Tin Whisker Mitigation of Lead-Free Assemblies

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April 1, 2026

Introduction

- Tin whiskers pose serious reliability risks
  - Do next generation Lead-Free solder pastes result in whisker growth?

- Conformal coatings can mitigate whisker growth
  - Coatings may degrade electrical performance (ex: RF applications)

- Project:
  - Identify next-generation “high reliability” solder pastes for Lead-Free applications and identify conformal coatings for said applications
  - Perform whisker risk analysis (Experiment 1) and RF analysis (Experiment 2)

Participant List

Company	Contact	Responsibility
Universal AREA Consortium	Michael Meilunas	Material procurement / PCB design / Assembly / Funding
RTX / Raytheon	Karen Ebner John Magnani Twinkle Shah Cathi Miles	Test Vehicle Design/Urethane Coating/Parylene
Indium Corporation	Emily Belfield Kevin Brennan	Solder paste (SnPb/SAC/DurafuseHR/DurafuseLT)
AIM Solder	Daniel Palma	Solder paste (Rel22/Rel61)
Heraeus Electronics	Kathryn Maylath	Solder paste (Innolot)
Cytonix	Luke Ratnasinghe	Conformal coating
SCS Coatings	David Ouradnik	Conformal coating
Kayaku/Advanced Materials	David Torres	Conformal coating
Fineline-USA	Eran Navick	PWB fabrication
Hatch Manufacturing Solutions	David Hatch	Consulting
Axiom Electronics	Rob Rowland	Consulting
Zestron Corporation	Jeff Kennedy Denis Barbini	Cleaning
Element Materials Technology	Daniel Phillips Keith Sellers	Testing services

Materials Selected for Evaluation

- Seven solder pastes
  - SnPb and SAC305 represent “Control” / “Baseline”
  - Pastes are “no-clean”, but cleaning required
- Four conformal coatings have been identified
- **Experiment 1**: Whisker risk assessment of all pastes and coating combinations
- **Experiment 2:** Solder paste selection is unlikely to impact coating effects on RF analysis
  - Only SnPb paste used for evaluation

PASTES
Indium SnPb w/NC-SMQ92J
Indium SAC305 w/8.9HF
AIM M8-REL22™-38-J5
AIM H10-REL61™-38-J5
Hereaus Innolot SMT660 IL-89M4
Indium Durafuse HR w/ 8.9HFRV
Indium Durafuse LT w/10.8HF

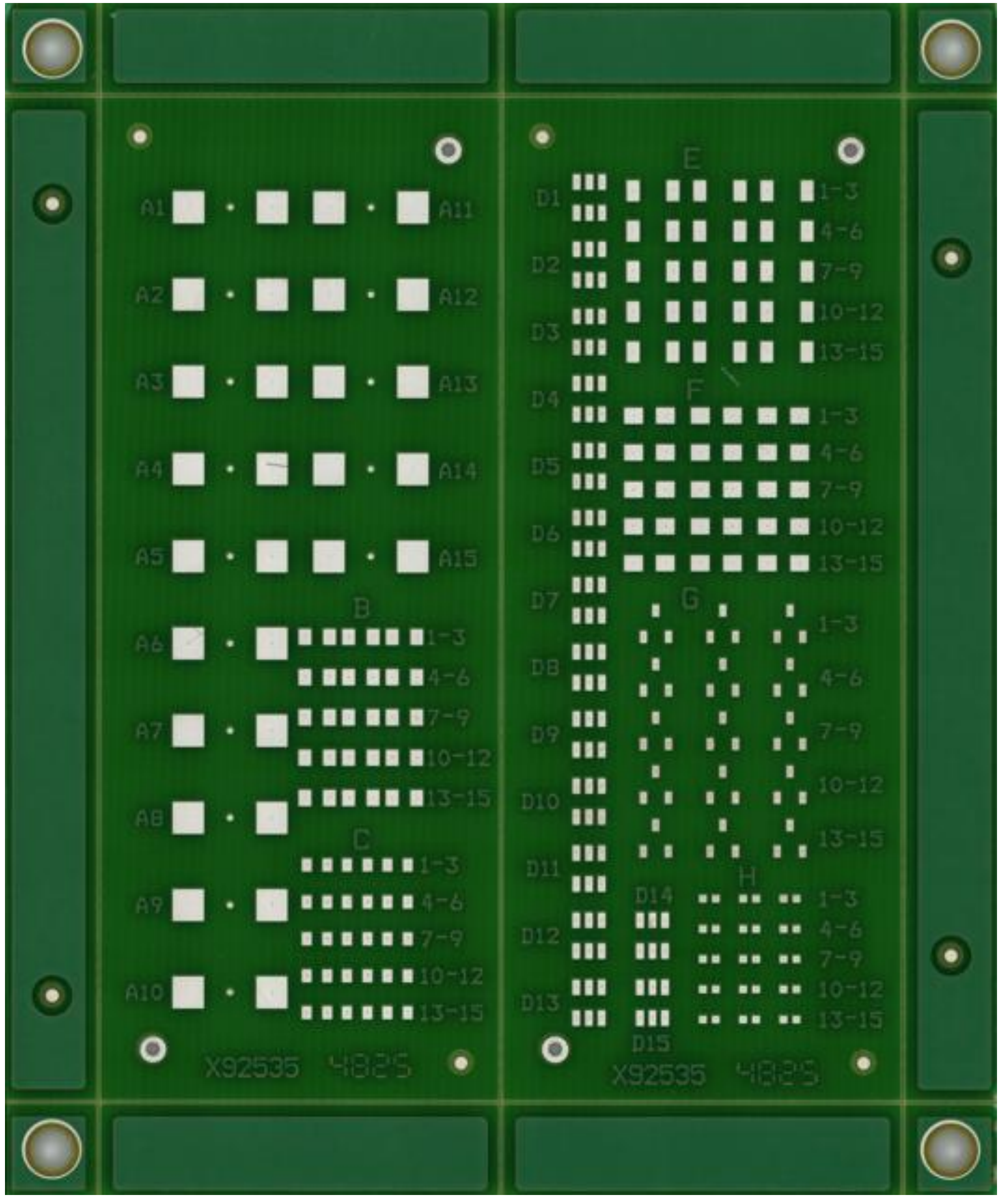
All Type 4

Coating
None
CytoCure D4
SignalSeal
CE-1155 Polyurethane
Parylene XY

AREA CONSORTIUM

Experiment 1: Whisker Test Vehicle

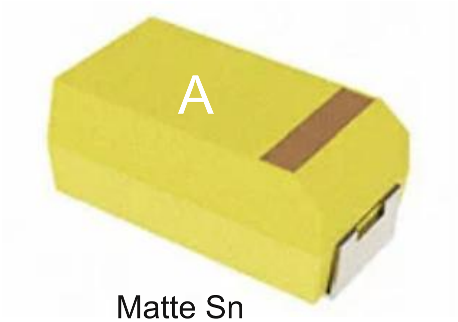
- Whisker test board
  - .062”
  - 2 layer
  - 1oz copper (+plating)
  - Immersion Silver
  - 120 placements



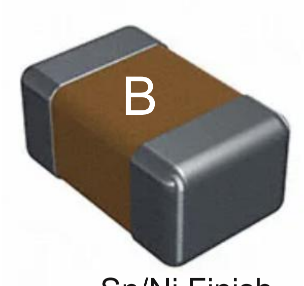
74x89mm

Whisker Test Vehicle

- Components are Lead-Free

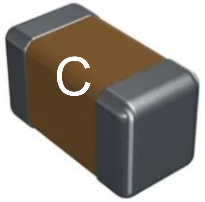


Matte Sn
Ni-Cu Lead

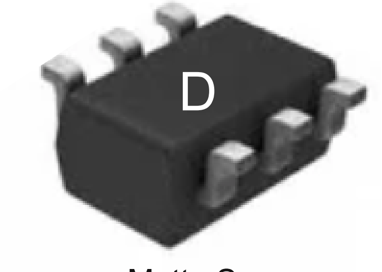


Sn/Ni Finish

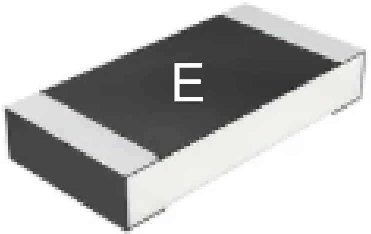
PCB Ink Coding	Component Part Number	Type	PCB Pad (mm)
A	T491D106M025AT	2917 Tantalum Capacitor	2.37x2.43
B	08055A271JAT2A	0805 Ceramic Capacitor	0.99x1.24
C	06035C102KAT2A	0603 Ceramic Capacitor	0.76x1.02
D	ESDA5V3sC6	SOT-23-6 Diode	0.60x1.20
E	CRCW12061K00FKEA	1206 Ceramic Resistor	0.99x1.60
F	TAJA105K020RNJ	1206 Tantalum Capacitor	1.42x1.23
G	MMBT2222ALT1G	SOT-23-3 Transistor	0.56x0.95
H	RK73H1ETTP2801F	0402 Thick Film Chip Resistor	0.61x0.61



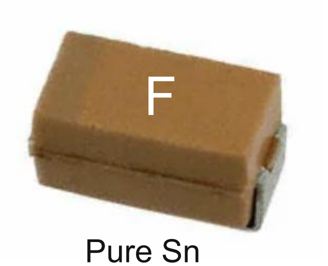
Plated Ni and Sn



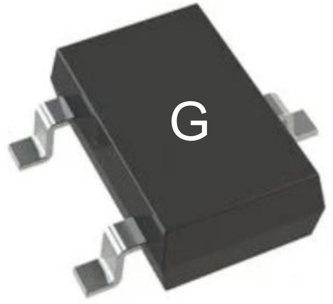
Matte Sn
Cu Lead



Pure Sn



Pure Sn



Matte Sn
Fe-Ni Lead

Sn

Images: Digikey.com

Experiment 1: Whisker Test Vehicle D.O.E.

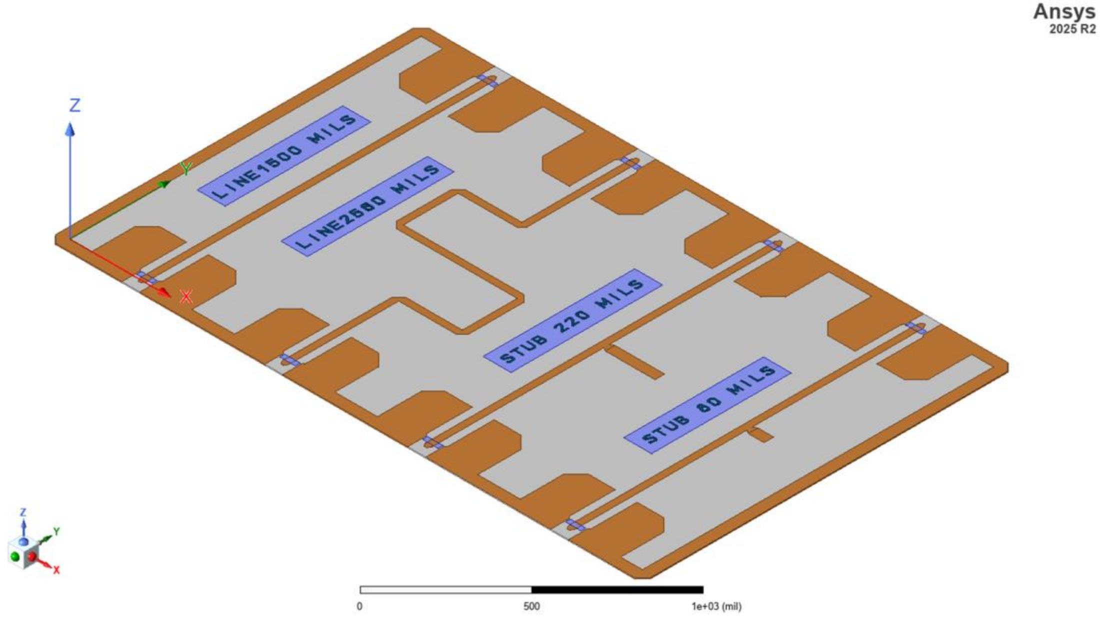
- Whisker testing involves samples subjected to:
  - Thermal Cycling
  - Temperature / Humidity
- Optical inspection performed after stress testing
  - 315 leads per alloy & coating combination per test condition

Paste	Coating	Component ID and Sample Size								PCB Quantity Required	T.C. 1000 Cycles	85 / 85 2000hr	85 / 85 4000hr
		A	E	F	B	C	H	G	D				
AIM Rel 61	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
AIM Rel 22	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
Indium DFHR	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
Indium DFLT	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
Heraeus Innolot	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
Indium SAC305	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1
Indium SnPb	None	45	45	42	45	45	45	45	45	3	1	1	1
	CytoCure D4	45	45	42	45	45	45	45	45	3	1	1	1
	SignalSeal	45	45	42	45	45	45	45	45	3	1	1	1
	CE-1155	45	45	42	45	45	45	45	45	3	1	1	1
	Parylene	45	45	42	45	45	45	45	45	3	1	1	1

Full-factorial DOE

Experiment 2: RF Test Vehicle

- RF test board
  - .060”
  - 4 layer
  - ROGERS RO4835 0.5 oz copper clad (+plating)
  - Immersion Silver
  - 6 connectors/board populated



Body
Stainless Steel 303

Contact Pin
Au over Nickel Underplating

Component Part Number	Type
292-J-P-EP-ST-EL-01-25551	Jack, Edge Launch Compression Mount

AREA Consortium

Experiment 2: RF Conformal Coat Test Vehicle D.O.E.

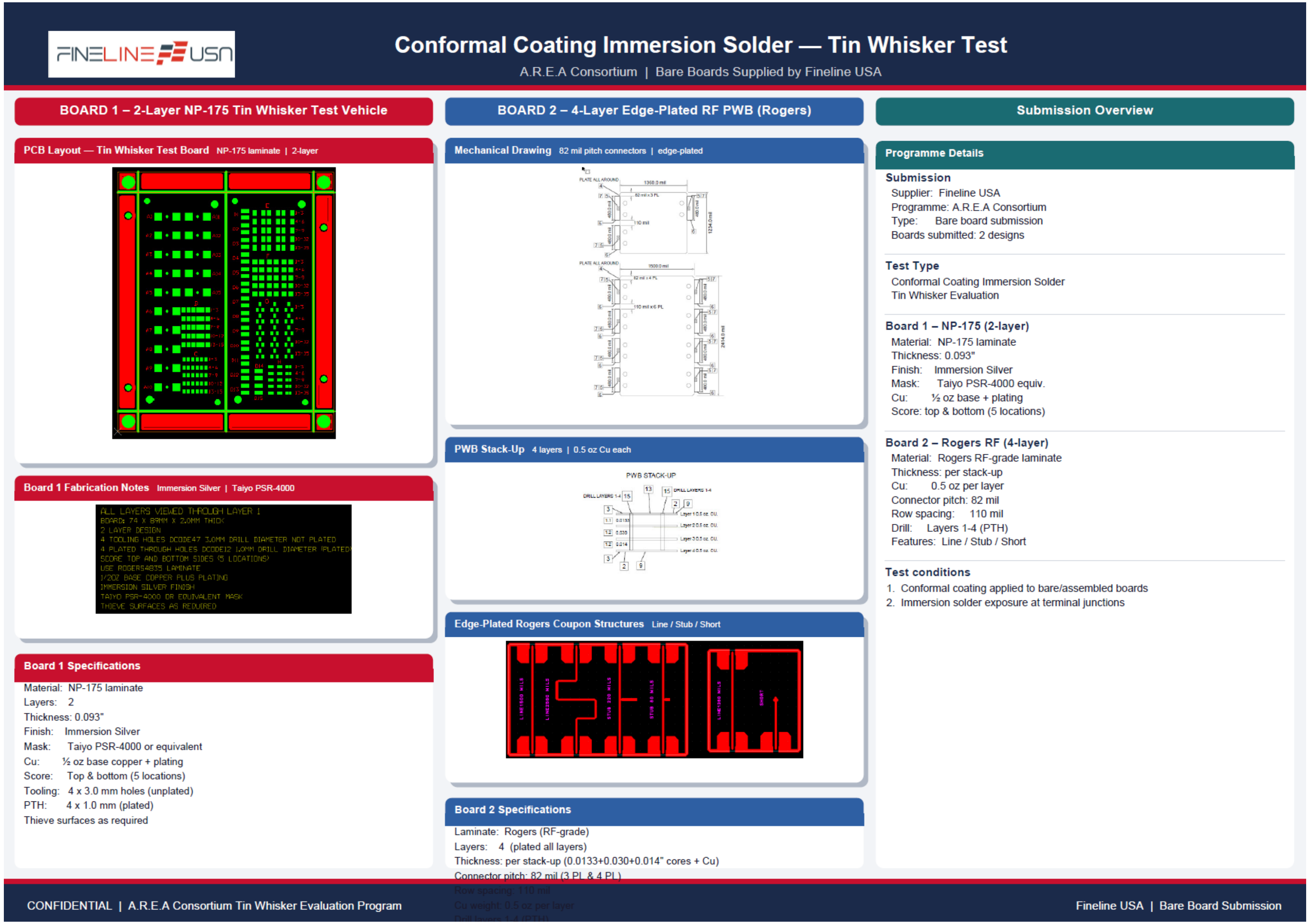
- RF analysis
  - Transmission Loss
  - Return Loss
  - Phase Shift Frequency

Paste	Coating	PCB Quantity Required	T.C. 1000 Cycles	85 / 85 2000hr	85 / 85 4000hr
SnPb	None	3	1	1	1
	CytoCure D4	3	1	1	1
	SignalSeal	3	1	1	1
	CE-1155	3	1	1	1
	Parylene	3	1	1	1

Full-factorial DOE

RF and Tin Whisker Board Fabrication

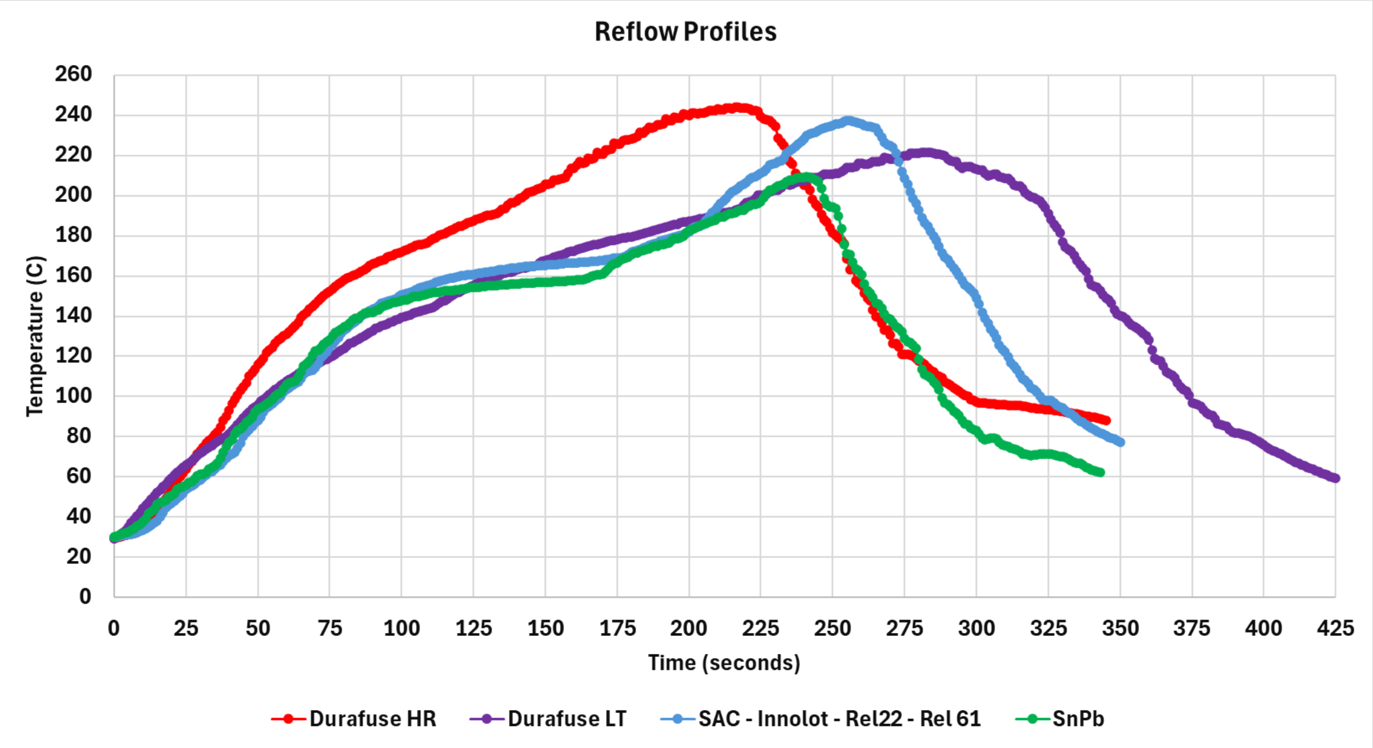
- Fineline USA fabricated the boards
  - Both designs are simple, but the Rogers material used for the RF board is expensive



AREA CONSORTIUM

Assembly – Tin Whiskers Test Vehicle

- Pastes were printed using a 0.10mm thick stainless steel stencil
  - 1:1 pad to stencil aperture ratio
- Four reflow profiles
  - Durafuse materials based on Indium recommendations
  - SnPb and SAC profiles based on participating member recommendations
  - Rel22, Rel61 and Innolot used SAC profile (“drop-in” materials)
- Reflow in nitrogen (less than 300ppm O_2)



Parameter	Durafuse HR	Durafuse LT	SAC / Innolot / Rel22 / Rel 61	SnPb
Peak Temperature (C)	244	221	237	209
Time above 183C (s)	132	140	83	54
Time above 200C (s)	100	95	64	20
Time above 217C (s)	71	27	43	0

Assembly Cleaning – Why Clean?

- There's lots of reasons for cleaning
  - Properly prepares the surfaces for conformal coat applications
- Zestron performed cleaning operations
  - Samples were overnighted from Binghamton to Manassas for timely cleaning

Inline Cleaning Process Settings

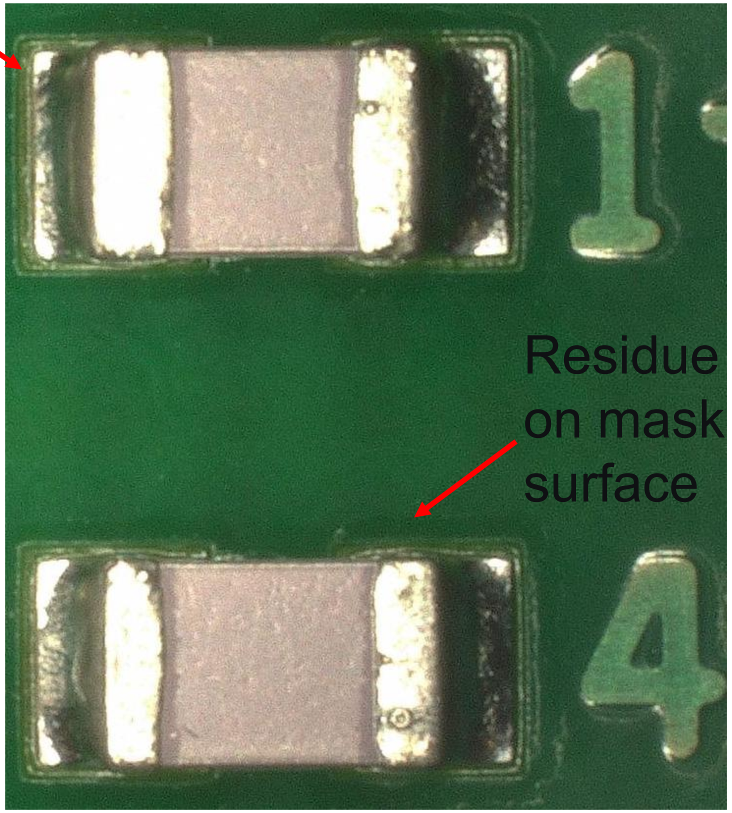
- Setup samples were provided to Zestron prior to final assembly for cleaning trials

Cleaning Agent (Conc.)	Vigon NX 728 (15%)
Conveyor Belt Speed	0.5 fpm
Wash Spray Configuration (Top spray bars)	V J V J H J V J V (high volume nozzles)
Pre-Wash Pressure (T/B)	55 PSI / 45 PSI
Wash Pressure (T/B)	75 PSI / 65 PSI
Wash Hurricane Pressure (T/B)	40 PSI / 30 PSI
Wash Temp	150°F
Chem Iso Pressure (T/B)	25 PSI / 20 PSI
Rinse Pressure (T/B)	85 PSI / 75 PSI
Rinse Hurricane Pressure (T/B)	40 PSI / 30 PSI
Rinse Temp	150°F
Final Rinse Pressure (T/B)	35 PSI / 30 PSI
Final Rinse Temp	Room Temperature
Drying Temperature (D1)	180°F
Drying Temperature (D2)	220°F
Drying Temperature (D3)	220°F

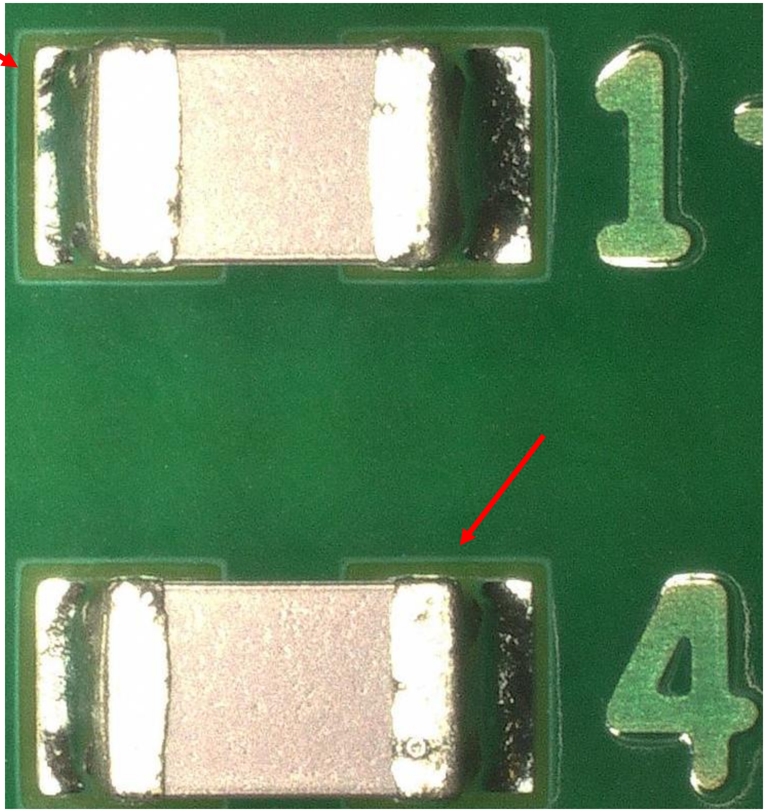
Cleaning Visual Inspection Before/After Images – SnPb Solder paste

Residue in mask opening

Before Cleaning

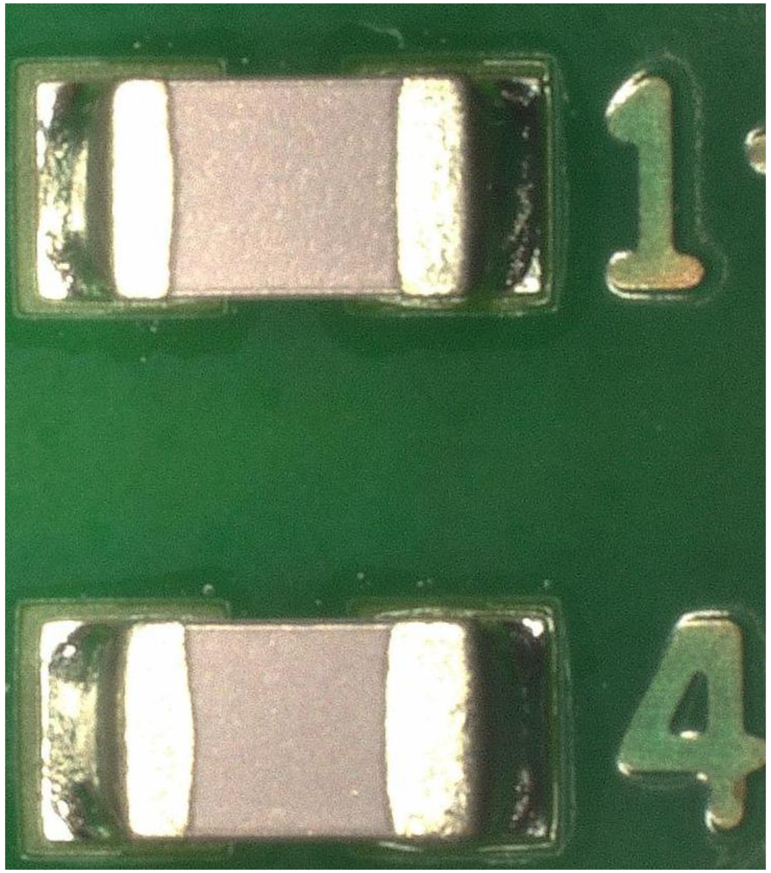


After Cleaning

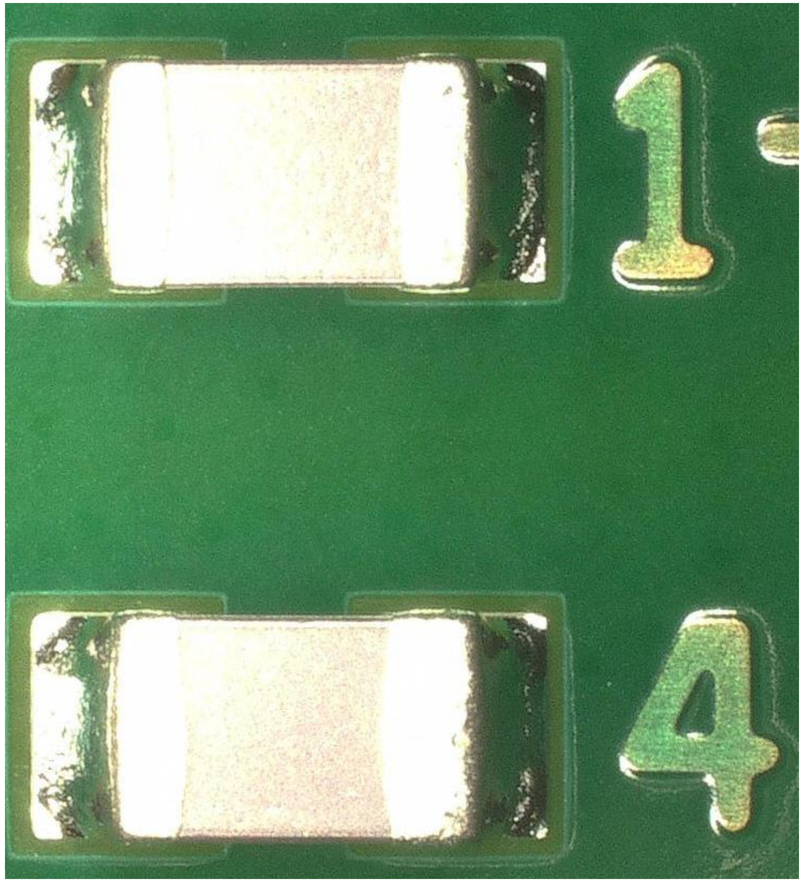


Cleaning Visual Inspection Before/After images – Pb-Free Solder Paste

Before Cleaning



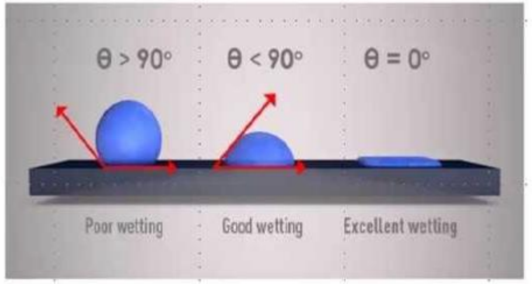
After Cleaning



Cleaning

- Zestron performed cleaning analysis

Surface Energy & Wetting Angle Measurement



	Contact Angle (°)			
	Supplier A		Zestron NX 728	
Sample	Before	After	Before	After
1	119.5	113.5	113.9	76.1
2	111.1	112.1	113.8	58.6
3	110.2	110.9	113.1	57.4
4	104.2	103.3	109.6	52.7
5	99.2	90.7	109.3	50.2
Average Contact Angle	108.8	106.1	111.9	59.0
Average Decrease in Contact Angle from Before to After Wash	2.7		52.9	

Note the variance in Cleaning chemistry – impact on Surface energy and wetting.

Important to run multiple fluids to capture polar & non-polar contributions

Data Physics benchtop goniometer unit in Zestron Lab.

Gives more information than simple Dyne Ink.

ZESTRON

AREA CONSORTIUM

Circuit Card Cleaning Surface Energy Method

Surface energy was calculated by measurement of contact angle using an OCA 15EC and the Owens, Wendt, Rabel and Kaelble (OWRK) method.

- Instrument: OCA 15EC optical contact angle and drop shape analyzer with single or double direct dosing (SD-DM or DD-DM) and ES electronic dosing units. The system uses video-based contour analysis with LED/halogen lighting and stable illumination compensation across OCA models.
- Software: SCA 20 (contact angle and hysteresis) and SCA 21 (surface free energy analysis and component calculation) modules for data capture and SFE computation.
- Measurement ranges: Contact angle 0–180°; surface/interfacial tension approx. 2–103 mN/m with ±0.01 mN/m resolution (model-dependent).

AREA CONSORTIUM

Circuit Card Cleaning Surface Energy

UIC - Raytheon Tin Whisker Project SFE Results		
Board	**Board side**	**SFE total (dynes/cm)**
2	**Front**	**87.27**
5	**Front**	**53.73**
8	**Front**	**90.03**
11	**Front**	**141.49**
14	**Front**	**44.32**
17	**Front**	**47.13**
20	**Front**	**47.89**
	Average	**73.12**

All samples exceed the IPC-CC-830 requirements at >38 Dynes/cm

RF Test Measurements

- RF testing will be done to assess the impact of individual conformal coating material and thermal cycles.

RF Transmission Line Physics 101

Microstrip line is considered inhomogeneous Quasi-TEM transmission line where the fields are split between air ($\in_r = 1$) and the substrate ($\in_r > 1$). Because of that the dielectric constant is not uniform and an effective dielectric constant is used.

microstrip line is dispersive, meaning the propagation velocity and effective dielectric constant change with frequency.

- The testing will measure RF performance in terms of insertion loss, return loss, and frequency shift, due to the change in material properties such as dielectric constant and conductivity.

- First, we will take baseline measurements for insertion loss, return loss and resonant frequency based on the stub length. Then, the same measurements will be repeated post conformal coat and Thermal cycles.

RF Test Measurements

- Network analyzer will be used to perform following measurements over range of frequencies from 10MHz to 22GHz. PNA is a 2-port RF instrument used for characterizing the scattering Parameters of the transmission line.

1. Reflection coefficient seen at port 1 when port 2 is terminated in a matched load (Z0 = 50 ohms)

$$S_{11} = \frac{{V_1}^-}{{V_1}^+} = \frac{Z_{in(1)} - Z0}{Z_{in(1)} + Z0}$$

2. Transmission coefficient from port 1 to port 2 is found by applying the incident wave at port 1 ${V_1}^+$ and measuring the outcoming wave at port 2 ${V_2}^-$

$$S_{21} = \left.\frac{{V_2}^-}{{V_1}^+}\right|_{V2^+=0}$$

Any change in resonant frequency post conformal coat will be an indication of change in effective dielectric constant (Dk) of the material.

RF Test Measurements

RF Test Equipment:

For our testing, we will need the following:
- A vector network analyzer (VNA) that can work up to 26.5 GHz
-RF testing cables (to connect port 1 and 2 of the VNA to the boards)
-3.5mm male cable adapter (they will be mated to the female connectors on the board)
-3.5mm female-to-female bullet connector
-8 in-lbs SMA torque wrench

RF Testing – Calibration/Test Process

- The VNA calibration routine standards use the three-connector board and one line from the eight-connector board
- Edge plating and conductive paint at connector/board interface ensure ground path integrity

RF Testing – Calibration/Test Process

- Measurements will be taken with a VNA (Vector Network Analyzer)
- TRL (thru, line, reflect) calibration method is used with VNA
  - The 3-connector board has the TRL thru and reflect standards (a short is used as the reflect)
  - The straight line on the 8-connector card is the TRL line. This has a know time delay relative to the TRL thru.
  - The calibration boards shown on previous slide covers a 10:1 cal range, from roughly 2 to 20 GHz

- Measurement taken will be:
  - The meander line on the 8-connector board is used for insertion loss and return loss measurements to characterize changes in effective loss tangent (Dk)
  - The two stubs on the 8-connector board will be used to look for resonance shifts to characterize the shift in effective dielectric constant (ε_r)
  - Resonance of the two stubs without conformal coat are at approximately 7.5 and 19 GHz

Summary

- Samples have been assembled and cleaned
- RF setup tests have begun
- Conformal coatings are being applied
- Stress testing should begin shortly
- Open for discussion regarding Phase 2 experimentation (if desired)

Thank You