iNEMI®

International Electronics Manufacturing Initiative

# BFR-Free High Reliability Project

*Project Leader*
*Stephen Tisdale,*
*Intel Corporation*

Advancing manufacturing technology

Thrust Area:
Energy & Environment

TIG:
ECE & Substrates

# BFR-Free High Reliability PCB Project

Feb-12

## •Project Members

Agilent Technologies

DELL

Celestica™

CISCO

DOOSAN Doosan Corporation Electro-Materials

EMC ELITE MATERIAL CO., LTD.

hp invent

intel

iST INTEGRATED SERVICE TECHNOLOGY

ITEQ

NAN YA

ROHM AND HAAS

Sun microsystems

# iNEMI BFR-Free High Reliability PCB Project

| *IS / IS NOT* | |
|---|---|
| **This Project IS:** | **This Project IS NOT:** |
| Technical evaluation of key electrical and mechanical properties | An EHS assessment |
| Focused on those attributes which are of most value to supply chain | Biased towards specific laminate suppliers, geographies, or market segments |
| Build on learning from prior investigations | Repeat of prior work |
| Focused on completely HF SMT and Wave Solder Assembly & Rework Capability | Focused on standard processing |
| Focused on circuit board materials in LF assembly and LF solder joint reliability - Board / Component Interaction | Focused only on materials characterization |

# •iNEMI BFR-Free High Reliability PCB Project

## •Phase 1: Design

•***Goal:*** *Review prior work and make recommendations for testing*
•*needed. Investigation should take into account the needs of*
•*electronic product sectors represented by iNEMI membership*

- **Identify market segment requirements**
- **Identify candidate materials**
- **Identify key performance characteristics and test criteria**
- **Design test vehicle(s) and test methodologies, leverage •standards where possible**
  - Identify Components to be used in this project to evaluate SJR / board reliability

# •iNEMI BFR-Free High Reliability PCB Project

## •Phase 2: Test

•***Goal:*** *Develop, manage, and execute performance testing*

- **Develop evaluation schedule**
- **Procure parts and test vehicles**
- **Assign teams to carry out completion of the testing in a •standardized fashion**
  **•.**
- **Perform mechanical and reliability testing on test vehicles.**

# •iNEMI BFR-Free High Reliability PCB Project

## •Phase 3: Results

•***Goal:*** *Compile results, assess significance, make recommendations,*
*•and publish report*

- **Assess performance relative to market segment requirements**
- **Assess technology readiness / identify gaps**

•• **Assess manufacturing capability and supply capacity**

•• **Publish results**

# •iNEMI BFR-Free High Reliability PCB Project

## •*Anticipated Outcomes*

- **Validate electrical and mechanical properties**
  - Loss tangent and Dk modeling over required range of signal speed
  - Mechanical performance validation for lead free assembly and rework
    - (delamination)
  - Critical Test Parameter Evaluation (CAF, IST, flex, etc.)

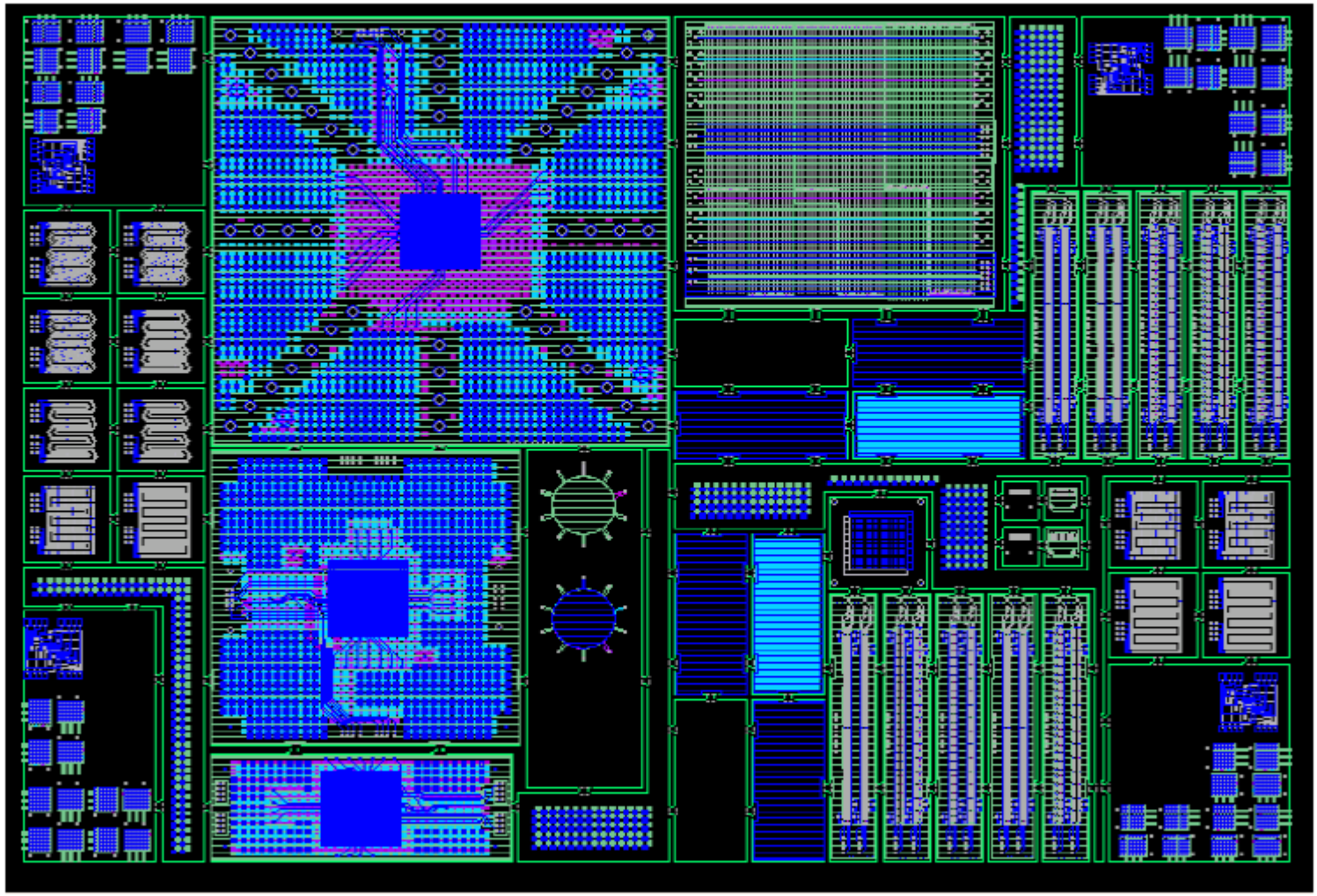
- **Validate Board Level Reliability Capability**
  - PCB Modulus / Thickness Impact on Mechanical Capability
  - HF Board Level Assy / Rework Process Characterization
  - Mechanical Characteristics (Pad Crater / Ball Pull etc)
  - CTE Characteristics
  - SJR (Shock / TC etc)
  - HF Component / HF PCB

# iNEMI HFR-Free High Reliability PCB Project

- Focus is on Hi-Rel (Server) Market Segment Application Space
- PCB and PCBA components are HFR-free (Low-Halogen)
- Board Thicknesses are 0.093” & 0.125” (MEB’s) & 0.116” (Agilent)
  - PCB Material should be LF compatible, low / med loss and HVM capable – 8 BFR-free Materials Identified with 1 Halogenated Material as Control
  - All TV’s have been completed and are being tested (estimated completion is end of Q4’11)

| | | | |
|---|---|---|---|
| | | | |
| | MEB III | MEB III | nt |
| Thick | yer / 0.093 | yer / 0.125 | / 0.116 |
| ill Sizes | 0mil / 12mil | l / 14 | |
| tch | 1.0mm | 1.0mm | m |

# Intel MEB 93 – 18 Layer



- 22.25” X 15.75” in size
- Modular in design
- MEB125 – 24 Layer same footprint

# •Stack-ups

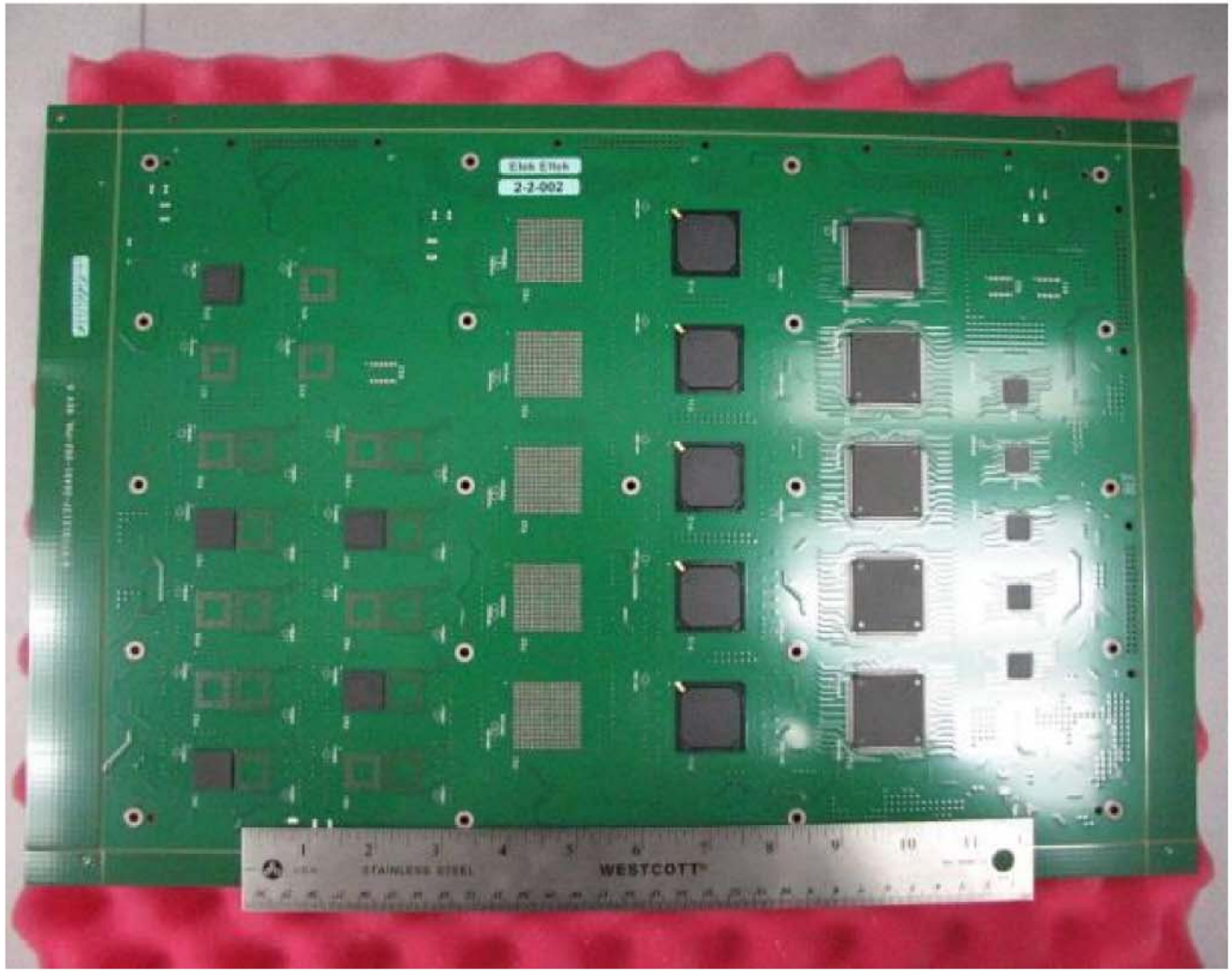
MEB 125 Stack up

| | Description | Layer Type | Thickness | |
|---|---|---|---|---|
| Layer 1 | Plated 1/2 oz Cu | S | 1.6 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 2 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 3 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 4 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 5 | Unplated 1 oz Cu | S | 1.4 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 6 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 7 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 8 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 9 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 10 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 11 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 12 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 13 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 14 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 15 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 16 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 17 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 18 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 19 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 20 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 21 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 22 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 23 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 24 | Plated 1/2 oz Cu | S | 1.6 | mils |

MEB 93 Stackup

| | Description | Layer Type | Thickness | |
|---|---|---|---|---|
| Layer 1 | Plated 1/2 oz Cu | S | 1.6 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 2 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 3 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 4 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 5 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 6 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 7 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 8 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 4 | mils - 1 ply 2116 |
| Layer 9 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 10 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 4 | mils - 1 ply 2116 |
| Layer 11 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 12 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 13 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 14 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 15 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 16 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 4 | mil core - 1 ply 2116 |
| Layer 17 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 18 | Plated 1/2 oz Cu | S | 1.6 | mils |
| | | | 95.7 | |

# •Agilent Test Board




| Components | Quantity |
|---|---|
| BGA388T1.0C-DC264D | 5 |
| BGA208T.8C-DC170D | 5 |
| QFP120T30T3.2-DE-D | 5 |
| MLF68T.5-T-DE-D | 5 |

•**Stencil Information**

•Thickness: 5 mils

•Type: Laser Cut

•Aperture Size:

•BGA208 - Round 15.000 milBGA388 - Round 20.000 milQFP120 - Rectangle 15.000 mil x 75.000 mil

•QFN 68 - Oblong 9.000 mil x 37.000 mil

•**Paste**

•OM338PT (Type 3)

# •Agilent Stack-up

Agilent Stackup

| | Description | Layer Type | Thickness | |
|---|---|---|---|---|
| Layer 1 | Plated 1/2 oz Cu | S | 1.6 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 2 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 3 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 4 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 5 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 6 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 7 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 8 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 9 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 10 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 11 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 12 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 13 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 14 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 15 | Unplated 2 oz Cu | P | 2.6 | mils |
| | Prepreg | | 4.5 | mils - 2 ply 1080 |
| Layer 16 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 17 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Core | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 18 | Unplated 1 oz Cu | P | 1.3 | mils |
| | Core | | 5 | mil core - 1 ply 2116 |
| Layer 19 | Unplated 1 oz Cu | S | 1.3 | mils |
| | Prepreg | | 3.5 | mils - 1 ply 2113 or 3313 or 2112 |
| Layer 20 | Plated 1/2 oz Cu | S | 1.6 | mils |
| | | | 115.8 | |


| Materials Chosen For Evaluation | MEB 0.093" | MEB 0.125" | Agilent TV |
|---|---|---|---|
| A | Complete | Complete | Complete |
| B | Complete | Complete | Complete |
| C | Complete | Complete | Complete |
| D | Complete | Complete | Complete |
| E | Complete | Complete | Complete |
| F | Complete | Complete | Complete |
| G | Complete | Complete | Complete |
| H (Control) | Complete | Complete | Complete |
| I | Complete | Complete | Complete |

## •Assembly Conditions at Celestica

18 layer 0.093" MEB:
- 6 panels @ 245C 6X
- 6 panels @ 245C 10X
- 6 panels @ 260C 6X
- 6 panels @ 260C 10X
- 6 panels – no reflow conditioning

24 layer 0.125" MEB:
- 6 panels @ 245C 6X
- 6 panels @ 245C 10X
- 18 panels – no reflow conditioning

20 layer 0.116" Agilent:
- 8 panels assembled with components @ 245C
- 5 panels bare @ 245C 6X
- 5 panels no reflow conditioning

# •iNEMI BFR-Free High Reliability PCB Project
# •MEB Test Status

| Material / Stackup | A | | B | | C | | D | | E | | F | | G | | I | | H (Control) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 | .093 | .125 |
| IST - Intel | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| CAF - Doosan/Intel | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Flex Mod - Doosan | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Tg / z- CTE - Doosan | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Solder Float - ITEQ | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Dk & Total Loss up to 30GHz - Intel | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Moisture Diffusivity Insertion Loss - Intel | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 | 3/1 |
| Drill Reg - Intel | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| HATS - IBM | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |
| Board Side Ball Pull - Intel | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C | C |

•Not started

•In Process

•Complete

- Moisture Diffusivity testing to complete in March by Intel

- IST - IPC TM-650-2.6.26, 10% resistance change cycled RT to 150C to a maximum cycle count of 1000.

- CAF - IPC-TM-650-2.5.25.1
  1. Stabilize samples for 24 hours at 23C and 50%RH
  2. Perform initial measurements
  3. Precondition samples for 96 hours at test temp and humidity
  4. Apply bias and perform Insulation Resistance (IR) measurements for 1000 hrs

  •The testing differences at Doosan and Intel were as follows:

| Test Site | Test Temp | Test Humidity | Test Voltage |
|---|---|---|---|
| Doosan | 65C | 85% | 100V DC |
| Intel | 85C | 85% | 80V DC |

- Flex Modulus - ASTM D790 procedure. Test samples in X and Y direction

  Instrument: Instron 4202
  •Specimen dimension: 75 mm X 32 mm
  •Fixture: 3 point bending
  •Span: 38.4mm
  •Crosshead speed: 0.45mm/min


- **Tg/ Z-CTE – IPC-TM-650-2.4.24**
  - **Instrument: TMA 2940**
  - **Specimen dimension: 6.35mm X 6.35mm**
  - **Mode: Expansion**
  - **Preconditioning: for 2hrs at 105℃**
  - **Program: Ramp 10℃/min to 200℃, isothermal 5min, and ramp 5℃/min to 280℃**

- **Solder Float – IPC TM-650-2.6.8 Test Condition A (288C for 10 sec) repeat to 6X**

- **Dk and Total Loss – S parameter extraction**
  - **Instrument: Agilent E8364B Performance Network Analyzer**
  - **Specimen dimension: 5 mil nominal trace, 5 inches long**
  - **Test structures: Microstrip (Layer 1 to 2, no soldermask), Microstrip (Layer 1 to 2, soldermask), and Stripline (Layer 2 to 1 and 3)**
  - **Frequency Range: 10MHz to 50GHz**

- **Moisture Diffusivity – S parameter extraction**
  - **Instruments: Espec ECL 2CA Temperature Humidity chamber and HP 8510C VNA**
  - **Test structures: 5 mil nominal trace as microstrip and embedded microstrip every layer**

  **Frequency Range: 10MHz to 20GHz**
  - **Test Conditions: 1) initial readings, 2) soak at 35C/85% RH until readings reach asymptotic state, 3) dry bake at 105C/0%RH until readings reach asymptotic state, 4) soak at 85C/85%RH until readings reach asymptotic state, and 5) dry bake at 105C/0%RH until readings reach asymptotic state.**

# •iNEMI BFR-Free High Reliability PCB Project
# •MEB Test Parameters

- **Drill Registration - Electrical test Beep test coupon by layer**

- **HATS - Modified IPC TM-650-2.6.7, 10% resistance change cycled -45C to 145C to a**
  - **maximum cycle count of 500.**
  - **Instrument: ITRS HATS Tester**
  - **Specimen: In-line and offset 10 mil via daisy chains at 18 and 22 mil via to via spacing**

- **Ball Pull - IPC 9708 Test Standard (Ball Pull Method).**
  - **Instrument: Dage 4000 with 5Kg Ball Pull cartridge and 750um jaw**
  - **Specimen: 20 mil SAC 405 Ball on 16 mil nominal diameter PCB pad**
  - **Test Parameters: 23psi clamp pressure, 1 sec jaw closing time, 5mm/sec pull speed**

# iNEMI BFR-Free High Reliability PCB Project - Agilent Bd

| MATERIAL | A | B | C | D | E | F | G | I | H (Control) |
|---|---|---|---|---|---|---|---|---|---|
| Monotonic Bend and FA - IST | Complete | Complete | Complete | Complete | Complete | Complete | Complete | Complete | Complete |
| HALT and FA - HP | Update | Update | Update | Update | Update | Update | Update | Update | Update |
| Aging - HP | Complete | Complete | Complete | Complete | Complete | Complete | Complete | Complete | Complete |

- HALT testing & FA update: Intel shipped 1 of each material type (aged board) to HP for initial testing week of Feb 20th. Completion Date TBD.

•Aging for the Agilent RTV boards was performed at HP with the following
•equipment / conditions :
- •Equipment: Thermotron Environmental Test Chamber
- •Model: SMX-64-705-705
- •Capacity: 64 $ft^3$
- •Capability: -87° C - 190° C; 20% - 95% RH

•Aging conditions: Isothermal @ 85° C w/humidity @85%RH, stressed for 496 hours (20.7 days)

# •iNEMI BFR-Free High Reliability PCB Project Agilent Bd •Testing Procedures

- **Monotonic Bend : Modified IPC 9702 Test Standard (Bare Board Test)**
  - Equipment: Load Frame
  - Strain Gauge: KYOWA KFG-02-120-C1-11L3M2R
  - Gauge Specifics: Factor – 2.18 + 1%, Resistance - 119.6±0.4 Ω
  - Test Conditions:
    - Global PWB strain-rate:5000μstrain/sec
    - Load Span:100 mm
      Support Span: 200 mm
  - Monitor resistance of nets 1 and 4 for failure (open circuit)

- **HALT Testing Profile Conditions:**
  1. Ambient temp and no vibration (starting point) – 25C
  2. Vibration ramp step with dwell – each step 2.4 GRMS increase with 5 minute dwell
  3. Cold ramp step with dwell – each step -3C decrease with 15 minute dwell
  4. Hot ramp step with dwell – each step 3C increase with 15 min dwell
  5. Return to ambient ramp with no dwell
  6. Repeat steps 2 through 5 for 25 steps to 60 GMRS, -50C, and 100C endpoint. Monitor package/ PCB daisy chains for failure.

# •Project Timeline

•Milestone Date

- Complete all remaining MEB testing March 2012
- Complete testing on Agilent Board Addendum
- Write Final report April, 2012
- iNEMI Webinar May, 2012

# www.inemi.org

**Email contacts:**

**Jim McElroy**

**jmcelroy@inemi.org**

**Bob Pfahl**

**bob.pfahl@inemi.org**

**Jim Arnold**

**jim.arnold@rissastudios.com**

iNEMI®

Advancing manufacturing technology