2017 iNEMI Roadmap Highlights Impacting Board Assembly Over the Next 5-10 Years

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Topics

- iNEMI Introduction
- iNEMI Roadmap Process Overview/Statistics
- Situation Analysis
- Technology Needs
- Strategic Concerns
- Paradigm Shifts
- IoT/Wearables Product Emulator Highlights
- Board Assembly Chapter Highlights
- Optoelectronic Chapter Highlights
- iNEMI Collaboration Projects
- Summary/Next Steps
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Roadmap
Process &
Scope
<table>
<thead>
<tr>
<th>Emulator</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless / Portable</td>
<td>Produced in high volumes, cost is a primary driver, hand held battery powered products are also driven by features, size, weight reduction and battery life</td>
</tr>
<tr>
<td>Office / Consumer Systems</td>
<td>Driven by the need for maximum performance and lowest cost</td>
</tr>
<tr>
<td>Automotive Products</td>
<td>Products that must operate in an automotive environment</td>
</tr>
<tr>
<td>High-End Systems</td>
<td>Products that serve the high end computing, networking, datacom and telecom markets and cover a wide range of cost and performance targets</td>
</tr>
<tr>
<td>Medical Products</td>
<td>Products that must operate with high reliability and, in some cases, support life critical applications</td>
</tr>
<tr>
<td>Aerospace / Defense</td>
<td>Products that must operate reliably in extreme environments</td>
</tr>
<tr>
<td>IoT / Wearables</td>
<td>Presently driven by a wide range of costs and capabilities. By adding internet connectivity and some intelligence to sensors/actuators, a wide range of applications including consumer and industrial product and process monitoring and control are made possible.</td>
</tr>
</tbody>
</table>
2017 Technology Working Groups (TWGs)

- Modeling, Simulation, and Design Tools
- Solid State Illumination
- Flexible Hybrid Electronics
- Semiconductor Technology
- Ceramic Substrates & Photovoltaics Technology
- Organic PCB
- Board Assembly
- Final Assembly
- Customer
- Test, Inspection & Measurement
- Thermal Management
- Power Conversion Electronics
- Energy Storage Systems
- Mass Storage (Magnetic, Optical & Solid State)
- Optoelectronics
- Passive Components
- RF Components & Subsystems
- MEMS/Sensors
- Packaging & Component Substrates
- Connectors - Electronic/Photonic
- Information Management Systems
- Sustainable Electronics
- Red=Business
- Green=Engineering
- Purple=Manufacturing
- Blue=Component & Subsystem
2017 Roadmap

- > 500 participants
- > 350 companies/organizations
- 20 countries
- 21 Technology Working Groups (TWGs)
- 7 Product Emulator Groups (PEGs)
- > 2300 pages of information (Largest and most comprehensive thus far)

Roadmaps the needs for 2017-2027
Technical Plan for Members
5 Year Plan for Implementation

• Implementation Plan for Key Areas
  • Key Gaps Prioritized by TC/TIGs
  • Pre-competitive Collaboration projects/plans developed by Members
Chapter 1: Introduction

Chapter 2: Research Needs to support iNEMI Technology Implementation Groups (TIGs) and current Projects

Chapter 3: Research Needs For Selected Enabling Emerging Technologies

Chapter 4: Research Priorities Summarized by Research Area
  Design
  Manufacturing Processes
  Materials & Reliability
  Sustainability
  Summary

Appendixes
2017 iNEMI Roadmap Situation Analysis
Situation Analysis Examples: Technology

- Consumers’ demand for thin multifunctional products has led to increased pressure on alternative high density packaging technologies.

- High-density 3D packaging has become the major technology challenge

- SiP:
  - Technology driver for small components, packaging, assembly processes and for high density substrates

- New sensors and MEMs:
  - Expected to see exponential growth driven by portable products
  - Motion gesture sensors expanding use of 2D-axis & 3D-axis gyroscopes
  - Segment maturing, encouraging industry collaboration
Technology Needs - Examples

- New MEMS/Sensors driven by Automotive, Medical, IoT and Cell Phone applications
- Thermal Management for Portable Products
- Cooling Solutions for Portable Electronics (3D-TSV)
- Reliability Evaluation and functional testing of MEMS
- Testing of Energy Managed modules
- Functional Testing of Complex SIPs
- High Reliability Low Temperature Processing
- Significant development will be required to drive down the cost of batteries for EV (Electric Vehicle) applications to: $150/KWh.
Paradigm Shifts

- Need for continuous introduction of complex multifunctional products to address converging markets favors modular components or SiP (2-D & 3-D):
  - Increases flexibility
  - Shortens design cycle

- Cloud connected digital devices have the potential to enable major disruptions across the industry:
  - Major transition in business models
  - New Power Distribution Systems for Data Centers
  - Huge data centers operating more like utilities (selling data services)
  - Local compute and storage growth may slow (as data moves to the cloud)
  - “Rent vs. buy” for software (monthly usage fee model)

- Rapid evolution and new challenges in energy consuming products such as SSL, Electric Cars & more

- Sensors everywhere – MEMS and wireless traffic!

- “More Moore” (scaling of pitch) has reached its forecast limit and must transition to heterogeneous integration - “More Than Moore”.


Paradigm Shifts (continued)

- The Internet of Things (IoT) is making sensors ubiquitous; however, there are concerns about network security as cyber attacks become more pervasive.
- The focus in portables will shift to “wearables” with multiple sensors providing unique user interfaces and user interaction.
- Advancement of automotive safety systems and potentially broader use in other segments.
2017 Roadmap IoT/Wearables
Product Sector Highlights
IoT/Wearables Product Emulator Group

- IoT (what is it anyway?)
  - Wiki => Network of physical objects (devices, vehicles, buildings and other items) which are embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data

- PEG formed officially EOY’15 & first version of IoT Roadmap delivered in mid 2016
The Internet of Things is clearly a growing market
- Connected devices are used in a broad range of applications => Entertainment, convenience, efficiency, and/or safety benefits

The market is over-hyped, figures are quoted without clear reference to definitions

For suppliers of electronics hardware, it is difficult to understand the impact of IoT on their businesses

Prismark and iNEMI define connected devices as:
- Devices that connect to the Internet directly or through a gateway
- Each device is an independently deployable entity

Five separate market segments:
- Wearables, home, industrial, medical, and automotive connected devices
- For purposes of this roadmap, the two principal market segments of interest are wearables and industrial IoT devices

The wearables market is one of the most visible segments of the IoT market:
- Limited to devices that are worn directly on the body
- The total world population is expected to grow to 7.6Bn by 2019
- 7.6Bn bodies times many locations per body calculates to a very large market opportunity
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Useful/Actionable Data Gathering
World On A Laptop

Mobile devices along with connectivity revolutionized our way of interaction
IoT & Wearables Product Emulator

Technology roadmap: The Internet of Things

- Miniaturisation, power-efficient electronics, and available spectrum
- Software agents and advanced sensor fusion
- Teleoperation and telepresence: Ability to monitor and control distant objects
- Physical-World Web
- Ubiquitous Positioning
- Vertical-Market Applications
- Supply-Chain Helpers

- Cost reduction leading to diffusion into 2nd wave of applications
- Ability of devices located indoors to receive geological signals
- Locating people and everyday objects

- Demand for expedited logistics
- Surveillance, security, healthcare, transport, food safety, document management

Source: SRI Consulting Business Intelligence
IoT REVENUES IN PERSPECTIVE

2014

Connected Devices
- Wearable 0.3%
- Home 2.7%
- Industrial 0.6%
- Medical 0.1%
- Automotive 4.8%

Other Electronics 56.4%

Smartphones 19.6%
Computers 15.0%
Wi-Fi Ap 0.4%

TOTAL ELECTRONICS: $1,746Bn

2019

Connected Devices
- Wearable 1.6%
- Home 4.6%
- Industrial 1.1%
- Medical 0.7%
- Automotive 8.8%

Other Electronics 48.7%

Smartphones 20.5%
Computers 13.5%
Wi-Fi Ap 0.5%

TOTAL ELECTRONICS: $2,081Bn

Source: Prismark LLC
### CUMULATIVE NUMBER OF IoT DEVICES IN 2019

<table>
<thead>
<tr>
<th>Connected Devices</th>
<th>M Units</th>
<th>Production 2014</th>
<th>Production 2019</th>
<th>Cumulative Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearables</td>
<td>51</td>
<td>295</td>
<td></td>
<td>502</td>
</tr>
<tr>
<td>Home</td>
<td>361</td>
<td>1,423</td>
<td></td>
<td>5,347</td>
</tr>
<tr>
<td>Industrial</td>
<td>147</td>
<td>432</td>
<td></td>
<td>1,820</td>
</tr>
<tr>
<td>Medical</td>
<td>8</td>
<td>153</td>
<td></td>
<td>335</td>
</tr>
<tr>
<td>Automotive</td>
<td>37</td>
<td>75</td>
<td></td>
<td>392</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>604</strong></td>
<td><strong>2,378</strong></td>
<td></td>
<td><strong>8,396</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gateway Devices</th>
<th>M Units</th>
<th>Production 2014</th>
<th>Production 2019</th>
<th>Cumulative Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphones</td>
<td>1,250</td>
<td>1,950</td>
<td></td>
<td>5,450</td>
</tr>
<tr>
<td>Computers</td>
<td>533</td>
<td>647</td>
<td></td>
<td>3,050</td>
</tr>
<tr>
<td>Wi-Fi AP</td>
<td>80</td>
<td>120</td>
<td></td>
<td>750</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,863</strong></td>
<td><strong>2,717</strong></td>
<td></td>
<td><strong>9,250</strong></td>
</tr>
</tbody>
</table>

| Total             | 2,467   | 5,095           |                 | 17,646               |

Source: Prismark LLC
WEARABLE CONNECTED DEVICES

- The body offers much prime real estate for wearable devices
  - Smartbands
  - Smartwatches
  - Smartglasses

- Wearables offer health, convenience, entertainment and security benefits
  - But market limited by base of well-off consumers

- Assembly and packaging comments
  - Mostly tethered to smartphones via Bluetooth LE
  - Small size and ergonomics warrant high-density packaging
  - Aesthetics and practical issues (e.g. washability) are important

Source:- Prismark LLC
Wearables Technology Example

Figure 1: Hybrid Approach, Combining Roll-to-Roll Printing with Silicon-Based Logic [Error! Bookmark not defined.].

Source: 2017 iNEMI Roadmap, MEMS Chapter
HOME CONNECTED DEVICES

- “Smart homes” is not a new concept, but is finally gaining traction
  - Home Internet access provides remote access
  - Readily available remote control units
  - Familiarity with concept

- Many interesting applications
  - Security
  - Energy management
  - Entertainment

- Assembly and packaging comments
  - Most use WiFi, although legacy standards also common
  - Typically not size constrained and benign environment
  - Modules common for connectivity functions

Source:- Prismark LLC
INDUSTRIAL CONNECTED DEVICES

- Broad range of applications
  - Smart Cities
  - Commercial applications
  - Heavy industrial applications

- In unit terms, smart cities and commercial applications are largest
  - Devices distributed throughout cities, buildings, stores and factories
  - Very fragmented market with many applications, users and suppliers

- Broad range of assembly and packaging requirements
  - Some traditional connectivity standards (e.g. WirelessHART), but increasingly Bluetooth, WiFi, cellular
  - Seldom as space constrained as wearable devices or smartphones
  - Often longer life expectancies, harsher environments

Source:- Prismark LLC
# INDUSTRIAL CONNECTED DEVICE MARKET 2014 – 2019

<table>
<thead>
<tr>
<th>M Units</th>
<th>2014</th>
<th>2019</th>
<th>Key Players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart Cities</td>
<td>110</td>
<td>230</td>
<td>Assa Abloy, Itron, Landis + Gyr</td>
</tr>
<tr>
<td>Commercial</td>
<td>26</td>
<td>170</td>
<td>GE, Estimote, Philips</td>
</tr>
<tr>
<td>Heavy Industrial</td>
<td>0.2</td>
<td>0.4</td>
<td>ABB, Siemens, GE</td>
</tr>
<tr>
<td>Others</td>
<td>11</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>147</strong></td>
<td><strong>432</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Prismark Partners LLC 2016
MEDICAL CONNECTED DEVICES

- Global healthcare in crisis
  - Developed countries spend 8-12% of GDP on healthcare; 17% in US
  - Aging and obesity rapidly increase number of people with chronic conditions

- Connected devices widely recognized as key solution
  - Data mining to detect inefficiencies and solutions
  - Automated patient monitoring to lower costs, improve care
  - Two categories of medical connected devices
    - Professional equipment, in hospitals or medical offices
    - Prosumer equipment, for out-patient use

- Assembly and packaging comments
  - Currently connectivity is add-on function with modules
  - Some equipment quite small and portable, but functionality is limited
  - Medical certification is tough and lengthens lead times

Source: Prismark LLC
AUTOMOTIVE CONNECTED DEVICES

- Broad push towards connected cars
  - Convenience
  - Safety
  - Energy savings
  - Value add

- Different ways to provide connectivity to cloud
  - Bluetooth connection to smartphone
  - Direct cellular connection

- Assembly and packaging comments
  - Must be designed for long lifetime in harsh conditions
  - Requires specific testing and certification, with long lead times
  - Modules allow for aftermarket adjustments

Source: Prismark LLC
IoT/Wearables Issues

- In reality, the market is much more limited in size:
  - By 2019, only about 1.6Bn people are expected to have the disposable income to possibly buy any wearable device
  - The wearable device has to be sufficiently compelling to trigger a purchase

- We believe that the bulk of the market will consist of just two locations and three types of devices:
  - Smartbands:
    - Focused on activity tracking
    - Identification (access, payment) and gesture control functions

  - Smartwatches:
    - Have an important role in tracking children and disabled adults
    - Larger market will be as smart accessories for smartphones, providing an additional unobtrusive display

  - Smart glasses:
    - Devices enabling virtual or augmented reality
    - Industrial/occupational applications
    - Bulk of the market will be driven by entertainment - gaming

- All wearables tend to have relatively short lifecycles—no more than three years – bolstering the market through repeat purchases:

- Prismark expects the wearable device market to grow to 295M units in 2019, from 51M in 2014
Industrial IoT
IoT / Industrial Issues

- Industrial applications offer a broad range of opportunities for connected devices
  - Use cases and implementations are just as broad

- Prismark/iNEMI divide the market into four specific segments: “Smart Cities”, “Commercial Applications,” “Heavy Industrial”, and one “other” category

- The industrial connected device is specified, purchased, and deployed by a corporation, government authority, or other institution with expected longer lifetimes, sometimes ten or more years in a harsh environment.
Smart Cities:

Cities with large populations (or densities) need to be managed carefully; otherwise, the quality of life degrades quickly.

The single largest industrial connected device category today is smart meters:
- Meter reading becomes even more efficient because it is now completely remote
- Second, the meter can be read at any time interval, even continuously, which allows for sophisticated pricing models

Another priority for smart cities is lighting management:
- Ranges from in-building to street lights to traffic lights
- LED bulbs with integrated links (wired, wireless, network), e.g. ZigBee, are widely available for indoor and outdoor applications

Energy management in buildings also requires tight control over the HVAC system:
- Individual thermostats are fitted with modules that allow remote monitoring and control
Commercial Connected Devices:

- Companies use connected devices in their factories or stores for energy management systems including lighting and HVAC control.

Additionally, the commercial sector has other specific IoT applications that are of interest:
- Beacons - can be used for proximity sensing - a shoe store may alert a smartphone user of a shoe store when the user passes by.
- Sensors to increase efficiency or ensure safety.
- Sensors networked to allow for remote monitoring.
- Enables centralized data collection.
The industrial IoT segment is one of the largest IoT markets, but it is extremely fragmented and rarely visible:

- Industrial connected devices range from very large, complex, and expensive, to very small, simple, and cheap.

Connected devices for heavy industrial equipment, which may be most easily recognizable as "industrial", is actually a very small market:

- Only 120,000 installed locomotives, 65,000 aircraft, 10,000 marine bulk carriers, and 800,000 pieces of heavy machinery.
- Only about 200,000 robots are sold annually worldwide.
- Thus volumes are modest; prices may be appealing.
## IoT Chapter – Key Attributes Spreadsheet Example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Descriptions</th>
<th>Metric</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2021</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB Costs</td>
<td>FR4 Unless Otherwise Stated</td>
<td>$ per cm²</td>
<td>0.0350</td>
<td>0.0336</td>
<td>0.0323</td>
<td>0.0310</td>
<td>0.0272</td>
</tr>
<tr>
<td>1 Layer Flexible</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0400</td>
<td>0.0384</td>
<td>0.0369</td>
<td>0.0354</td>
<td>0.0311</td>
</tr>
<tr>
<td>2 layer flexible</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0063</td>
<td>0.0060</td>
<td>0.0058</td>
<td>0.0056</td>
<td>0.0049</td>
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<tr>
<td>2 layer Rigid</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.25</td>
<td>0.2400</td>
<td>0.2304</td>
<td>0.2212</td>
<td>0.1946</td>
</tr>
<tr>
<td>3 layer flex</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.26</td>
<td>0.2496</td>
<td>0.2396</td>
<td>0.2300</td>
<td>0.2024</td>
</tr>
<tr>
<td>4 layer flexible</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4 layer conventional</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0140</td>
<td>0.0137</td>
<td>0.0134</td>
<td>0.0132</td>
<td>0.0116</td>
</tr>
<tr>
<td>4 layer - embedded capacitor / resistor</td>
<td>High End</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>6 layer conventional</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.019</td>
<td>0.0182</td>
<td>0.0175</td>
<td>0.0168</td>
<td>0.0148</td>
</tr>
<tr>
<td>4 layer w/ microvia</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0274</td>
<td>0.0263</td>
<td>0.0253</td>
<td>0.0242</td>
<td>0.0213</td>
</tr>
<tr>
<td>6 layer rigid (with micro vias)</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0350</td>
<td>0.0336</td>
<td>0.0323</td>
<td>0.0310</td>
<td>0.0272</td>
</tr>
<tr>
<td>6 layer, blind/buried</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>6 layer - embedded capacitor / resistor</td>
<td>High End</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>8 layer</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0230</td>
<td>0.0221</td>
<td>0.0212</td>
<td>0.0203</td>
<td>0.0179</td>
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<td>8 layer w/ microvias</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0441</td>
<td>0.0423</td>
<td>0.0406</td>
<td>0.0390</td>
<td>0.0343</td>
</tr>
<tr>
<td>8 layer w/ blind/buried</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>8 layer colaminated (ALIVH)</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10 layer conventional</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0270</td>
<td>0.0259</td>
<td>0.0249</td>
<td>0.0239</td>
<td>0.0210</td>
</tr>
<tr>
<td>10 layer w/ microvias</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.0513</td>
<td>0.0492</td>
<td>0.0473</td>
<td>0.0454</td>
<td>0.0399</td>
</tr>
<tr>
<td>10 layer w/ blind / buried</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10 layer colaminated (ALIVH)</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>12 layer Conventional (FR4)</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>0.031</td>
<td>0.0298</td>
<td>0.0286</td>
<td>0.0274</td>
<td>0.0241</td>
</tr>
<tr>
<td>12 layer conventional (FR4) with buried vias</td>
<td>State of the Art (production volume)</td>
<td>$ per cm²</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Critical Gaps

“Some” of the critical gaps are =>

- Security, Privacy, Safety
- Interoperability between sensors and devices; particularly across domains (wearable to automotive for example)
- Timing synchronization across devices
- Evolving Standards

Wonderful opportunities exist for Innovation…☺
2017 Roadmap
Board Assembly
TWG Chapter
Highlights
Board Assembly Highlights
- NPI
- Assembly Material
- Press-Fit
- Repair and rework
- Wave/selective soldering
New Product Introduction Section

*Introduction*

- New Product Introduction is an activity which occurs at several points in the product development process. Not all product development cycles include all of these applications, but each has a unique objective, and as such, specific requirements:
  - Functional Verification/Testing
  - Proof of Concept
  - Manufacturing Readiness
  - Ramp to Volume
# Attributes of NPI

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Functional Verification</th>
<th>Proof of Concept</th>
<th>Mfg Readiness</th>
<th>Ramp to Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantities</strong></td>
<td></td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 100</td>
<td>100-1000+</td>
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<tr>
<td><strong>DfM</strong></td>
<td></td>
<td>&lt; 20%</td>
<td>&lt; 40%</td>
<td>60 - 100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td></td>
<td>Various</td>
<td>None</td>
<td>HALT, ESS, ALT, etc</td>
<td>Burn-in, HASA, ORT, etc</td>
</tr>
<tr>
<td><strong>Mfg Cycle Time</strong></td>
<td>Days in Mfg</td>
<td>&lt; 5</td>
<td>&lt; 10</td>
<td>Standard</td>
<td>Standard</td>
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<tr>
<td><strong>Test</strong></td>
<td></td>
<td>Various</td>
<td>Function with other assy</td>
<td>Production Level</td>
<td>Production Level</td>
</tr>
</tbody>
</table>
NPI Technology Needs

There are efforts to enhance NPI capabilities today, yet there is no real measure on how much time and cost of the overall product life cycle can be affected by improvements in this area. **Priorities (1 – 3 years)**

- DfX rule systems need to be consolidated but be flexible enough to accommodate new component and assembly technologies. Industry standards are valuable but only if they can have a much shorter development and revision cycle than what is supported today.
- Elimination (or easy identification) of counterfeit parts from the supply chain.
- 3-D Printing development and use in mechanical fit testing.

**Medium-term Priorities (3 – 7 years)**

- Modeling and simulation tools need to push towards the reduction / elimination of Functional Verification steps. Assembly process modeling can help minimize cost and cycle time. Reflow settings simulations or vapor phase processes can be reviewed.

**Long-term Priorities (8+ years)**

- Assembly material development to meet the needs of NPI can address several fronts:
  - NPI cycle time can be improved with a change to deposited materials which could replace discrete components
  - Material developments may help qualify high reliability applications.
  - New interconnect technologies may provide flexible routing options, reducing or eliminating PCB fabrication cycle time.
Assembly Material Section

Assembly Material 2017 Roadmap

Updating all material sections used in the second level Board Assembly process.

Areas of Focus/Trends

- **Solder Paste**
  - Lead-free continues to migrate into high-reliable products (automotive, industrial, medical, etc…)
  - Lead-free alloy alternatives for high reliable products (customer example)
  - Low process temperature than SAC305 with similar (or better) reliability performance.

- **Solder Bar**
  - SAC 305 Alternatives, Low Ag

- **Assembly Fluxes**
  - Halogen free, no halogen
  - Fluxes for higher temperature process
  - Fluxes to mitigate defects caused by component warpage such as HiP, NWO, etc…

- **Underfill**
  - Low standoff height component (QFN/LGA)

- **Heat Sink Attach/ TIM**
  - Low cost, high performance

- **Die Attach Material**
  - Lead-Free
  - High Thermal
Assembly Material

Some Areas of Focus/Trends (Cont’d)

- Conformal Coating
  - Low cost, but high performance for DC running in air with Sulfur and high T/RH

- Potting Materials
  - High power
  - Low pressure

- Other Encapsulants

- Nano Materials
  - Nano materials have been developed and more materials will be used in second level board assembly such as nano solder/adhesive, nano coating, etc...
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2021</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solder Paste</strong></td>
<td></td>
<td></td>
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<tr>
<td>Alloy</td>
<td></td>
<td>SAC/ Modified SnCu/ Low Ag SAC</td>
<td>SAC/ Modified SnCu/ Low Ag SAC</td>
<td>SAC/ Modified SnCu/ Low Ag SAC</td>
<td>SAC/ Modified SnCu/ Low Ag SAC</td>
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<tr>
<td>Alloy (Low Temp)</td>
<td></td>
<td>Low Temp</td>
<td>Low Temp</td>
<td>Low Temp</td>
<td>Low Temp</td>
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</tr>
<tr>
<td>Alloy (Lead-free)</td>
<td></td>
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<td>High Temp</td>
<td>High Temp</td>
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<td>High Temp</td>
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<tr>
<td>High Temp&gt;260C</td>
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<tr>
<td>Halogen-free</td>
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<tr>
<td>Zero Halogen</td>
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<tr>
<td><strong>Bar Solder</strong></td>
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<tr>
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<td>VOC Free</td>
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<td>higher performance</td>
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<tr>
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<tr>
<td>Zero Halogen</td>
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<tr>
<td><strong>Wave Solder Flux</strong></td>
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<td>SAC/ Modified SnCu/ Low Ag SAC</td>
<td>SAC/ Modified SnCu/ Low Ag SAC</td>
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<td>Halogen free</td>
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<tr>
<td>Zero Halogen</td>
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<tr>
<td><strong>Flux-cored Solder Wire</strong></td>
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<td>SAC/ Modified SnCu/ Low Ag SAC</td>
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<td>Low Temp</td>
<td></td>
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<tr>
<td><strong>Repair Fluxes</strong></td>
<td></td>
<td></td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
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<tr>
<td>Repair Gel/Tacky Fluxes</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Repair Liquid Fluxes</td>
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<td></td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
<td>Better performance, higher reliability</td>
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<tr>
<td><strong>Die Attach Preforms</strong></td>
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<tr>
<td>High Thermal conductivity</td>
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<tr>
<td>Matched CTE capability</td>
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<tr>
<td><strong>Die Attach Adhesives</strong></td>
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<tr>
<td>Lead-free compatibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JEDEC L1 @260, small die, paste</td>
<td></td>
<td>JEDEC L1 @260, small die, paste</td>
<td>JEDEC L1 @260, small die, paste</td>
<td>JEDEC L1 @260, small die, paste</td>
<td>JEDEC L1 @260, small die, paste</td>
<td>JEDEC L1 @260, small die, paste</td>
</tr>
<tr>
<td>Lead-free compatibility</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>JEDEC L1 @260, large die, paste</td>
<td></td>
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<td>JEDEC L1 @260, large die, paste</td>
<td>JEDEC L1 @260, large die, paste</td>
</tr>
</tbody>
</table>

**Key**
- Current Capability
- In Development
- Research Needed
Press-Fit Section

- Press-fit for electrical and mechanical interconnection
  - Cross Cut with Test and Inspection TWG
    - Improve methods to inspect compliant pin true position, absence and presence
  - Cross Cut with Connector TWG
    - Rework
    - DDR3 & 4 contact interconnect problem of >2000 dpm at SFT
      - The fanatic of particulate control and mgmt due to DIMM fallout
    - Higher Signal integrity requirement asking for different and advanced contact methodology beyond current press-fit
      - Phase 1-normal force of both contacts>50gf, SI test passed
      - Phase II & III
Rework and Repair Section - Situation Analysis

- The roadmap analysis for the repair and rework processes consist of hand soldering repair, PTH rework, SMT rework, and press-fit rework.

- The higher lead-free process temperatures forecast by all the product sectors will narrow the process window for rework (except press-fit).

- The selection of a common industry lead-free alloy for both SMT and PTH soldering has yet to be defined. Many variations of the SnAgCu and SnCu alloys are available for use.

- With this variation comes a continued requirement for understanding the quality and reliability of each alloy as well as the combination of alloys, through mixed rework scenarios.

- The trend toward tighter component pitches has required increased component placement accuracy for rework. High component pin counts and larger component body sizes will challenge current rework placement and reflow techniques and impact rework yields.

- For leadless device rework the lack of “affordable”, capable x-ray capabilities to discern mirrored devices without destructive means is critical for widespread rework capacity.
## Hand Solder Rework

<table>
<thead>
<tr>
<th>Soldering Process</th>
<th>Parameter</th>
<th>Units</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2021</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SnPb</strong></td>
<td>Soldering iron peak temperature used</td>
<td>°C</td>
<td>375</td>
<td>375</td>
<td>375</td>
<td>375</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Total contact time</td>
<td>Sec</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Smallest pitch to be reworked by hand</td>
<td>Mm</td>
<td>0.35</td>
<td>0.3</td>
<td>0.275</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Smallest type of discrete being reworked Imperial/ [Metric]</td>
<td>-</td>
<td>0201/ [0603]</td>
<td>01005/[0402] and [03015]</td>
<td>01005/[0402] and [03015]</td>
<td>008004 /[0201]</td>
<td>008004 /[0201]</td>
</tr>
<tr>
<td></td>
<td>Type of wire alloy used</td>
<td>-</td>
<td>Sn37Pb</td>
<td>Sn37Pb</td>
<td>Sn37Pb</td>
<td>Sn37Pb</td>
<td>Sn37Pb</td>
</tr>
<tr>
<td><strong>Pb-free</strong></td>
<td>Soldering iron peak temperature used</td>
<td>°C</td>
<td>375</td>
<td>375</td>
<td>375</td>
<td>375</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Total contact time</td>
<td>Sec</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Smallest pitch to be reworked by hand</td>
<td>mm</td>
<td>0.35</td>
<td>0.3</td>
<td>0.275</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Smallest type of discrete being reworked Imperial/ [Metric]</td>
<td>-</td>
<td>0201/ [0603]</td>
<td>01005/[0402] and [03015]</td>
<td>01005/[0402] and [03015]</td>
<td>008004 /[0201]</td>
<td>008004 /[0201]</td>
</tr>
<tr>
<td></td>
<td>Type of wire alloy used</td>
<td>-</td>
<td>SAC305/ SnCuNi (low tip dissolution alloys)</td>
<td>SAC305/ SnCuNi (low tip dissolution alloys)</td>
<td>SAC305/ SnCuNi (low tip dissolution alloys)</td>
<td>SAC305/ SnCuNi (low tip dissolution alloys)</td>
<td>SAC305/ SnCuNi (low tip dissolution alloys)</td>
</tr>
</tbody>
</table>
## Area Array and Non-Standard Package Rework

<table>
<thead>
<tr>
<th>Soldering Process</th>
<th>Parameter</th>
<th>Units</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2025</th>
<th>2027</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum package size</td>
<td>mm</td>
<td>50</td>
<td>55</td>
<td>60</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Minimum package size</td>
<td>mm</td>
<td>2</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Smallest type of discrete being reworked</td>
<td>-</td>
<td>0402 metric (01005 Imperial)</td>
<td>0402 metric (01005 Imperial)</td>
<td>0201 metric (008004 Imperial)</td>
<td>0201 metric (008004 Imperial)</td>
<td>0201 metric (008004 Imperial)</td>
</tr>
<tr>
<td></td>
<td>Minimum reworkable pitch</td>
<td>mm</td>
<td>0.35</td>
<td>0.3</td>
<td>0.275</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Target delta T across solder joints</td>
<td>°C</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>Typical rework profile length (time) (SnPb rework)</td>
<td>min</td>
<td>6 to 8</td>
<td>6 to 8</td>
<td>6 to 8</td>
<td>6 to 8</td>
<td>6 to 8</td>
</tr>
<tr>
<td></td>
<td>Typical rework profile length (time) (Lead-Free Rework)</td>
<td>min</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Time Above Liquidus (TAL) (SnPb rework)</td>
<td>sec</td>
<td>45-90</td>
<td>45-90</td>
<td>45-90</td>
<td>45-90</td>
<td>45-90</td>
</tr>
<tr>
<td></td>
<td>Time Above Liquidus (TAL) (Lead-Free rework)</td>
<td>sec</td>
<td>60 – 90</td>
<td>60 – 90</td>
<td>60 – 90</td>
<td>60 - 90</td>
<td>60-90</td>
</tr>
<tr>
<td></td>
<td>Number of allowable area array reworks at a specific location</td>
<td>#</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Type of rework (Conv./IR/Other) (Other is Laser and Vapor Phase Rework)</td>
<td>%</td>
<td>80/15/5</td>
<td>80/15/5</td>
<td>70/15/15</td>
<td>70/10/20</td>
<td>60/10/30</td>
</tr>
<tr>
<td></td>
<td>Type redress approach (Non-Contact/SolderWick)</td>
<td>%</td>
<td>20/80</td>
<td>20/80</td>
<td>25/75</td>
<td>40/60</td>
<td>50/50</td>
</tr>
<tr>
<td></td>
<td>Type of medium deposit for BGA component rework (Paste on PCB/Paste on Part/Flux only) (See Note)</td>
<td>%</td>
<td>35/35/30</td>
<td>35/35/30</td>
<td>35/35/30</td>
<td>35/35/30</td>
<td>35/35/30</td>
</tr>
</tbody>
</table>

Note: The use of solder paste or tacky flux will depend on the type of component being reworked. Paste is typically used to reduce the effect of component warpage causing Head-in-Pillow component soldering defects during BGA and PoP part rework. In terms of ease of use and speed of rework, tacky flux is used more even though it may have an affect on first pass yield. The percentages mentioned for Paste versus Flux medium are for BGA rework and will vary dependent on the type of part being reworked. There is a trend to use more tacky flux but for applications such as BTC/QFN/MLF. This may cause a reliability issue due to insufficient solder joint standoff height which must be validated.
### Pick & Place Technology Forecast

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip Placement Speed</td>
<td>CPH per square meter using the IPC 9850 standard for 0603 components</td>
<td>15,000</td>
<td>17,000</td>
<td>19,000</td>
<td>22,000</td>
<td>28,000</td>
</tr>
<tr>
<td>IC Placement Speed - Large Size IC</td>
<td>CPH per square meter using the IPC 9850 standard for QFP 208</td>
<td>1,600</td>
<td>1,700</td>
<td>2,000</td>
<td>2,300</td>
<td>3,200</td>
</tr>
<tr>
<td>IC Placement Speed - Medium Size IC</td>
<td>CPH per square meter using the IPC 9850 standard for SO-16</td>
<td>7,000</td>
<td>7,500</td>
<td>8,500</td>
<td>10,000</td>
<td>15,000</td>
</tr>
<tr>
<td>IC Placement Speed - Die Placement</td>
<td>CPH per square meter</td>
<td>6,000</td>
<td>7,000</td>
<td>8,000</td>
<td>9,500</td>
<td>12,000</td>
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<tr>
<td>Placement Accuracy Chips</td>
<td>6 sigma X,Y Placement accuracy (microns)</td>
<td>80</td>
<td>75</td>
<td>70</td>
<td>65</td>
<td>50</td>
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<tr>
<td>Placement Accuracy Fine Pitch</td>
<td>6 sigma X,Y placement accuracy/rotation (microns/deg)</td>
<td>50/0.7</td>
<td>45/0.6</td>
<td>40/0.5</td>
<td>35/0.4</td>
<td>30/0.3</td>
</tr>
<tr>
<td>Placement Accuracy - Area Array (BGA, NGA, CSP, FC)</td>
<td>6 sigma X,Y placement accuracy/rotation (microns/deg)</td>
<td>50/0.7</td>
<td>45/0.6</td>
<td>40/0.5</td>
<td>35/0.4</td>
<td>30/0.3</td>
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<tr>
<td>Component Pick reliability</td>
<td>DPMO (based on 0201 (M0603) packaged per EAI 481)</td>
<td>1,000</td>
<td>500</td>
<td>300</td>
<td>300</td>
<td>150</td>
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<tr>
<td>Placement Force - Chips</td>
<td>Minimum (Grams)</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Placement force range (fine pitch and specialty components)</td>
<td>Minimum (Grams)</td>
<td>50</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
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<tr>
<td></td>
<td>Maximum (Grams)</td>
<td>5,000</td>
<td>5,000</td>
<td>6,500</td>
<td>7,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Feeder Capacity per Machine</td>
<td>Smallest component input/sq m</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Minimum Chip Package Sizes</td>
<td>L x W (mm)</td>
<td>0.4 x 0.2</td>
<td>0.4 x 0.2</td>
<td>0.4 x 0.2</td>
<td>0.2 x 0.1</td>
<td>0.1 x 0.1</td>
</tr>
<tr>
<td>Minimum Pitch - leaded</td>
<td>mm</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Minimum Pitch - CSP</td>
<td>mm</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Minimum Die Size</td>
<td>L x W (mm)</td>
<td>2 x 2</td>
<td>2 x 2</td>
<td>1.5 x 1.5</td>
<td>1.0 x 1.0</td>
<td>0.5 x 1.0</td>
</tr>
<tr>
<td>Maximum - Odd Form, Connector</td>
<td>Largest Dimension (mm)</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Component height</td>
<td>larger discrete (electrolytics) (mm)</td>
<td>13</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Component height</td>
<td>Odd form, connectors, modules, …</td>
<td>25</td>
<td>35</td>
<td>40</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>Component Mass - odd form, CPU, Modules</td>
<td>Grams</td>
<td>30</td>
<td>40</td>
<td>60</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Stacked Packages</td>
<td>Stacked Height</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Changeover time - new board width, 50</td>
<td>minutes</td>
<td>12</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Preventative maintenance time - based on 2,000 hours/year (1 shift)</td>
<td>hours/month</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Maintenance Skill Level</td>
<td>Level 2 maintenance</td>
<td>Level 1 maintenance</td>
<td>Level 1 Maintenance</td>
<td>Operator level</td>
<td>Operator Level</td>
<td></td>
</tr>
<tr>
<td>MTBF</td>
<td>Hours</td>
<td>1,500</td>
<td>1,800</td>
<td>2,000</td>
<td>2,500</td>
<td>5,000</td>
</tr>
<tr>
<td>MTBA (Mean time between assist)</td>
<td>per Semi E-10 (hours)</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>MPBA (Mean placements per assist)</td>
<td>Placements</td>
<td>100,000</td>
<td>120,000</td>
<td>140,000</td>
<td>160,000</td>
<td>200,000</td>
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<tr>
<td>Onboard Metrology</td>
<td>stand alone machine</td>
<td>fully integrated</td>
<td>fully integrated</td>
<td>fully integrated</td>
<td>Adaptive/Ineractive</td>
<td></td>
</tr>
<tr>
<td>MES Integration</td>
<td>Integration into business intelligence, manufacturing intelligent systems and MES type applications</td>
<td>Enabler/Passive</td>
<td>Enabler/Passive</td>
<td>Enabler/Active</td>
<td>Capability for Full integration</td>
<td>Capability for Full integration</td>
</tr>
</tbody>
</table>
# Board Assembly Gap Analysis (<5 years)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><strong>Materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Residue Fluxes for Wave Solder and hand solder rework processes (Reliability)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Alloys for solder fountain/mini-pot rework processes (Reliability)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Plastic Body materials for PTH Components, Sockets, Connectors (Reliability)</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lower Melting Bi-Sn based Solders for small form factor consumer products (Quality, Cost)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lower Cost Higher Reliability SAC based Solder Alloys (Cost, Reliability)</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Package Substrates for Reduction of Warpage during Reflow Soldering (Quality)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Equipment &amp; Assembly Process</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Soldering tools for miniature passive chip components (&lt;01005) (Quality)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Assembly Process Equipment with higher placement density capabilities and ability to handle complex components capabilities (Cost, Throughput)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-traditional Solder Paste application Processes, such as Jetting (Cost, Quality, Throughput)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Assembly Equipment Capability with Industry 4.0 Standards (Quality, Throughput)</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Rework Processes for One sided mirror image components (Quality)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Hot Air rework of Adjacent Components within 3 inches (Quality)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Large Area Array Components (&gt;50 mm body size) Assembly (Quality, Reliability)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection / Test for Increasing Component Density on Boards (Quality, Throughput)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Meeting of Cost Reduction Targets (Cost)</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>&lt;300 micron Fine Pitch Area Array components assembly with coarser pitch components (Quality, Reliability)</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Studs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Remediation of PCB and Component Moisture Handling Standards to address the impact of moisture in flux residues, baking on the solderability of PCB lands and component terminations, and facility environments (Quality, Reliability)</td>
<td>Med</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
2017 Roadmap
Optoelectronic
TWG Chapter
Highlights
The 2017 Roadmap Structure

• The Optical Electronic Roadmap is Organized around the 11 Main Applications of Optical Data Communications
• The eleven are:

Telecommunications  Backplanes
LANS                On-Card
Data Centers         On-to and Off-of-Package
FTTX                On-Chip
Active Optical Cables Free Space
Plastic Optical Fiber (POF)

• Each of the Eleven Sections have separate “Key Attributes, Situation Analysis, etc.” per the standard iNEMI Roadmap Outline.
### Roadmap of Quantified Key Attribute Needs (Example FTTX)

Table 12. FTTX (X = curb, house, desk, antenna, etc.) - Key Attribute Needs

Covers the "Final Link" for Telecommunications, and CATV systems, that are typically less than 1 Km. Includes fiber from the head end to hubs, hubs to nodes and from the nodes to the home/desk/etc.

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2021</th>
<th>2027</th>
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<tbody>
<tr>
<td>End users with fiber, %</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Downlink, Data rate/wavelength, Gb/s</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>User Downlink Data rate, Gb/s</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>User Uplink, Data rate, Gb/s</td>
<td>0.1</td>
<td>0.4</td>
<td>1</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>Effective Bandwidth per End Customer (Mbps)</td>
<td>300 (10-GPONs)</td>
<td>300 (10-GPONs)</td>
<td>2,000 (WDM-PON S)</td>
<td>2,000 (WDM-PON S)</td>
<td>4,000 (WDM-PON S)</td>
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<tr>
<td>Optical wavelength, single mode</td>
<td>1310/1490/1550</td>
<td>1310/1490/1550</td>
<td>1310/1490/1550</td>
<td>1310/1490/1550</td>
<td>1310/1490/1550</td>
</tr>
<tr>
<td>max # wavelengths/fiber, down and up</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Modulation Method, TDM or WDM</td>
<td>TDM</td>
<td>TDM</td>
<td>TDM/WDM</td>
<td>TDM/WDM</td>
<td>TDM/WDM</td>
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<tr>
<td>Modulation Format</td>
<td>analogue, 1024 QAM</td>
<td>analogue, 1024 QAM</td>
<td>analogue, 1024 QAM</td>
<td>analogue, 1024 QAM</td>
<td>analogue, 2048 QAM</td>
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<tr>
<td>Optical mode; multi/single</td>
<td>multi mode/single mode</td>
<td>multi mode/single mode</td>
<td>single mode</td>
<td>single mode</td>
<td>single mode</td>
</tr>
<tr>
<td>Power dissipation, watts/wavelength</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Transceiver Form Factor</td>
<td>Diplexer/Triplexe r, SFP</td>
<td>Diplexer/Triplexe r, SFP</td>
<td>Diplexer/Triplexe r, SFP, XFP</td>
<td>Diplexer/Triplexe r, SFP, XFP</td>
<td>Diplexer/Triplexe r, XFP, ?</td>
</tr>
<tr>
<td>Link loss, before amplification or regeneration, db</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>30</td>
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<tr>
<td>BER, per link</td>
<td>$10^{-6}$ or $10^{-9}$</td>
<td>$10^{-6}$ or $10^{-9}$</td>
<td>$10^{-6}$ or $10^{-9}$</td>
<td>$10^{-6}$ or $10^{-9}$</td>
<td>$10^{-6}$ or $10^{-9}$</td>
</tr>
<tr>
<td>Cost per lane, $/Gbit</td>
<td>$21.14</td>
<td>$15.27</td>
<td>$11.04</td>
<td>$7.97</td>
<td>$4.16</td>
</tr>
</tbody>
</table>

**Technology Status (ITRS format)**
- Manufacturable solutions exist, and are being optimized
- Manufacturable Solutions are Known
- Manufacturable solutions are NOT known
## Market and Application Mapping

<table>
<thead>
<tr>
<th>Application areas ⇒ iNEMI PEG (Market Segment) ↓</th>
<th>Table 2: Optical Data Communications Application, Group #1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Telecom</strong></td>
<td><strong>FTTX</strong></td>
</tr>
<tr>
<td>Consumer/Office Systems</td>
<td>Products Stable</td>
</tr>
<tr>
<td>High End Systems</td>
<td>N/A</td>
</tr>
<tr>
<td>Medical</td>
<td>Some Application</td>
</tr>
<tr>
<td>Automotive</td>
<td>N/A</td>
</tr>
<tr>
<td>Portable/Wireless</td>
<td>Products Stable</td>
</tr>
<tr>
<td>Aerospace/Defense</td>
<td>Products Stable</td>
</tr>
<tr>
<td>IoT &amp; Wearables</td>
<td>Applications Emerging</td>
</tr>
</tbody>
</table>
## Table 2: Optical Data Communications, Group #2

<table>
<thead>
<tr>
<th>Application areas</th>
<th>Table 2: Optical Data Communications, Group #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>iNEMI PEG (Market Segment)</td>
<td>Backplane</td>
</tr>
<tr>
<td>Consumer/Office Systems</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>High End Systems</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>Medical</td>
<td>N/A</td>
</tr>
<tr>
<td>Automotive</td>
<td>N/A</td>
</tr>
<tr>
<td>Portable/Wireless</td>
<td>Some Application</td>
</tr>
<tr>
<td>Aerospace/Defence</td>
<td>Product R&amp;D</td>
</tr>
<tr>
<td>IoT &amp; Wearables</td>
<td>NA</td>
</tr>
</tbody>
</table>
Optoelectronic Substrate Issues

- Laminated and embedded wave guides are likely to be enabling technologies for high speed optical backplane and chip-to-chip applications.

- Outsourcing of manufacturing by OEMs to CMs and EMS companies, leads to wider dissemination of previously closely held package, assembly process and test knowledge. There is a growing realization that most of the intellectual property (IP) is in the design and functional performance.

- A major impediment to acceptance of lower cost “datacom” components by network service providers is the requirement for rigorous reliability and testing to “telecom” standards, such as Telcordia GR1221

- Detailed Roadmap needs for photonics is being refined by the iNEMI led International Photonics Systems Roadmap (IPSR)
  - Key pre-competitive collaboration priorities were published on June 30, 2016.
The growing demand for greater data transmission capacity, smaller physical size and lower power consumption increasingly favors optical methods and results in optical technologies replacing copper as soon as the total cost of the optical solution is competitive.

With the cost of power rising, and data transmission rates increasing, optical technologies will continue to replace copper at shorter distances.

The current crossover where optical methods are better than copper is a distance of 1 to 10-meters when data rates are 10 to 100 Gb/s.

The historic major market has been metro and long haul telecommunications but that market is now being surpassed by the demand for optics in Data Centers.

The major reasons for adopting optical data transmission are:

- Its ability to transfer data at 10 to 100 Gb/s rates.
- The relatively small amount of power
- The ~75% smaller size of optical cables vs copper cables in high (10Gb/s+) data rate applications.
Use in Long Haul and Metropolitan Communications continues with 100 Gb/s capability growing in importance.

Ethernet is moving to 100 Gb/s data rates implemented with 4 x 25Gb/s methods.

400 Gb/s Ethernet using 4 x 100 Gb/s under discussion.

Data Centers are major consumers and drivers of optical technology, especially AOCs (Active Optical Cables) to implement Ethernet and Fiber Channel links.

FTTX, including CATV that utilizes hybrid fiber coax technology, is an important high speed data link to the consumer for the “last mile”.

FTTX is growing as fiber is taken closer to the end user to provide high data rate connectivity to the internet.

Backplanes
- Copper is OK to 20+ Gb/s - up to 1 meter.
- No widely adopted approach to utilizing optics in backplanes has emerged although the introduction of daughter card to backplane optical connectors utilizing the expanded beam concept is promising.
- A major barrier to adoption is the high risk of re-engineering backplanes to incorporate optical transmission media.

On-card data transfer
- Use is beginning with much interest and several applications announced.
- Much technology has been demonstrated but cost is questionable unless data rates are > 10 Gb/s and the application demands optical methods.

In-to and Out-of Package
- Optical methods offer a potential solution for the 10Tb/s+ IO data rates forecast by the ITRS for multicore processors in 2017.
- Optical methods offer lower power and more bandwidth in less area.

On-chip
- Exploring for lower power and more bandwidth.
- A modulated light source is needed.
- Application not expected for 10+ years.

Free Space
- Interest for local data transmission within a room is developing due to the greater security resulting from the elimination of RF.
- Communication through space where the security of a tight communication beam is important.
Results From the Roadmap Activity


- The PSMC #1 Effort was Highly Successful and a Follow On Effort called IPSR is Continuing as Part of the AIM IP Consortium.

- IPSR is Being Expanded Beyond Data Communications to Sensors, Analogue RF and Optical Arrays.

- New iNEMI/IPSR Board-Level Optical Interconnect Project Started (May 2017)

- To Get Involved Contact Bill Bader @ bill.bader@inemi.org
From the Roadmap comes collaborative Projects. Example: Board Level Optical Interconnects Project, IPSR

Tom Marrapode
Background

• Single mode operation requires precision (sub-micron) alignment in optical connections, both inside the package and in optical connectors; the tight mechanical tolerances needed in connector parts result in high cost components.

• To address the need for lower-cost SM connections, manufacturers have begun developing expanded-beam optical connectors.

• The optical mode of the SM fiber (~10 microns diameter) is expanded to a larger collimated beam (e.g. 80 microns in diameter) thus relaxing the alignment tolerance between connector elements from submicron to a few microns....tolerances that can be held in injection molded parts.

• However, to date, expanded-beam versions of SM connectors have higher losses than desired by system designers, and thus have not been commercialized.
Background

- Project is aligned with AIM (American Institute for Manufacturing Integrated Photonics), iNEMI, MIT MicroPhotonics Consortium, and industrial roadmaps

- These roadmaps predict that silicon-photonics-based transceiver modules will provide the most cost-effective solutions for on-board interconnections in the future

- This is based on the expected reduction of optoelectronic chip cost to be achieved via leveraging of the CMOS silicon foundry infrastructure

- Before the anticipated cost benefits of silicon photonics can be realized, new high-performance and cost effective solutions to optical packaging and connectorization must be developed

- Optimum performance and functionality from silicon photonics devices requires single mode (SM)
Project Purpose

• Assess the system-level benefits and issues associated with SM expanded beam coupling for on-board interconnect

• Therefore, allowing the industry to properly prioritize component development required to accelerate the silicon-photonics-implementation inherent in the roadmaps
<table>
<thead>
<tr>
<th>Affiliation</th>
<th>Participant</th>
<th>Title</th>
<th>Proposed Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molex</td>
<td>Tom Marrapode, IPSR Project Leader</td>
<td>Director of Advanced Technology Development</td>
<td>-Interconnects: backplane, front panel, I/O and cables</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-Prototype single mode expanded beam MT ferrules</td>
</tr>
<tr>
<td>Celestica</td>
<td>Tatiana Berdinskikh</td>
<td>Principal Optical Engineer</td>
<td>Rack Hardware</td>
</tr>
<tr>
<td>Juniper Networks</td>
<td>Bo Zhang, Valery Kugel</td>
<td>Distinguished Engineer</td>
<td>Link test procedures and performance evaluation</td>
</tr>
<tr>
<td>Macom</td>
<td>Richard Grzybowski</td>
<td>Director of Research &amp; Development</td>
<td>-SiPh CWDM TX with pigtailed fiber on evaluation board</td>
</tr>
<tr>
<td></td>
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<td>-HS photodetector</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-In-house testing</td>
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<tr>
<td>US Conec</td>
<td>Darrel Childers, Sharon Lutz</td>
<td>Director of Development</td>
<td>Prototype single mode expanded beam MT ferrules.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Interconnects; backplane, front panel, I/O</td>
</tr>
<tr>
<td>MRSI Systems</td>
<td>Yi Qian</td>
<td>VP Product Management</td>
<td>Develop proper tool requirements and prototypes in the future phases.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Assess process design for manufacturing, manufacturing costs, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>high volume automation tool needs</td>
</tr>
<tr>
<td>Rochester</td>
<td>Drew Maywar</td>
<td>Associate Professor</td>
<td>Test Process</td>
</tr>
<tr>
<td>Institute of</td>
<td></td>
<td></td>
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<tr>
<td>Technology</td>
<td>Tom Brown</td>
<td>Professor</td>
<td>Observer</td>
</tr>
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<td>U of Rochester</td>
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<tr>
<td>3M Company</td>
<td>Terry Smith</td>
<td>Senior Staff Scientist</td>
<td>Organizer-Planning for next phases</td>
</tr>
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<td>US Competitors</td>
<td>John Mac Williams</td>
<td>Principle</td>
<td>Advisor-Planning for next phases</td>
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<td>MIT</td>
<td>Kazumi Wada</td>
<td>Professor</td>
<td>Advisor-Planning for next phases</td>
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<tr>
<td>IPSR</td>
<td>Robert Pfahl</td>
<td>Director of Roadmapping</td>
<td>Facilitator-Planning for next phases</td>
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Roadmap Next Steps: Identify Initiatives to Close Gaps

- Technology Evolution
- Product Needs
- Research
- Disruptive Technology
- Academia
- Government
- Industry Solution Needed
- Projects
- Implementation
- Available to Market Place
- No Work Required or Outsourced
- iNEMI
- Users & Suppliers
- Regional Collaboration
- Global Participation
iNEMI
Collaborative Project Activities
Why Collaborative Projects?

- Reduce cost by leveraging resources
  - Reduce cost by new technologies
  - Reduce resource demands and $ investments for each company
  - Stimulate standards and common specification development
  - Work on issues facing all your suppliers/customers
  - Disseminate efficient business practices

- Reduce risk of technology introduction
  - Gain knowledge and accelerate deployment of new technologies
  - Developing industry infrastructure, source of supply
  - Ensure reliability and technology readiness when required

- Reduce environmental risks
  - Ensure sustainable solutions are put in place and in sync with industry
Profile of Successful iNEMI Projects

- Addresses knowledge gap of industry
  - Common problem solved by working together
  - Often a pre-cursor to standards development

- Brings together a segment of supply chain to provide industry-wide response

- Direct alignment with member companies’ commercial interests.

LCA Estimator  Tin Whisker Susceptibility  Warpage Characterization of Organic Packages  Creep Corrosion
## 12 Ongoing Projects July - August 2017

<table>
<thead>
<tr>
<th>Project Name</th>
<th>TIG</th>
<th>Est Start Date</th>
<th>Est End Date</th>
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<tbody>
<tr>
<td>BiSn Based Low Temperature Soldering Process and Reliability</td>
<td>Board Assembly</td>
<td>2/1/2016</td>
<td>10/31/2017</td>
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<td>Characterization of Pb-Free Alloy Alternatives Project</td>
<td>Board Assembly</td>
<td>11/17/2015</td>
<td>6/30/2017</td>
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<td>Characterize and quantify the inspection capability of the AXI on HoP HiP defects</td>
<td>Test &amp; Inspection</td>
<td>7/28/2016</td>
<td>1/31/2018</td>
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<td>Connector Reliability Test Recommendations Project, Phase 2</td>
<td>Board Assembly</td>
<td>3/1/2017</td>
<td>3/29/2019</td>
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<td>Development of Cleanliness Specification for Expanded Beam Connectors Project, Phase II</td>
<td>Optoelectronic</td>
<td>3/1/2017</td>
<td>3/2/2018</td>
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<td>Final Assembly Automation and Optimization</td>
<td>Other</td>
<td>9/6/2016</td>
<td>12/1/2017</td>
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<td>Impact of Low CTE Mold Compound on Second Level Board Reliability Phase 2</td>
<td>Board Assembly</td>
<td>3/31/2016</td>
<td>2/28/2018</td>
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<td>IPSR - Board-Level Optical Interconnect Project</td>
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<td>5/5/2017</td>
<td>5/31/2018</td>
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<td>QFN Package Board Level Reliability Project</td>
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<td>12/29/2017</td>
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<td>Qualification Test Development for Creep Corrosion, Phase 3</td>
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<td>8/4/2017</td>
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<td>Reuse and Recycling Metrics - Phase 2</td>
<td>Sustainable Electronics</td>
<td>4/6/2017</td>
<td>2/28/2019</td>
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<td>SiP Module Mold-ability Study</td>
<td>Packaging</td>
<td>6/10/2016</td>
<td>12/1/2017</td>
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<td>Initiative Project Name</td>
<td>Status</td>
<td>TIG</td>
<td>Chair Name</td>
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<tr>
<td>PCB Warpage Characterization and Minimization Project</td>
<td>TC Approval/In Sign-up</td>
<td>Board Assembly</td>
<td>Srinivasa Aravamudhan</td>
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<td>Warpage Characteristics of Organic Packages Phase 4</td>
<td>TC Approval/In Sign-up</td>
<td>Board Assembly</td>
<td>Wei Keat Loh</td>
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<td>Wafer and Panel Level Package: Warpage and Flowability</td>
<td>In-Progress</td>
<td>Board Assembly</td>
<td>Renn Chan Ooi</td>
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<td>Solder Joint Fracture as a Function of Warpage</td>
<td>Consideration</td>
<td>Board Assembly</td>
<td>Ron Kulterman</td>
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<td>Value Recovery from Use Electronics Phase 2</td>
<td>TC Approval/In Sign-up</td>
<td>Sustainable Electronics</td>
<td>Bill Olson</td>
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<td>Eco-Design Best Practices</td>
<td>TC Approval/In Sign-up</td>
<td>Sustainable Electronics</td>
<td>Pamela Gordon</td>
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<td>Methodology for Qualifying New Packaging Technology</td>
<td>TC Approval/In Sign-up</td>
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<td>Fine Pitch Circuit Pattern Inspection/Metrology Project Plase2</td>
<td>In-Progress</td>
<td>Packaging</td>
<td>Feng Feng Xue</td>
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<td>High Temperature, Pb-free Die Attach Material Phase 2</td>
<td>Consideration</td>
<td>Packaging</td>
<td>Sze Pei Lim</td>
</tr>
</tbody>
</table>
Initiative Example
Approaches to minimize Printed Circuit Board (PCB) warpage in Board Assembly Process to improve SMT Yield

Call for Project Sign Up
September 2017

Initiative Leaders: Srini Aravamudhan & Chris Combs, Intel; iNEMI Staff: Haley Fu
Proposed Mitigation to Problems

- **Guidelines for PCB design on:**
  - Copper balancing across PCB layers
  - Outrigger - Board area copper balancing
  - Outrigger tab size and placement
  - PCB location impact within panel during PCB fabrication

- **Guidelines on Reflow pallet design**
  - Design features
  - Pallet materials

- **Other uncovered factors / solutions to minimize PCB warpage in SMT assembly process**
Potential Mitigation Paths for PCB Design Guidelines

- Unbalanced copper ratio between outrigger and board area leads to varying rates of thermal expansion in reflow and drives warpage in PCB.

- Recommend for each layer that the outrigger copper content to be 1:1 or greater (100-120%) of the single board image to minimize panel warpage.
Thermal mismatch (ΔT) across the PCB due to the Pallet design (overlap heatsink effect) is the primary factor that drives panel warpage post 1st pass reflow.

Pallet material also plays a role in warpage reduction.
iNEMI Board Warpage Strategy

- iNEMI project goal is to leverage the Intel data & solutions while working with Industry partners to further development & learning through increasing the board design and process envelope.
- OEMs are key in board design decisions/procurement spec and influencing ODMs.
- ODMs design the reflow pallets and manage the board warpage impact to mfg & yield.
- PCB suppliers make Cu balance & other PCB fab decisions that impact board warpage.

Key Industry Influencing Partners:

- **ODMs:**
  - Wistron
  - Quanta
  - Compal
  - Foxconn
  - ...

- **CMs:**
  - Flex
  - Sanmina
  - Jabil
  - ...

- **OEMs:**
  - Microsoft
  - Apple
  - Lenovo
  - LG
  - Asus
  - Dell
  - Intel

- **PCB Suppliers:**
  - Nanya
  - Hannstar
  - GCE
  - Tripod
  - Dynamic
  - OPC (aka TTM)
  - AT&S
  - LG Innotek
  - Unimicron

- **Mkt Share & Dev’t partner:**
  - Nvidia

- **Mkt Share:**
  - Intel

- **Low Vol Dev’t partner:**
  - Qualcomm

- **Tech focus / strat partner:**
  - Qualcomm

Acknowledgements:
- Tim Swettlen
Completing the 2017 iNEMI Roadmap/Starting the 2019 Cycle

- 2017 iNEMI Roadmap Development Cycle is wrapped up!
- 2017 iNEMI Technology Plan Planned for Publication End of September
- 2017 Roadmap Available Free to iNEMI Member Companies
- Available To Industry:
  - Order the 2017 iNEMI Roadmap via download at www.inemi.org
  - Individual roadmap chapters are also available as a PDF document download at www.inemi.org
- 2019 iNEMI Roadmap is being developed now for publication to members in late December, 2018 and the industry in late March, 2019 so take advantage of the opportunity to participate (iNEMI Membership not required for roadmap participation).

- Contact Chuck Richardson for more details at crichardson@inemi.org
Contact Information

www.inemi.org

Bill Bader
Bill.bader@inemi.org