sec	**0.4**	**235°C**	**137sec**	**- 0.2**
TC4 Outer Corner	**0.5**	132sec	**0.5**	**236°C**	**159sec**	**- 0.2**
TC5 Center	**0.5**	132sec	**0.5**	**236°C**	**182sec**	**- 0.1**
TC6 Center	**0.5**	138sec	**0.5**	**238°C**	**185sec**	**- 0.2**

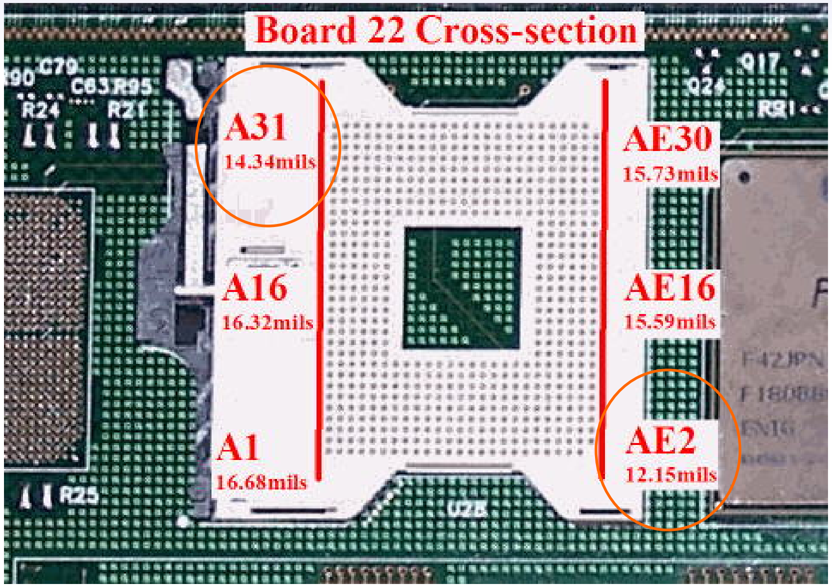
- **Flux activation time is above target of 100 second and falling rate ramp is slow**
- **Time above liquidus (217°C) is on the high side (up to 186 sec)**

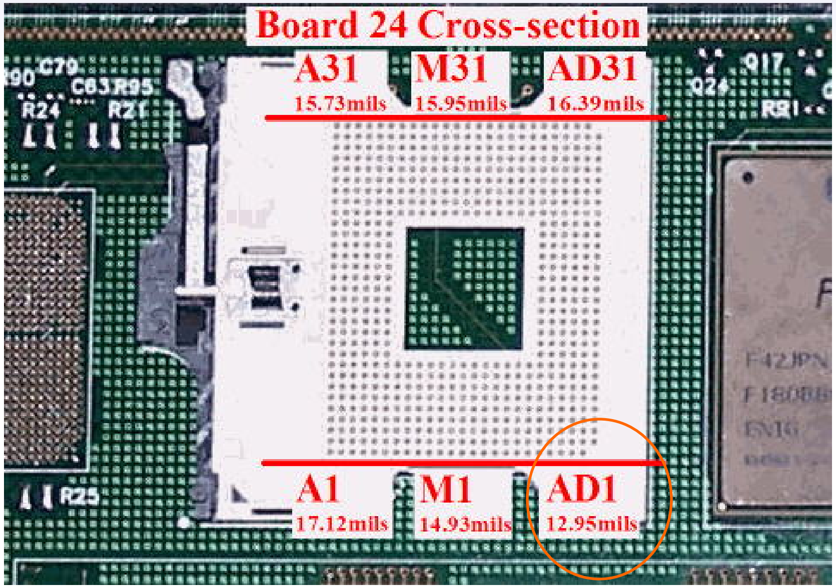
BGA604 Socket Rework Temperature Profile (continued)

Thermocouple Description	Socket Body Temperature (260°C Maximum)	Maximum Board Temperature
TC10 Socket Top Body	**257°C**	**X**
TC11 Socket Top Body Pin Hole	**239°C**	**X**
TC13 CAF1 Board Location	**X**	**217°C**

- Socket body below 260°C (257°C)
- Part of the CAF1 board area is at or above the reflow temperature (217°C)
  - All the area within 0.7 inch of the BGA604 socket
- Time above liquidus for sockets are very long (up to 186 sec) because the heat gets trapped in the center
  - The BGA rework machine had a bottom heater that is 14 X 21inch
    - This heater size makes it hard to heat up and cool down quickly
    - Compare this with J-STD-020D standard which indicates Time above liquidus for a component should be between 60 and 150 seconds
- All four reworked boards passed electrical resistance test

604 Socket Stand-off Results





–Board 22 cross-section shows that the socket sinks chips down on the A31 & AE2 corners

- The A31 corner stand-off is approximately 2.5mils lower
- The AE2 corner stand-off is approximately 3.5mils lower

–Board 24 cross-section shows only the AD1 corner to have a larger collapse than all other measurements

- The AD1 corner stand-off is approximately 4mils lower

–This is a fairly common observation in Lead-free BGA socket rework

Summary

– Flux activation time and falling ramp rate exceeds specification
  - The BGA rework machine has large bottom heater which makes it hard to heat up and cool down quickly

– Time above liquidus for sockets are very long (up to 186sec)
  - Compare this with J-STD-020D standard (Time above liquidus for a component should be between 60 and 150 seconds)

– Reworked BGA socket sinks down on the certain corners
  - This is a fairly common observation in Lead-free BGA socket rework

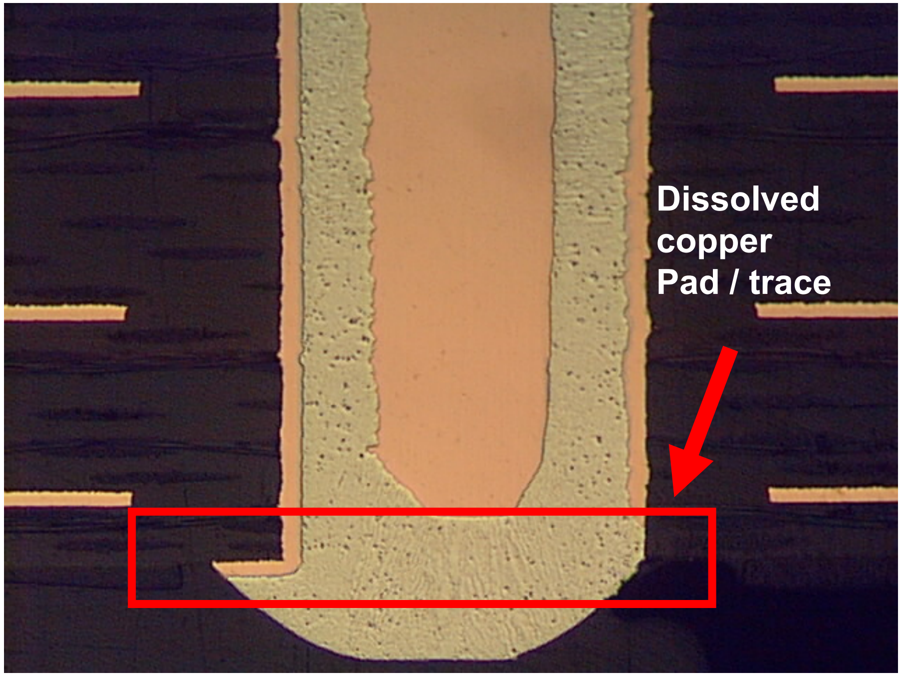
– Reworked BGA socket passed electrical measurements

Next Steps

- Cross-sectional analysis for reworked boards for intermetallic measurements
- Further optimize rework process ready for reworking boards for ATC testing.

Previous iNEMI Mini-Pot Payette Board Results Showing PCB Copper Dissolution of Reworked PDIP16 Solder Joint (SnAgCu, NiAu board, 135 mil thick)

- Challenge
  - –Simulate current production process
  - –Remove and replace a PDIP without board preheat
- Rework Observations
  - –Achieving sufficient holefill resulted in the copper pad/trace dissolution on the bottom-side



Cross-section View of Solder Joint (274

Total time in mini-pot= 60sec

Enough time to dissolve nickel layer

iNEMI

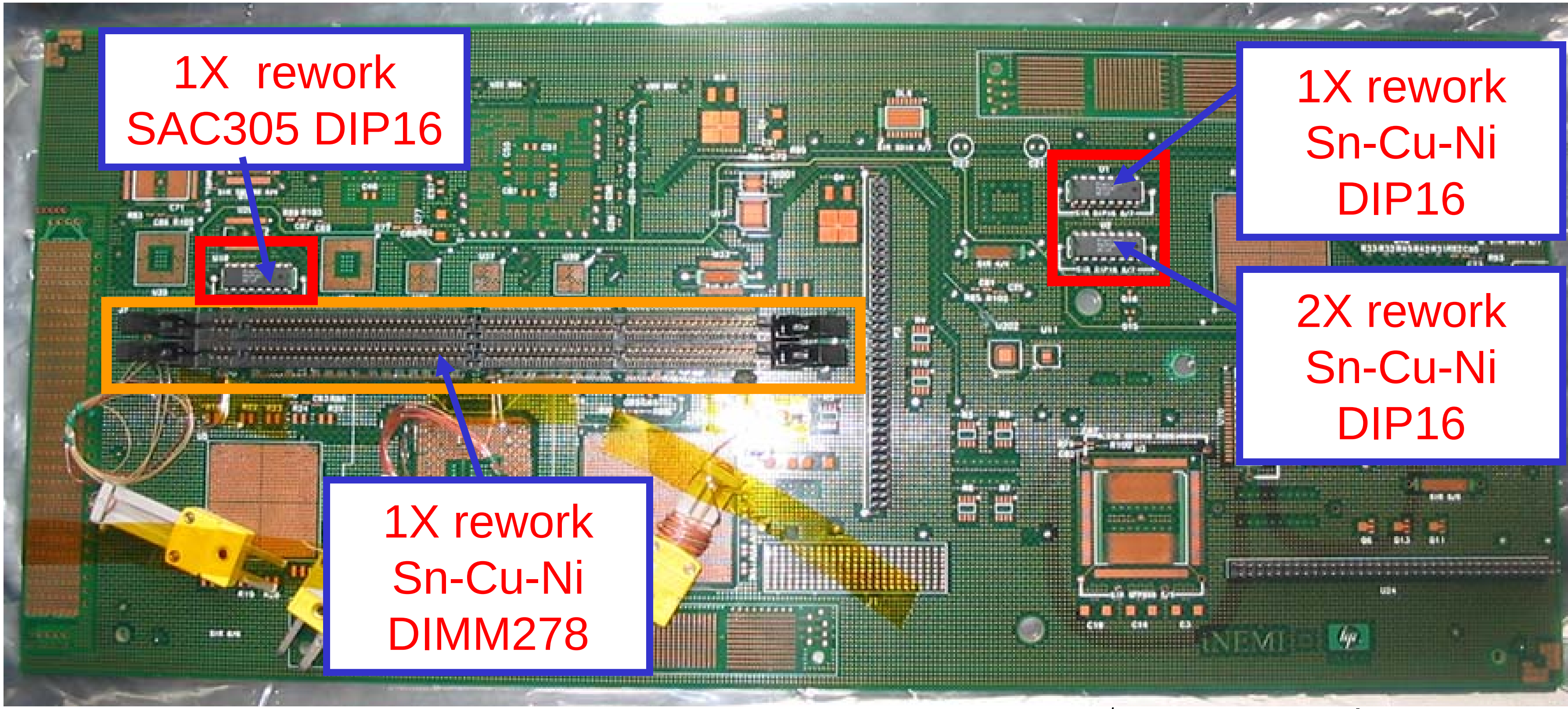
Advancing manufacturing technology

Mini-pot Rework (Phase 1)

- Generally speaking there was evidence of reduced copper dissolution when reworking 1st pass SnAgCu wave soldered boards with Sn-Cu-Ni compared with rework using SnAgCu.

- Further optimization and development work will be done on the iNEMI Payette Board which is 125mil thick (OSP coated) with concentration on the DIMM 278 connector and DIP16 component (Phase 2)

PTH Rework Locations (Phase 2)

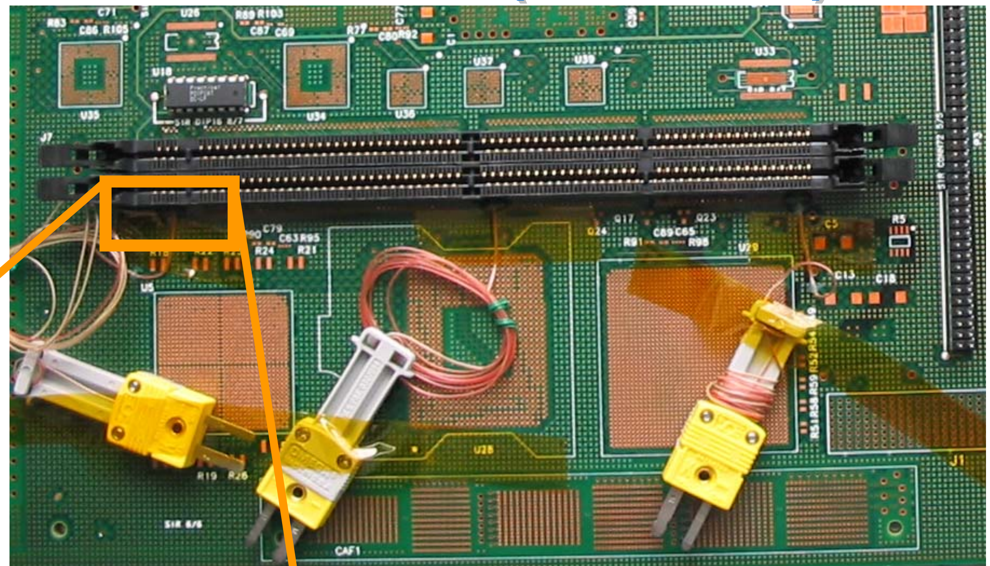


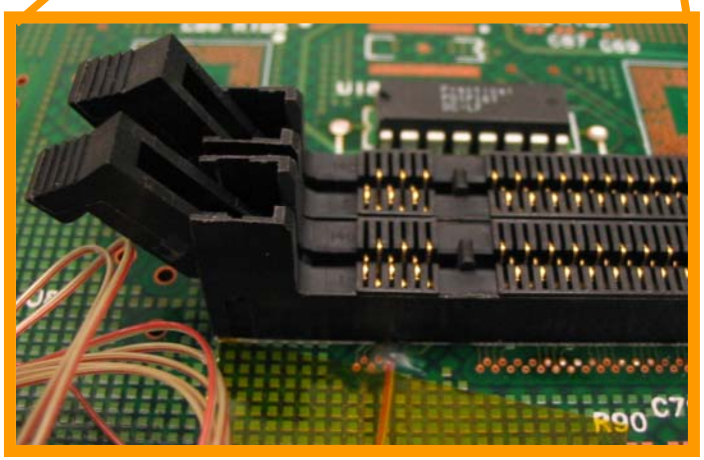
- 2 DIMM278 Connectors
- 3 PDIP16 Components

Note: 1st pass wave using $Sn_3Ag_{0.5}Cu$

iNEMI

DIMM Connector Rework Thermocouple Locations (Phase 2)





- 3 Thermocouple Locations, topside lead
- Edge and center lead locations
- Monitor temperature to understand contact time required for reflow
- Also used to profile preheat profile
- Dummy copper traces on bottom side to measure copper dissolution

Phase 3 PTH Rework Matrix (ATC testing)

Component ›	µBGA 1	µBGA 2	CBGA 1	CBGA 2	BGA Socket	QFN-20	QFN-56	DIMM 1	DIMM 2	PDIP 1	PDIP 2	PDIP 3	TOTAL 1X Reworks	TOTAL 2X Reworks
REWORK ALLOY ›							SAC305	Sn-Cu-Ni	SAC305	Sn-Cu-Ni	Sn-Cu-Ni	SAC305		
Ref Desig. ›								J7	J8	U1	U2	U18		
Board 1								1X	N/A	1X	2X	1X	7	2
Board 2								1X	N/A	1X	2X	1X	7	2
Board 3								1X	N/A	1X	2X	1X	7	2
Board 4								1X	N/A	1X	2X	1X	7	2
Board 5								1X	N/A	1X	2X	1X	7	2
Board 6								1X	N/A	1X	2X	1X	7	2
Board 7								1X	N/A	1X	2X	1X	7	2
Board 8								1X	N/A	1X	2X	1X	7	2
Board 9								1X	N/A	1X	2X	1X	7	2
Board 10								1X	N/A	1X	2X	1X	7	2
Board 11								1X	N/A	1X	2X	1X	7	2
Board 12								1X	N/A	1X	2X	1X	7	2
Board 13								1X	N/A	1X	2X	1X	7	2
Board 14								1X	N/A	1X	2X	1X	7	2
Board 15								1X	N/A	1X	2X	1X	7	2
Board 16								1X	N/A	1X	2X	1X	7	2
Board 17								1X	N/A	1X	2X	1X	7	2
Board 18								1X	N/A	1X	2X	1X	7	2
Board 19								1X	N/A	1X	2X	1X	7	2
Board 20								1X	N/A	1X	2X	1X	7	2
Board 21								1X	N/A	1X	2X	1X	7	2
Board 22								1X	N/A	1X	2X	1X	7	2
Board 23								1X	N/A	1X	2X	1X	7	2
Board 24								1X	N/A	1X	2X	1X	7	2
Board 25								1X	N/A	1X	2X	1X	7	2
Board 26								1X	N/A	1X	2X	1X	7	2
Board 27								1X	N/A	1X	2X	1X	7	2
Board 28								1X	N/A	1X	2X	1X	7	2
Board 29								1X	N/A	1X	2X	1X	7	2
Board 30								1X	N/A	1X	2X	1X	7	2
Board 31								1X	N/A	1X	2X	1X	7	2
Board 32								1X	N/A	1X	2X	1X	7	2
Board 33 TIME ZERO Cross Section								1X	N/A	1X	2X	1X	7	2
Board 34 TIME ZERO Cross Section								1X	N/A	1X	2X	1X	7	2
Board 35 TIME ZERO Cross Section								1X	N/A	1X	2X	1X	7	2
TOTAL 1X Reworks							2	32	0	32	0	32		
TOTAL 2X Reworks								0	0	0	32	0		
TOTAL 1X Hand Rwks	0	0	0	0	0	0	0	0	0	0	0	0		

PTH Rework Objectives:

- Validate process and reliability of reworking a Sn3Ag0.5Cu joint with Sn-Cu-Ni alloy (mixed case)
- Validate process and reliability (ATC) of reworking Sn3Ag0.5Cu joint with Sn3Ag0.5Cu alloy
- Measure levels of Cu dissolution for both types of reworked joints
- 1X rework on DIMM278
- 1X and 2X rework on DIP16

Next Steps

- Develop rework process for DIP16 with SnAgCu and SnCuNi alloys
- Develop rework process for DIMM278 components with SnCuNi
- Cross-sectional analysis for reworked boards to measure copper dissolution and solder joint integrity
- Further optimize rework process ready for reworking boards for ATC testing.

NEMI Rework Optimization Project Next Steps

- Group's work has concentrated on
  - Mini-Pot rework optimization
  - Rework Machine Temperature Repeatability
  - Adjacent component temperatures during rework
  - BGA socket

Optimize process for Mini-pot rework, adjacent component and BGA socket rework before ATC testing of reworked boards

Acknowledgements

- The main group and sub-group chairs would like to thank the INEMI rework project team for their input and efforts into this work.