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Process Improvements for First Pass Yield Gains during Tri-Temperature Automotive Package Test

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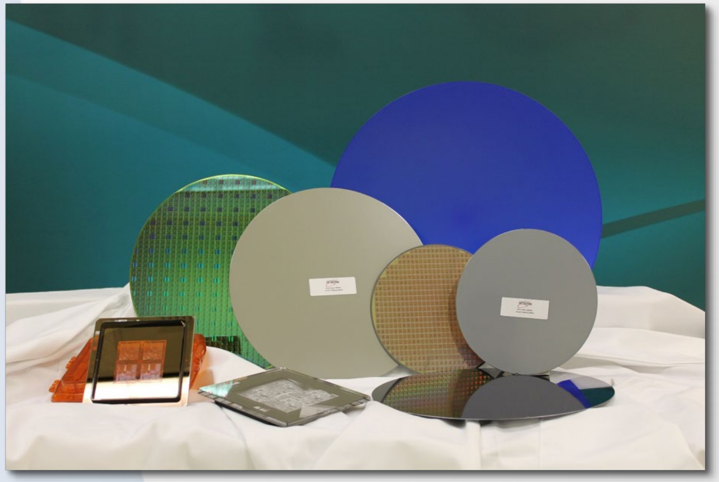
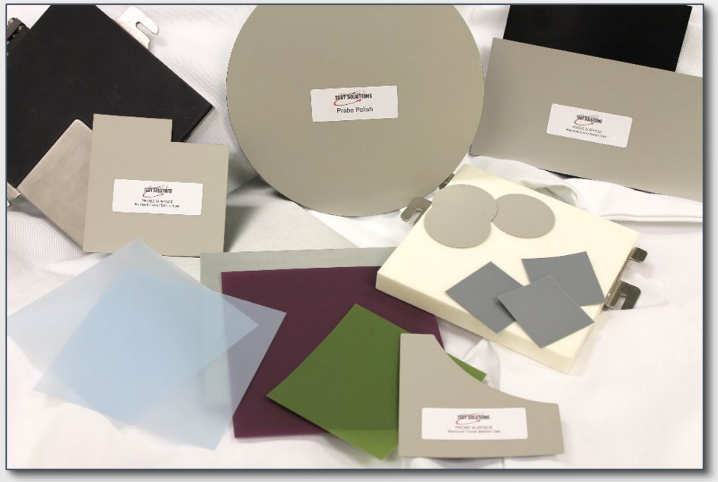
IMPROVING YIELD THROUGH INNOVATION.

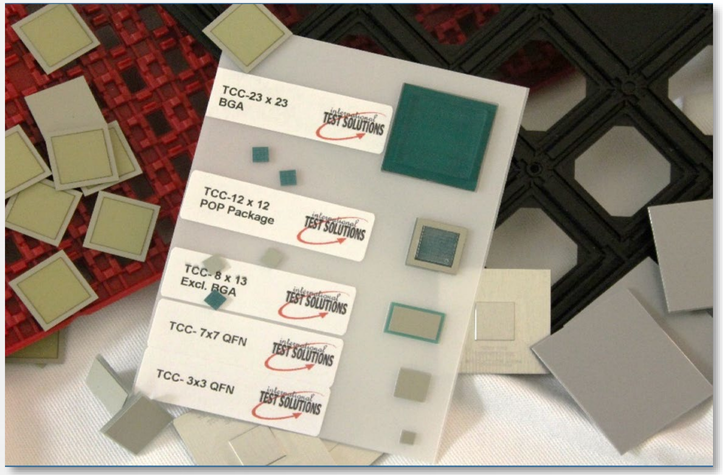
Overview

- Introduction and Market Requirements
- Importance of Automated Contactor Cleaning (ACC)
- ACC for Increased Yield and Throughput Gains
- Customer Case Studies – Increased Yield and Test Time Reduction
- Summary and Conclusions

International Test Solutions (ITS) at a Glance







Front End Products since 2011

Chuck Cleaning Wafer (CCW) Products

- Stage Clean for Litho Tools - Removes debris that causes defocus errors and extends times between wet-cleans.
- Etch Clean for Etch Tools - Removes debris that causes Helium leak faults and reduces downtime.
- Sputter Clean for PVD Tools - Removes debris that causes defocus errors

Wafer Sort Products since 1998

Probe Card Cleaning (PCC) Products

- Elastomeric Cleaning Materials - Advanced polymers with abrasive particles for probe shaping and debris collection
- Abrasive Cleaning Materials - Low wear precision films for adherent contamination removal and tip texturing
- Functional Feature Polymer Materials – Surface featured elastomeric material engineering for advanced for probe cards applications.

Final Test Products since 2004

Test Contactor Cleaning (TCC) Products

- Engineered cleaning solutions matched to handler, device, socket, and thermal requirements
- Materials for thermal performance tri-temperature test conditions (from -55 to +175C)
- Critical for stable first pass yields, reduced retest, and high final yields

Application Landscape Drives Complexity

Data Cloud and AI
Explosion of Data, High-Capacity Storage, and HPC growing from 5 Zetabytes to > 40 Zetabytes

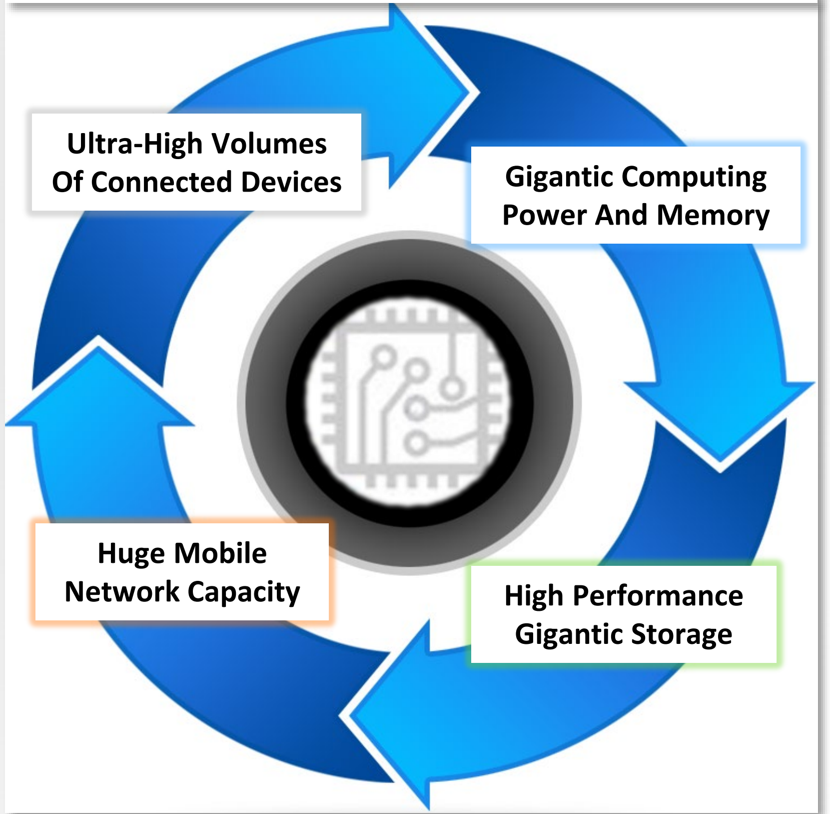
5G and Massive Connectivity
More than 1.1 billion smart-device and high-volume connections

Smart Devices
More than 250 million wearables and high-performance devices

Internet of Things
50B connected devices of low-cost devices and massive data volumes

Automotive Electronics
89 million connected cars each generating and processing > 1GB of data per second

Common Requirements

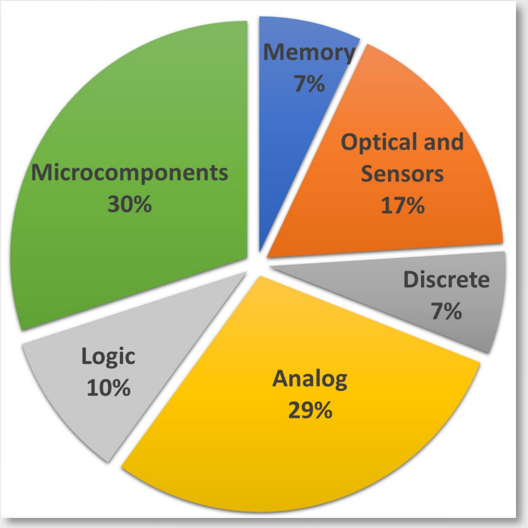


Source: IHS Markit, Gartner, VLSIResearch

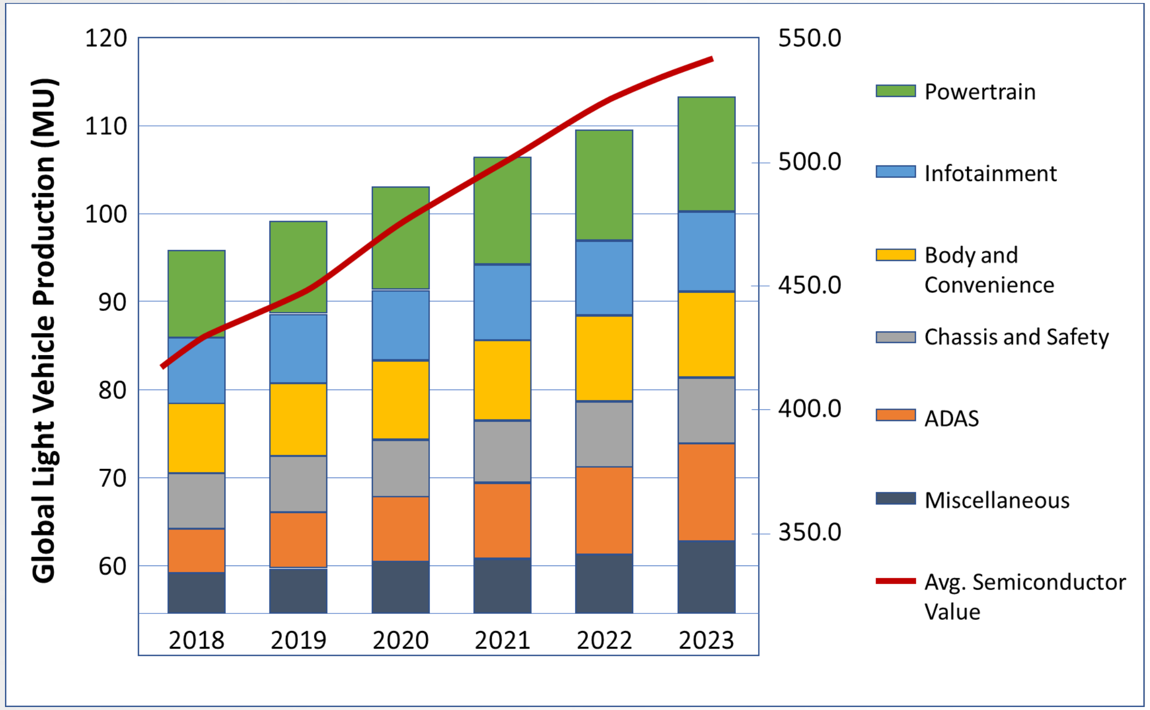
Automotive Electronics is a Fast-Growing Market

- **Auto industry expects 3%~12% CAGR over next 5 years**
  - Light Vehicles uses more semiconductors than ever before.
  - Shortage of automotive IC could delay this sector's supply chain recovery after the pandemic.

- **Automotive IC growth**
  - Safety Systems
  - Fuel Efficiency
  - Navigation
  - Communication
  - Infotainment
  - Electrification



Automotive Semiconductor Market Sectors



Source: IHS Markit, Automotive Sensors Intelligence Service, Strategic Analytics

A modern automotive vehicle can include as many as 8,000 active semiconductors in up to 100 interconnected control units.

Source: Audi Semiconductor Lab

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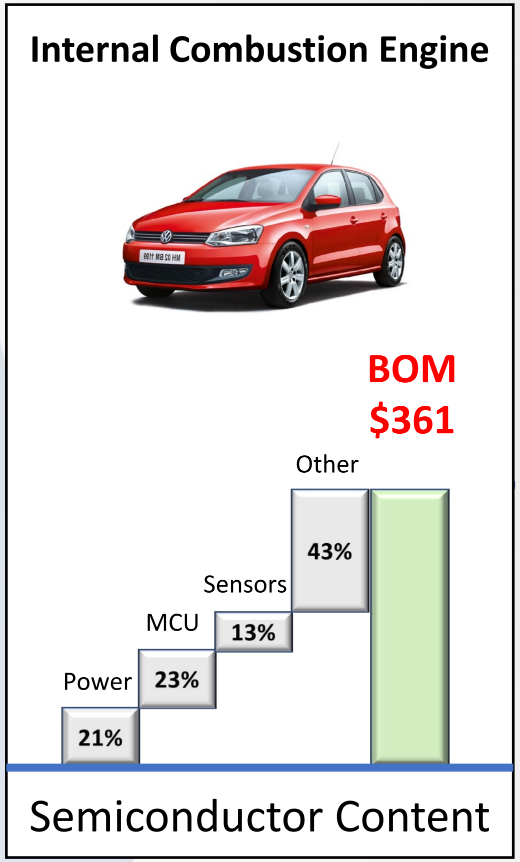
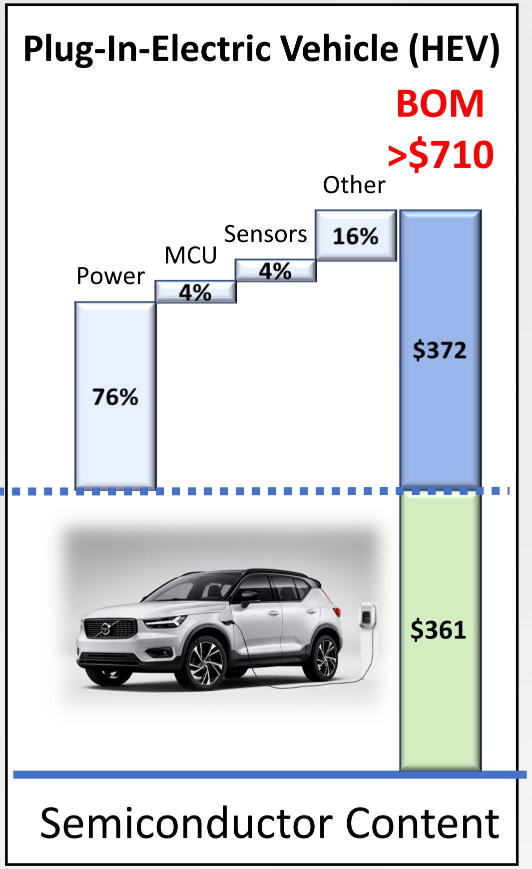
Electrification is a "Game Changer"

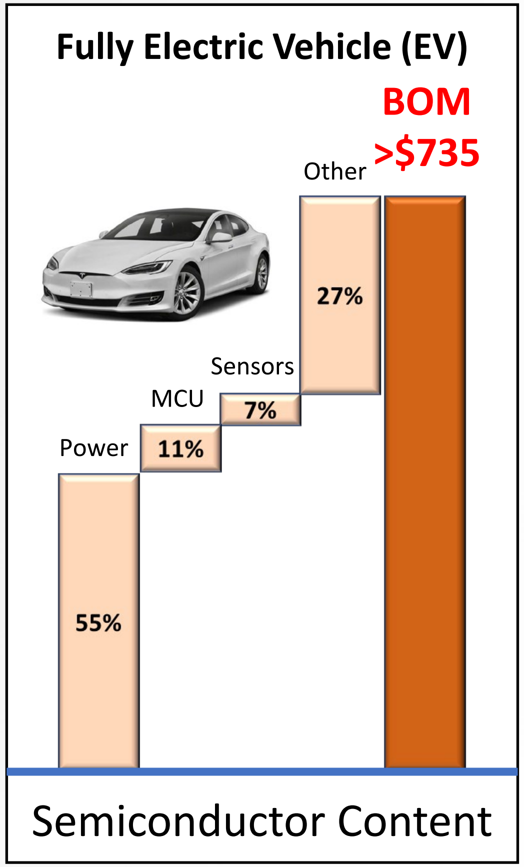
- Over 10% of all semiconductors produced worldwide are sold into the automotive segment.
- Accelerated growth with electrification, connectivity and autonomous driving.





Total Power IC Content

Increases by ~15X



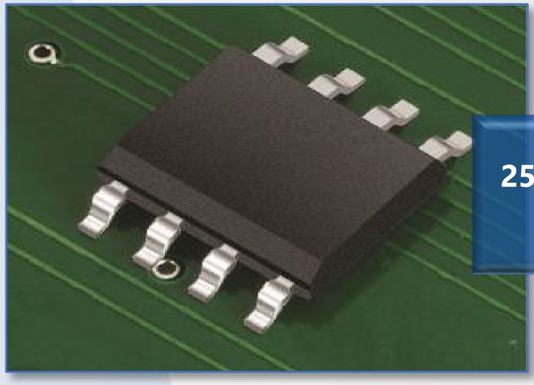
Sources: K. Konrad, IS-Test Workshop 2019, SEMI Mobility Blog 2021

Automotive Defect Levels are 10X More Stringent

- Parts per billion (ppb) failure rates mandate "Zero-Defect" manufacturing.
- Performance and reliability are getting measured in "Raw Incidents".
- Corrective and preventive actions are required, even for single unit failures.

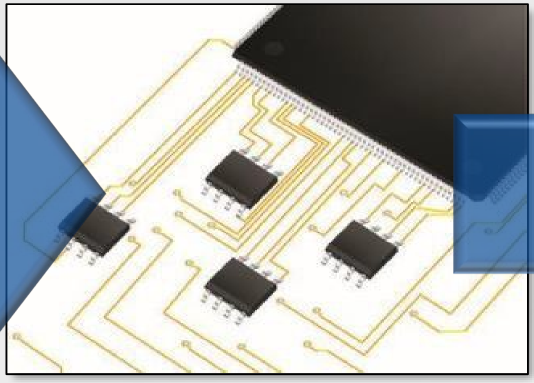
1. Quality management: IATF 16949
2. Functional safety: ISO 26262
3. Environmental: ISO 14001
4. Qualification: AEC-Q100

Component



250 Components Per System

System



40 Systems Per Car

Car

Component	System	Car	
1 ppm	250 ppm	10,000 ppm (1.0%)	Too High (10K Fails)
<0 ppm	10 ppm	400 ppm (0.04%)	Target ? (400 Fails)
0 ppb	~ 0 ppm	<1 ppm (0.00001%)	"Zero-Defect"

Source: Infineon Technologies, C. Lee, Amkor SiP China 2018; J. Broz, et. al, CSTIC 2020

Automotive Requirements Create Device Test Challenges

Requirements

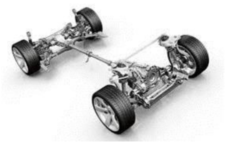
- Harsh outdoor environment
- Testing across thermal range
- Minimize reliability impact
- Support large volume demand
- Lower test cost

Critical Test Challenges

- Package test with multiple insertions:
  - tri-temp (cold, room, and hot)
- High temp test required
  - 125°C ➔ 150°C ➔ 175°C
- Multiple insertions with same device
  - limited or no retest allowed

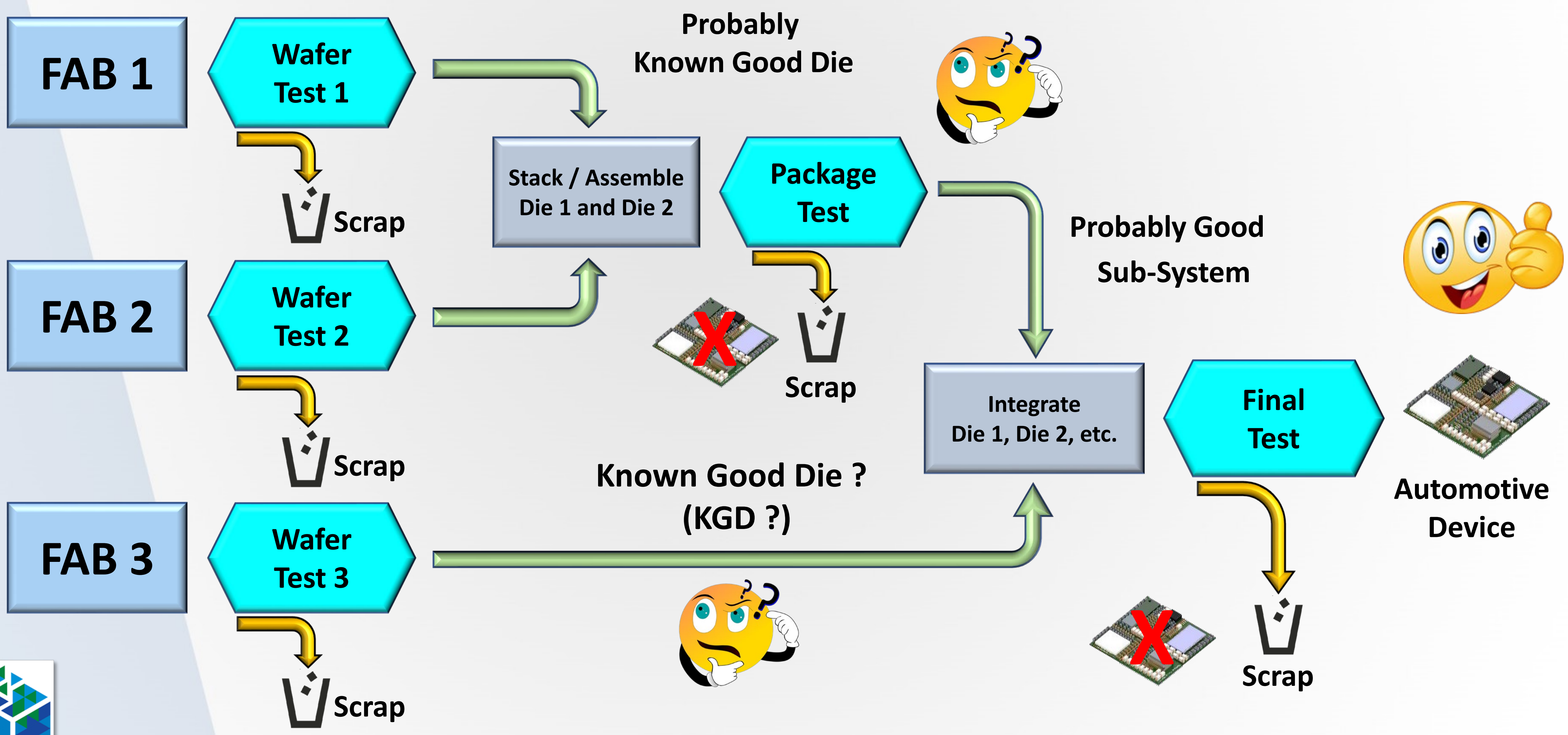
Automotive Reliability Grade Level Mapping (AEC)

- **In the past, automotive ICs used mostly mature device and packaging technologies.**
- **Current trends to enable ADAS and infotainment.**
  - Advanced silicone nodes
  - Advanced packaging strategies
  - Heterogenous integration
- **Device integration is pushing test requirements to greater than 175C and, in some instances, up to 200C.**

AEC Q100	Temperature	Segment	
0	-40°C to +150°C	Powertrain	
1	-40°C to +125°C	Body, ADAS	
2	-40°C to +105°C	Chassis, ADAS, Safety, Powertrain	
3	-40°C to +85°C	ADAS, Sensors, Infotainment	

Source: Automotive Electronics Council : AEC-Q100

Wafer and Package Test Flow

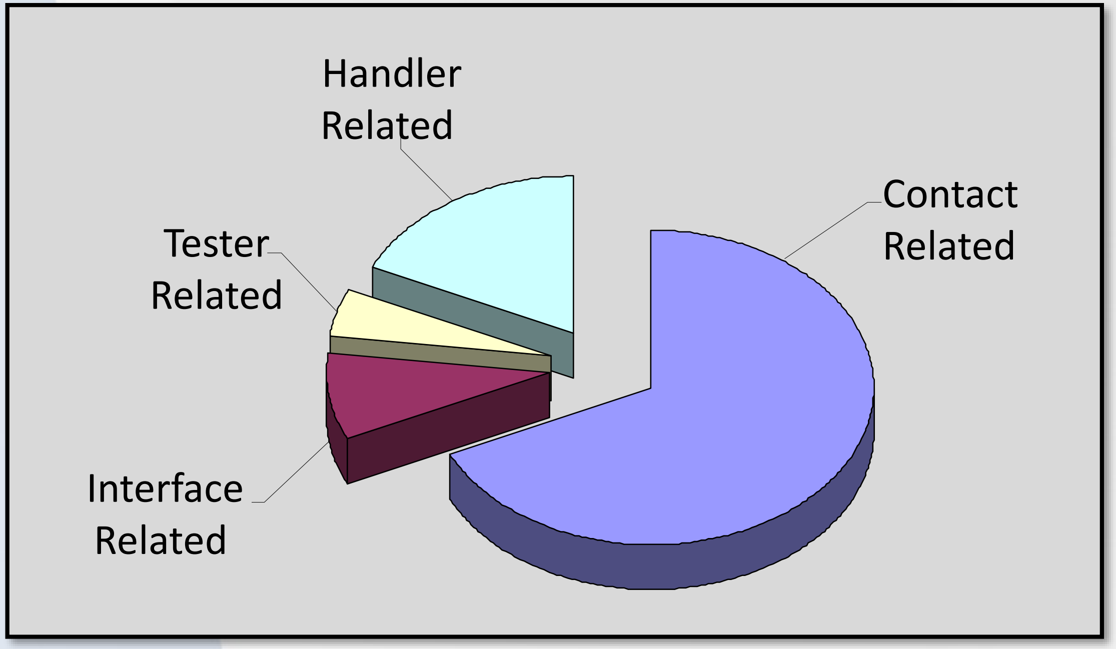


Source: J. Broz, MEPTEC Lunch Series 2020; Broz, et. al, CSTIC 2020

Unstable Contact Affects Test Performance

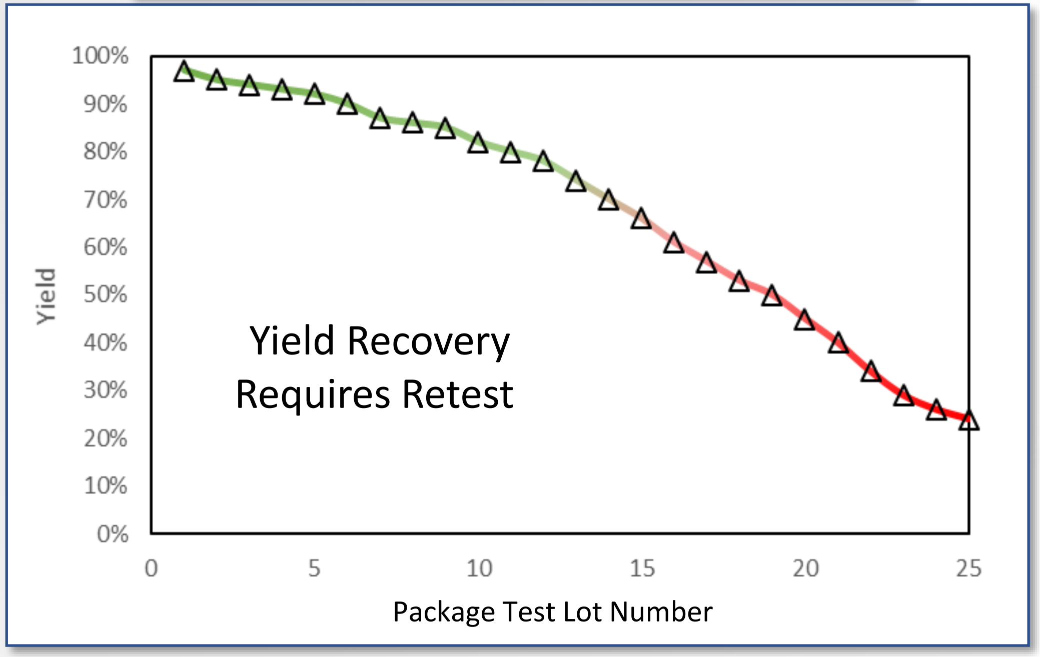
- First Pass Yield (FPY) fallout attributable to contact related issues.

Causes of First Pass Yield Fallout



Source: B. Gibbs and K. McNamara, IEEE BiTS Workshop 2006

First Pass Package Yield Drops When No Socket Cleaning is Performed

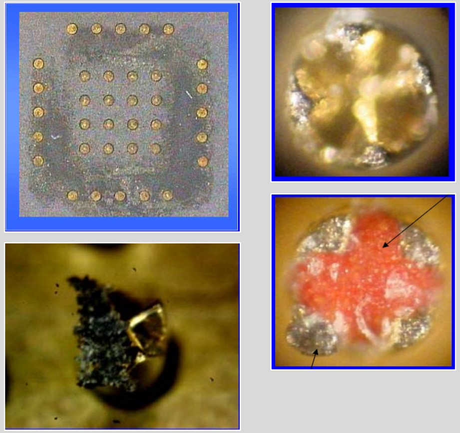


Source: J. Broz and B. Humphrey, BiTS Workshop 2012

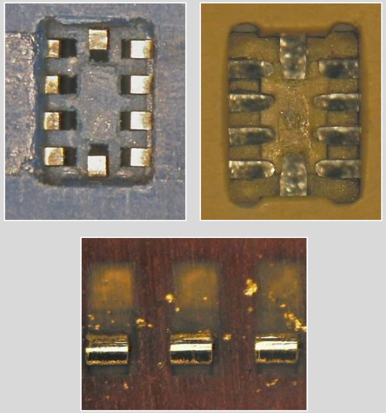
Package Test is a "Dirty Business"

- Semiconductor packages carry debris and oxides that can contaminate test or burn-in sockets.
- Contaminants accumulate on spring pins, contactors, and surfaces within the socket to degrade electrical contact during test execution.
- Contact Resistance (CRES) instability is entirely attributable to interfacial phenomena across contact areas and with adherent contaminants.
- Film resistance is affected by non-conductive contaminants.
- Non-conductive contamination interferes with the "Metal on Metal" Contact.

Spring Pin Contamination



Contactor Contamination



Source: BiTS Workshop; TestConX

METALLIC CONTACT

$$C_{RES} = \frac{(\rho_{probe} + \rho_{pad})}{4}\sqrt{\frac{\pi H}{P}} + \frac{\sigma_{film} H}{P}$$

CONTAMINATION

R. Holm, 1967

Creates Critical Yield Fallout

Source: J. Broz and G. Humphrey, IEEE BiTS Workshop, March 2004

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In-Situ Cleaning for Contamination Control

- **Socket cleaning units are designed to be handled like a standard DUT**
  - Cleaning polymer is applied to the "I/O side" of the unit.
- **Cleaning unit is actuated into the socket to remove debris.**
  - Polymer is compressed against pins, contactors, and socket floor
  - Critical contact surfaces are cleaned, and debris is collected.
- **Advanced units are functionalized with polymer "cleaning balls"**
  - Alignment within a floating socket for precise ball to pin alignment.
- **How does it work ?**

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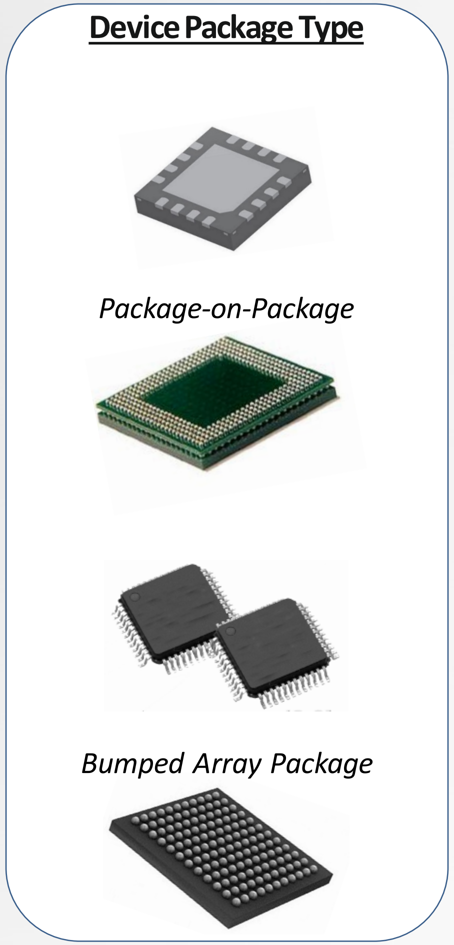
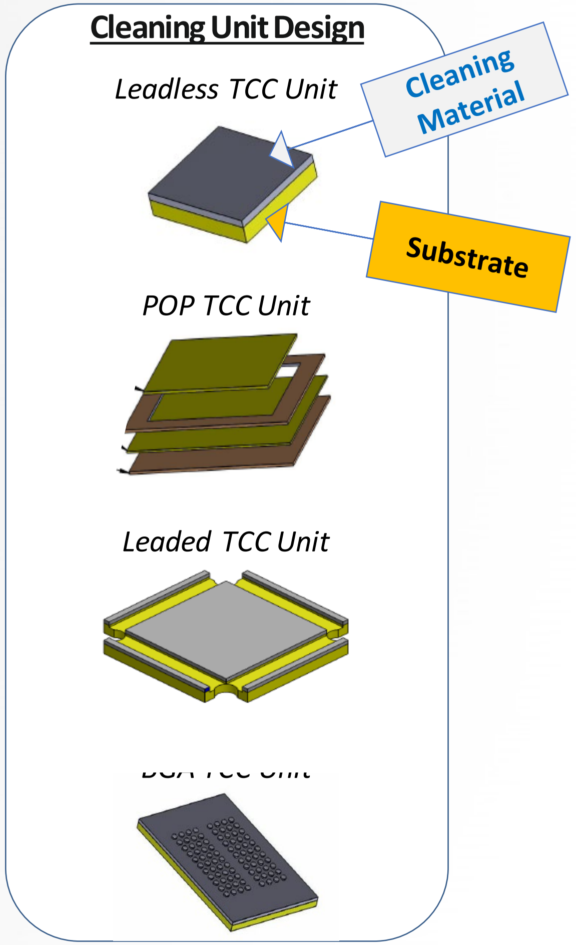
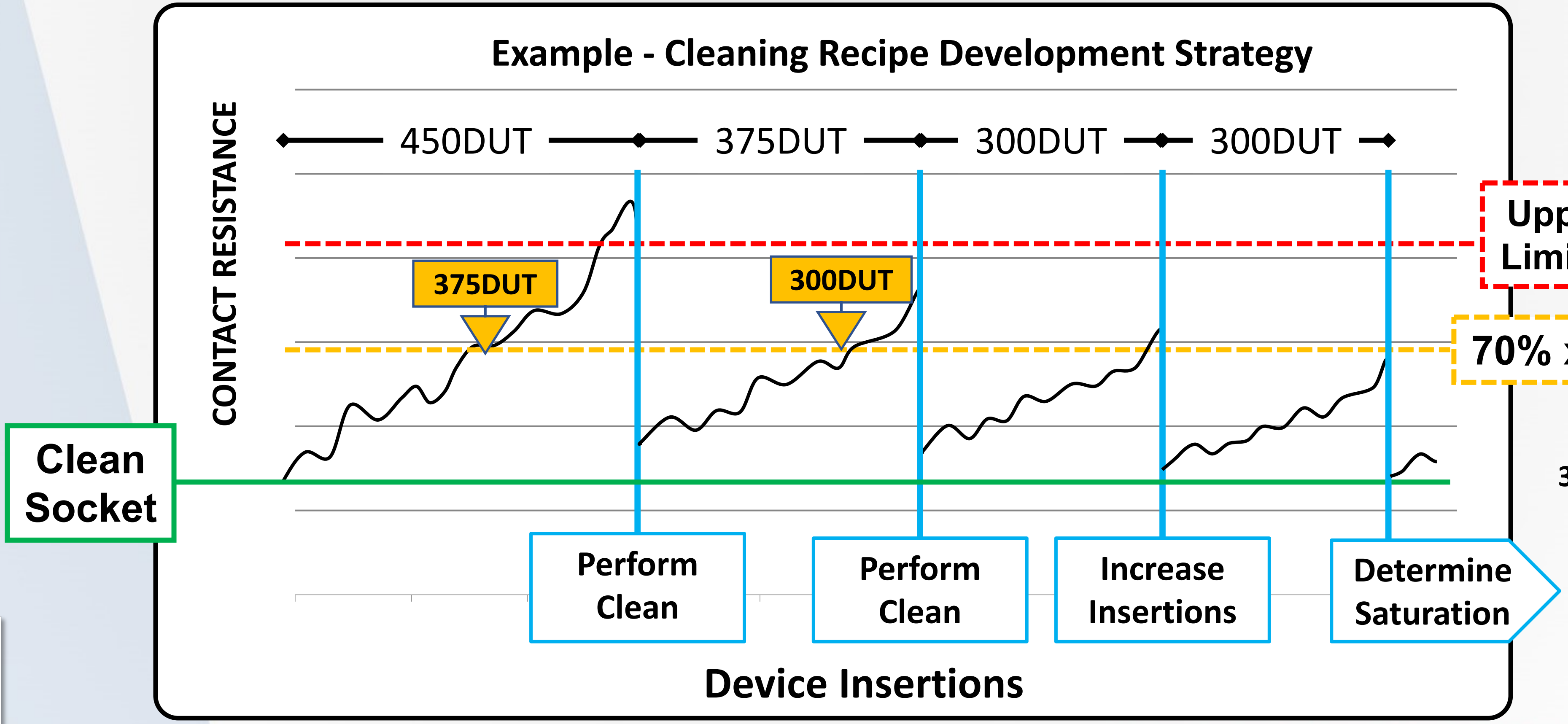




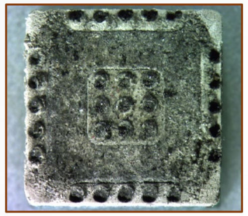
Pat.: US10,195,648; US8,801,869; US8,790,466; US8,371,316

Implementation for High Volume Testing

- **Optimized parameters provide best yield and lifetime for each unique environment.**
  - Cleaning interval to maximize stability ➔ depends on the socket and contactor
  - Number of insertions per cleaning cycle ➔ depends on the dirtiness of the socket
  - Optimum cleaning unit lifespan ➔ depends surface saturation



300 total insertions



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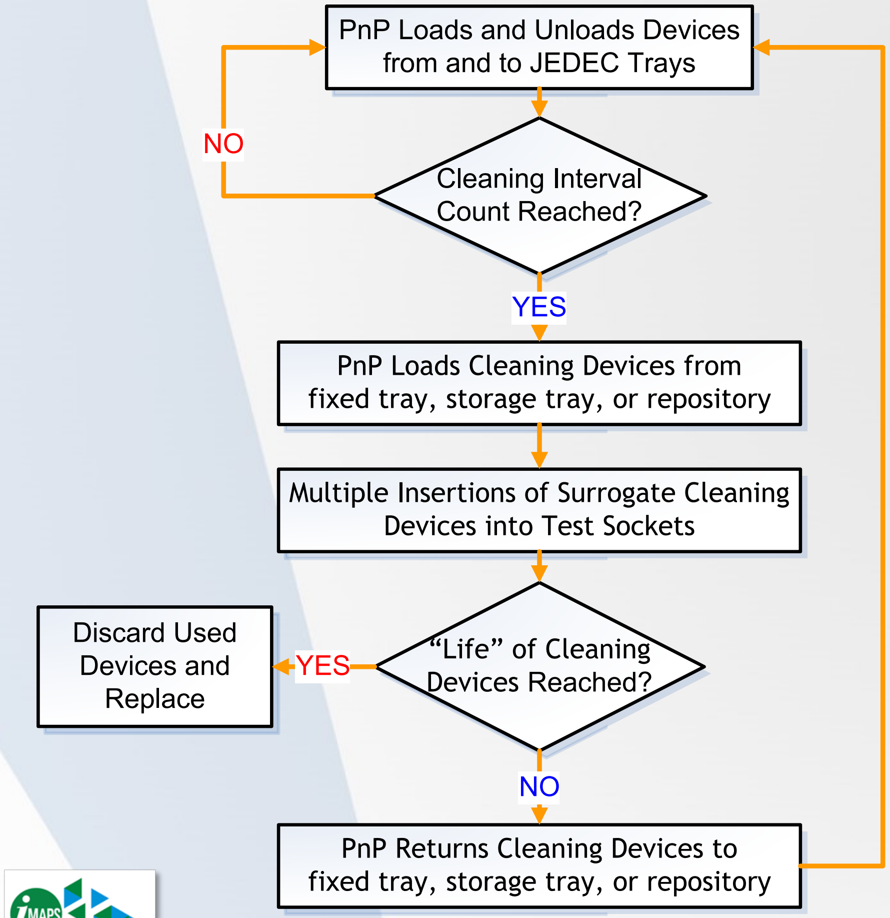
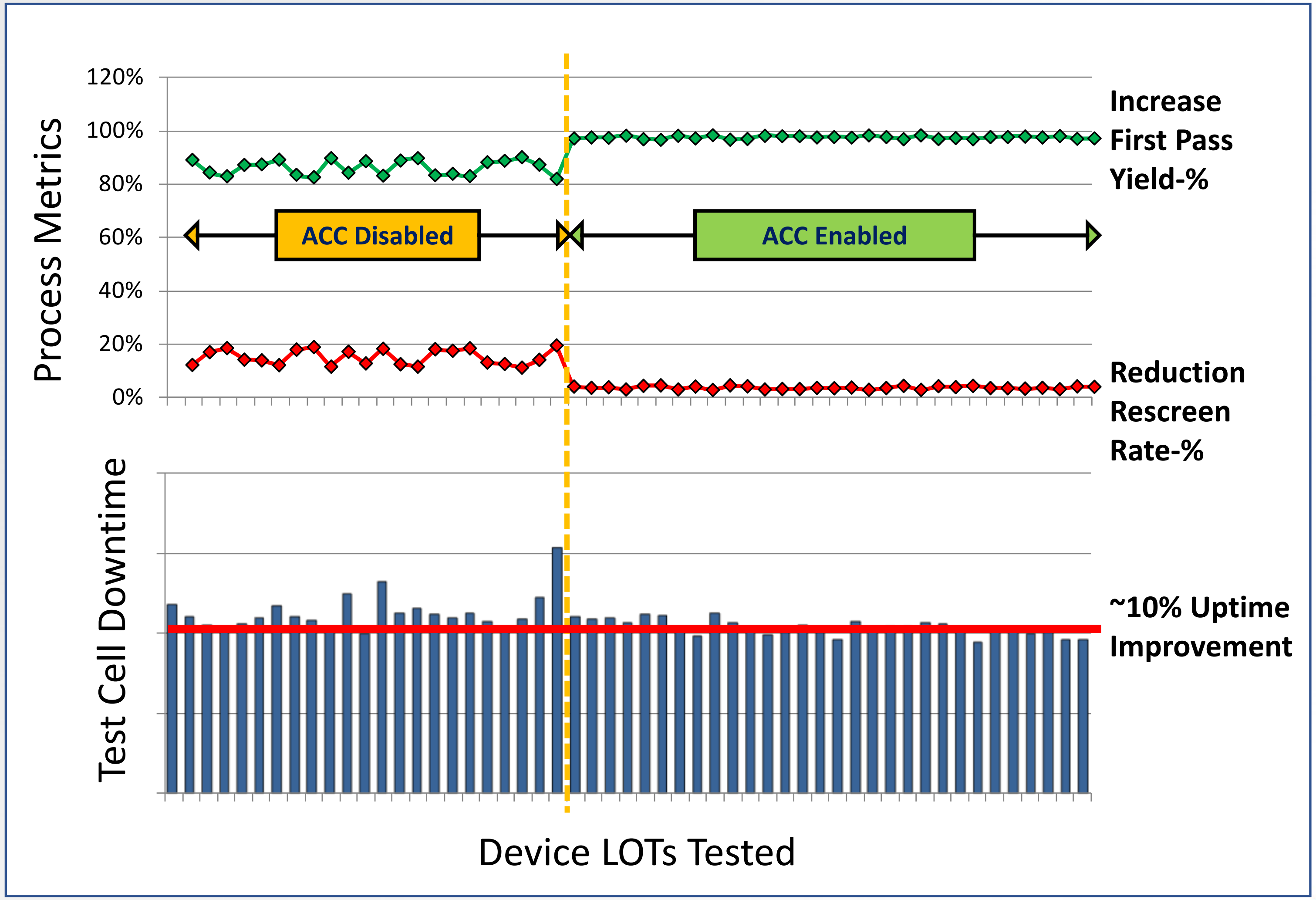
Test Process Improvement in HVM Process

Auto Contactor Cleaning Flowchart





Source: B. Gibbs and K. McNamara, SEMI techXBOT 2007; COHO -Delta Design Matrix

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Customer Study 1 – HVM Validation

Presented in Part at IEEE CSTIC-2020, June 26-July 17, 2020

- **High-volume PA Duplexer Modules (Devices A, B, and C) were selected for the qualification of ACC cleaning.**
- **Device A was tested on three production test setups**
  - 2-handlers with manual cleaning and 1-handler with ACC function
  - Monitored for one-month ➔ ~700K devices tested per setup
- **Device B and C were tested on six production test setups**
  - 2-handlers with manual cleaning and 4-handlers with ACC function
  - Monitored for one-month ➔ ~1M devices tested per setup
- **Monitors for all three devices (A, B, and C)**
  - Device yield metrics (first pass and retest)
  - Test-time metrics (first pass, retest, and total)

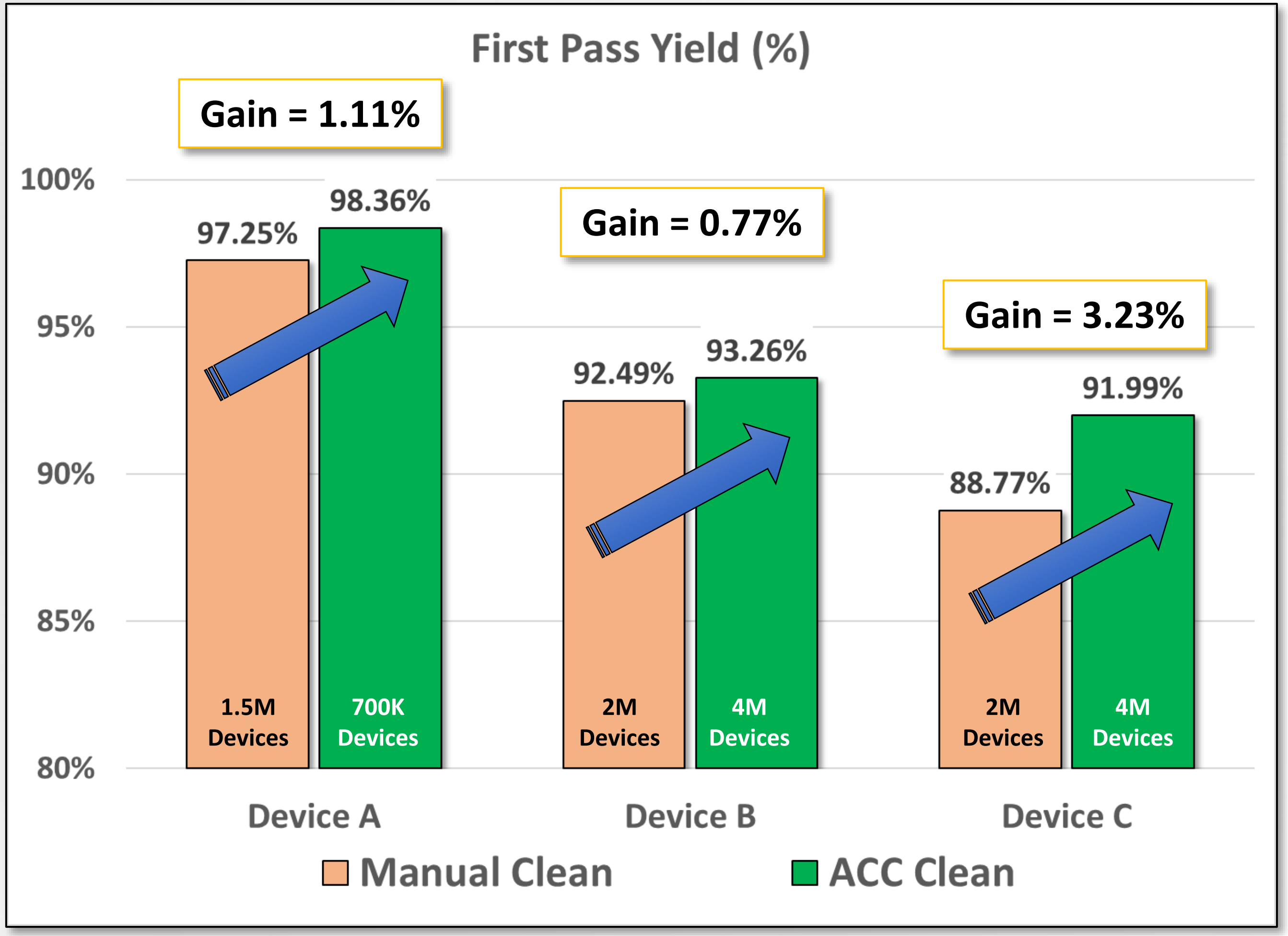
SRM XD248 Bowl Fed Handler

Source for Handler Image: http://www.srm.com.my/

Results – First Pass Yield Increase

Device A	First Pass Yield	Devices Tested	Retest Yield
Manual Clean	97.25%	1.5M	1.40%
ACC Clean	98.36%	700K	0.57%
Yield Gain	1.11%		
Device B			
Manual Clean	92.49%	2M	3.04%
ACC Clean	93.26%	4M	2.48%
Yield Gain	0.77%		
Device C			
Manual Clean	88.77%	2M	3.86%
ACC Clean	91.99%	4M	2.61%
Yield Gain	3.23%		

CRES (and Data Quality) was controlled during test to significantly increase first pass yields.

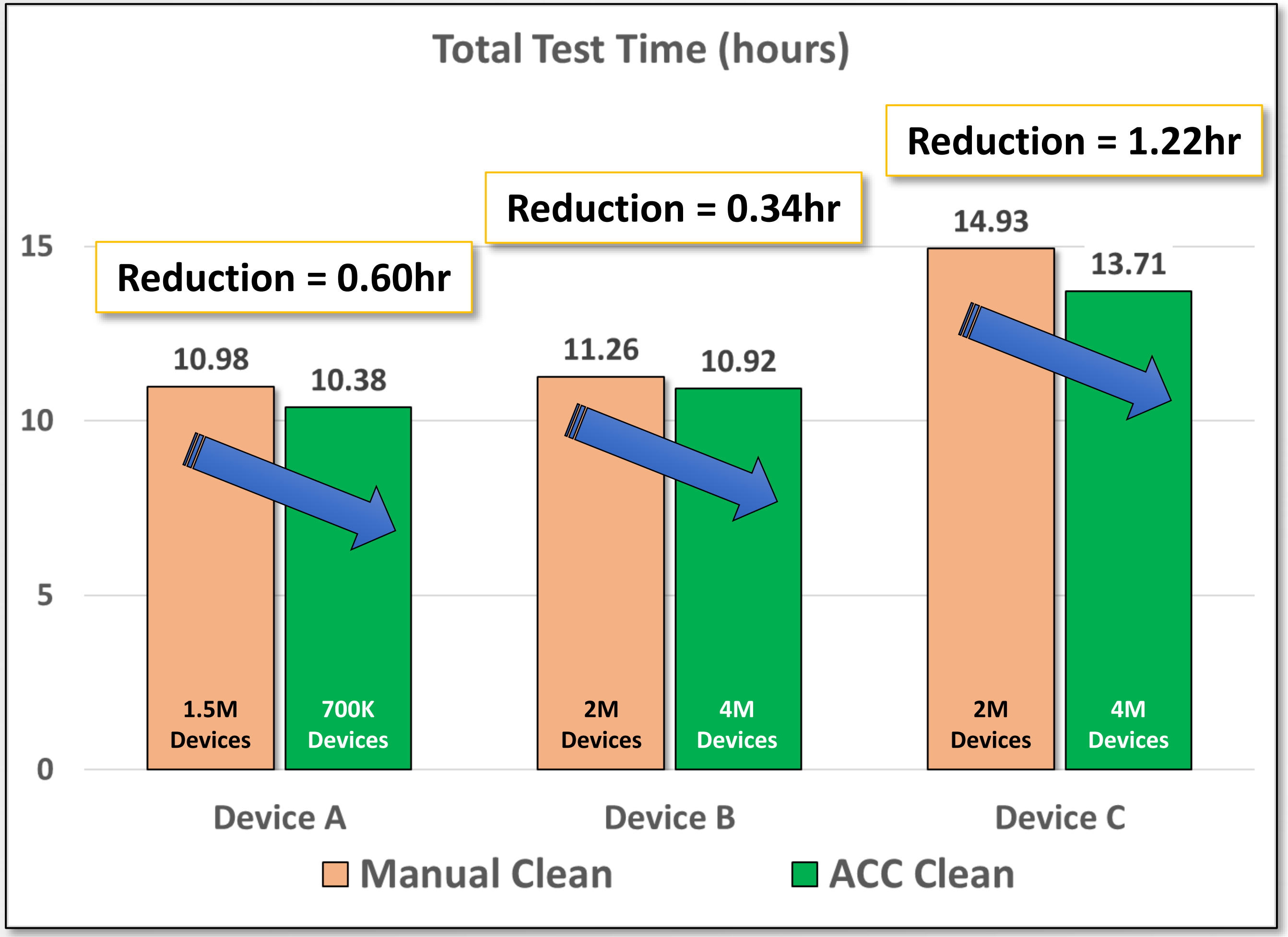


Source: B. Edington. BiTS Workshop 2014; J. Broz and B. Humphrey, IEEE CSTIC-2020

Results – Test Time Reduction

Device A	First Pass Test Time (hr)	Retest Test Time (hr)	Total Test Time (hr)
Manual Clean	10.57	0.41	10.98
ACC Clean	10.16	0.22	10.38
Time Reduction	0.40	0.19	0.60
Device B			
Manual Clean	10.15	0.89	11.26
ACC Clean	10.37	0.77	10.92
Time Reduction	0.22	0.12	0.34
Device C			
Manual Clean	13.36	1.56	14.93
ACC Clean	12.64	1.06	13.71
Time Reduction	0.72	0.50	1.22

Handlers did not need unscheduled idle time for cleaning and test times were significantly decreased.



Source: B. Edington. BiTS Workshop 2014; J. Broz and B. Humphrey, IEEE CSTIC-2020

Customer Study 2 – Tri-Temperature Automotive

Presented in Part at IEEE CSTIC-2021, March 14-15, 2021

- **AEC qualified automotive devices must pass demanding stress tests and meet high levels of quality and reliability**
- **Tri-temperature testing was required for this project:**
  - T = –35C
  - T = 25C
  - T = 150C
- **Cleaning units are designed and built for test operations at T = – 50C to +175C**
- **Due to restrictive device requirements and high costs with retest, limited or no rescreen was allowed.**
- **Unscheduled downtime from non-automated cleaning significantly affects production throughput.**

Cleaning Units

12 x 12mm PoP Unit

7 x 7mm QFN Unit

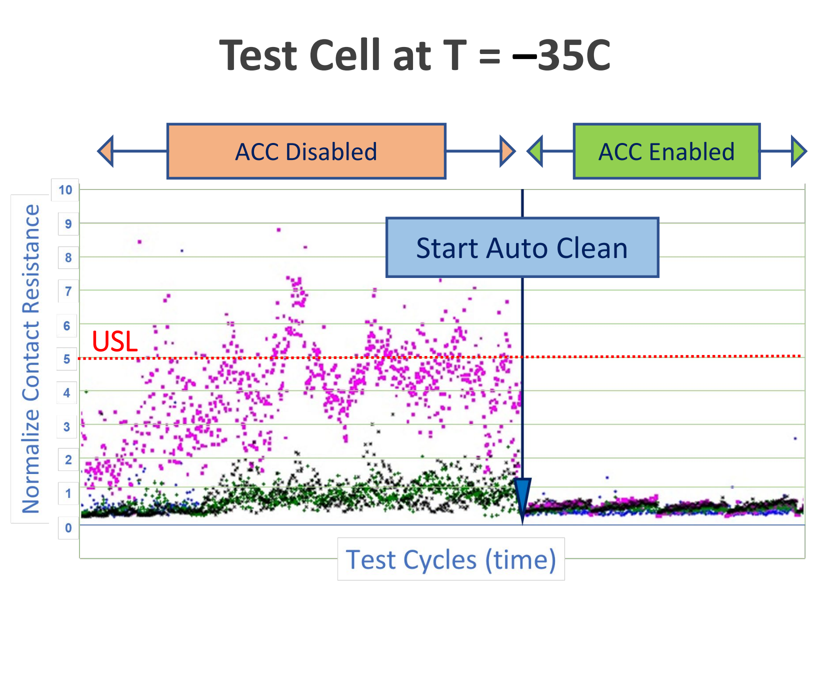
Representative Handlers with ACC Function

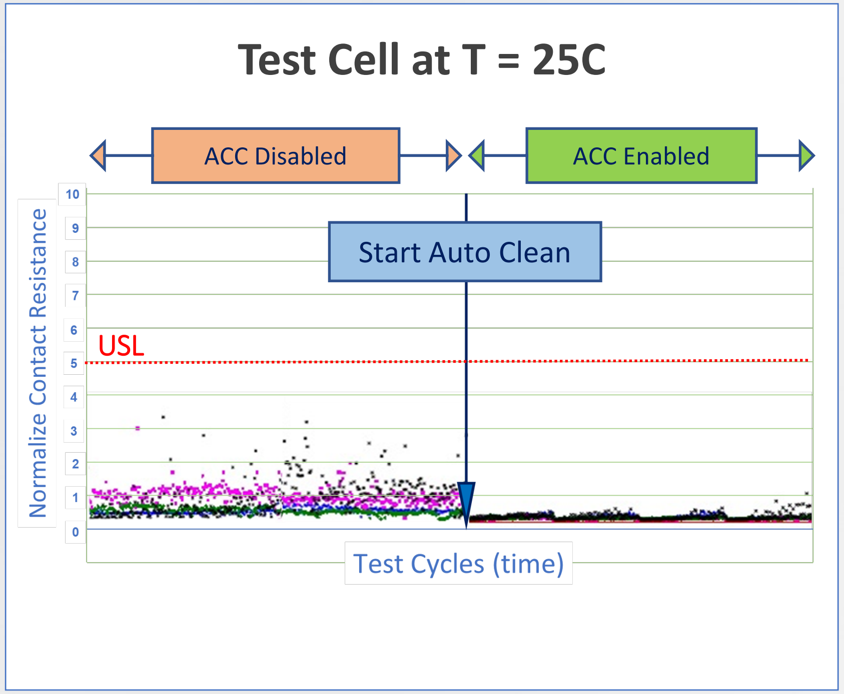
Cohu®- Delta Design Matrix

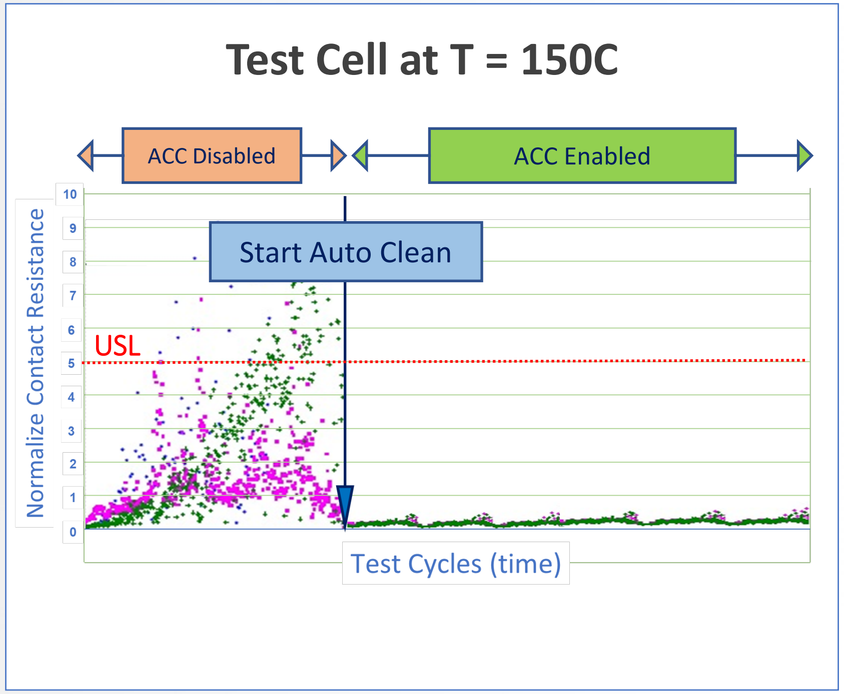
Cohu®- MT9510

Source for Handler Images: https://www.cohu.com/pick-and-place

Results – Tri-Temperature Test Stability





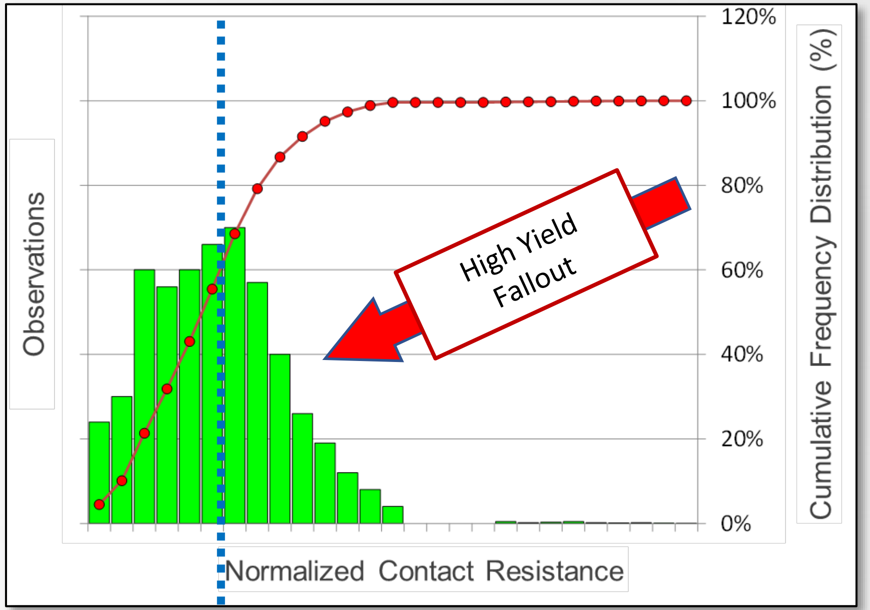


- For tri-temperature testing, implementation of in-situ cleaning with ACC enabled resulted in significant first pass yield gains and more stable contact.
- Cleaning parameters for optimal stability and socket lifetime were developed for each unique testing environment.

Source: J. Broz and B. Humphrey, IEEE CSTIC-2021

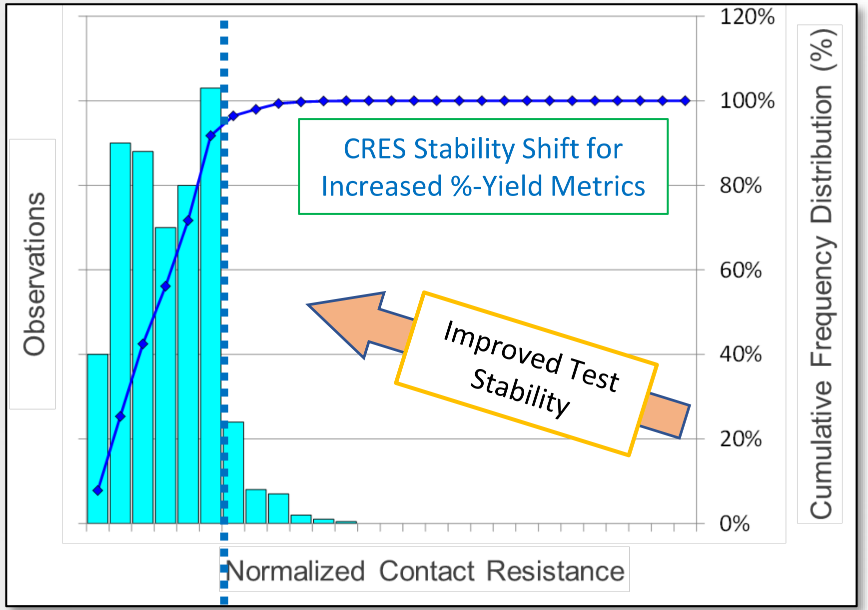
Results – Tri-Temperature Test Stability

ACC Disabled



Specification Limit

ACC Enabled



Specification Limit

- **CFD highlights CRES stability and measurements at specification limits that are indicative of expected yield.**
- **With ACC enabled, a dramatic shift in the CRES to attain substantially higher yields at the specification limit.**
- **In-situ cleaning process produced tight distributions with lower continuity failures during first pass test.**

Source: J. Broz and B. Humphrey, IEEE CSTIC-2021

Results – Retest Reduction

- **With ACC enabled at during tri-temperature testing.**
  - First pass yields were significantly higher.
  - Recovery yield metrics were consistently lower.
  - Additional retest events, if performed, did not provide significant recovery yields.

- **Reduction of retest events has clear benefits for reducing the total cost of test.**
  - By eliminating retest events, tester availability can be dramatically increased to attain higher test-floor throughput.

- **Some critical automotive devices are not allowed to have multiple re-test events; thereby, increasing the importance of stable and reliable contact during the first pass when tri-temperature testing.**

Source: J. Broz and B. Humphrey, IEEE CSTIC-2021

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Summary / Conclusions

- **Automotive sector is expected to grow substantially over the next 5 years.**
  - Nearly every type of semiconductor device is included in automotive application
  - Safety devices and ADAS are expected to play a dominant role in this growth
- **New test strategies, tooling, and materials are necessary.**
  - Significant impact for Cost of Test with longer test times to assure thoroughness.
  - Heterogeneous integration and multi-chip strategies use "best-in-class IP" to advance device performance.
- **Automotive electronics have strict quality standards (ISO-26262 and AEC-Q100) requirements.**
  - Significant impact for cost of test with longer test times to assure ZERO Defects.
  - Increased number of measurements are needed for AEC-Q100 Class Requirements.
- **In-situ cleaning during tri-temp testing for stable date, higher first-pass yield, and tester utilization.**
  - Consistent contact resistance and contamination control are critical for tri-temperature testing of automotive devices.
  - Significant reductions in test time enable higher UPH and reduce the need for additional testing hardware.
- **Test stability improvement have immediate benefits for throughput, net revenue, and lowered cost of test.**

Acknowledgements

- Authors would like to thank the technical collaborators for this project that have asked to remain anonymous.

Thank You for your Attention !

Questions ?

International Test Solutions

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