Assessment of Automotive EEE Components Suitability For Space Applications

ESCCON 2021

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Introduction

Background:

- ESA awards two parallel contracts to assess potential suitability of automotive EEE COTS components for use in space applications.
- One contract awarded to TAS-E with Tyndall as sub-contractor (4000126343/19/NL/hh).
- Work commenced in 2019, tests completed in early 2021, final analysis of data in progress.

Objectives:

- To identify the additional testing (“delta testing”) to align automotive qualified (AEC-Q) EEE parts with space standards.
- To identify & procure suitable candidate components based on market analysis and review of published data.
- To define and carry out the “delta test” programme on the selected components.
- To evaluate the test programme results and formulate recommendations on the suitability of the selected component families for space use.

Introduction

SPACE

Quality by Inspection: • 100% Screening • Lot Acceptance test • Customer Source Inspection & DPA
Very Large Initial Qualification Sampling
Partial Requalification for Changes
Temperature Range -55ºC/+125ºC
Lifetime: 20 years at 110ºC (GEO) (all ON or all OFF)
Power ON/OFF cycles: • 50K to 150K for LEO
Radiation Environment: YES (electron, proton, neutron, gamma, heavy ions): TID, TNID, SEE
Humidty: NO
Vacuum, Rapid Depressuritation: Yes, $< 10^{-7}$ torr
Agency / US Government certification as per ESCC/MIL standards

Different missions, different strategies

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But similar quality target, lifetime and thermal fatigue.

↓

Same Components could meet both (if Radiation allows it)

AUTOMOTIVE

Quality by Process Control • SPC with zero failues (<ppm) • Cpk > 1.67
Small Initial Qulification
Partial Requalification for Changes
Temperature Range -40ºC/+125ºC
Lifetime: 15 years at 85ºC 600 000 km 12000 hours Engine ON 3000 hours Engine OFF 116 400 hours Non Operating
Power ON/OFF cycles: • 50K (no Start-Stop) • > 300K (with Start-Stop)
Radiation Environment: NO
Humidty: Yes, 15% to 93% RH
Vacuum, Rapid Depressuritation: NO
Self-certification per IATF 16949 and AEC-Q standards

Project Tasks

WP1: AEC-Q MAPPING

- Compile an AEC QPL list based on the state of the art.
- Compile a list of the most demanded devices for Space applications.
- Generate an update of the AEC PPL for Space applications.
- Select candidates for test from the AEC PPL.

WP2: COMPARE AEC-Q & SPACE

- Compare AEC standards and flow versus Space standards (ESCC, MIL, ECSS and NASA).
- Define recommended delta-approval tests
- Procured 3 lots of each candidate within a 3 years of date code

WP3: TESTS

- Check for variability Lot to Lot and part to part:
- Constructional Analysis, Glass transition (Tg) & CTE, Outgassing
- Life test
- HAST/THB
- Temperature Cycling

WP4: RECOMMENDATIONS

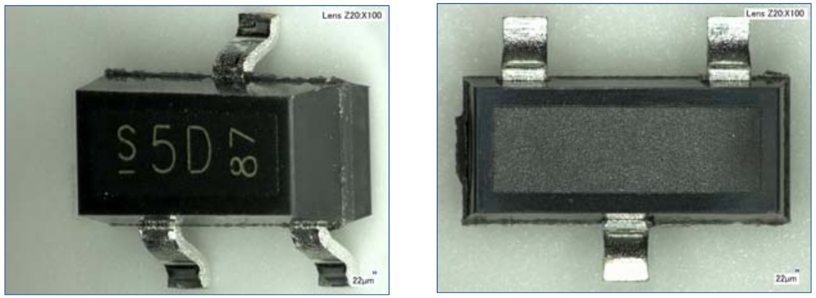
WP1 AEC-Q Mapping

- **Mapping Task: AEC Description. History. Standard. ISO16949 & IAT16949, PPAP.**
- **Compilation of an Almost exhaustive AEC-Q QPL with components published as being AEC-Q100, Q101 or Q200:**
  - *212288 items listed from 72 families. 37K for AEC-Q100 +36K for AEC-Q101 + 176K for AEC-Q200. Total no. ~ 600K (2019).*
  - *117 manufacturers: with info about published certifications IATF16949 / PPAP available*
  - *No reported devices qualified by AEC-Q102 (Optoelectronics), Q103 (MEM Sensors) nor AEC-Q104 (MCM)*
  - *Crystals, Oscillators and MEM's could be listed under AEC-Q100 or AEC-Q200. Optoelectronics listed under AEC-Q101*
  - *Most MCM are listed under AEC-Q100*
  - *Most Sensors (pressure, temperature, accelerometers..) are under AEC-Q100, other under AEC-Q200*
  - *More than 70% of the microcircuits meet the Military Temperature Range (grade-0 plus grade-1). Similar for discrete and passive.*
  - *Some passives rated for high temps.*
  - *Some bare dice, 78% plastic package, 20% ceramic, < 1% metal packages. Majority, non-hermetic, no cavity.*
  - *BGA, QFN, DFN & CSP recognised as assembly0critical for automotive community.*
  - *97% SMT parts, 3% thru-hole (DIP, Axial leads, etc.)*
  - *Popular sizes 0402, 0603, 0805, 1206, 1210 for capacitors, resistors, inductors. DFN-3 & DFN-4 for transistors & MEMS oscillators.*
  - *97% ROHS-compliant.*
  - *Most Manufacturersfrom US & Europe & Japan, but with manufacturing plants certified to IATF16949 in Far East.*
  - *Top 10 IC suppliers account for 85% of automotive IC market.*
  - *Some technologies not seen in space (Power GaN, Power SiC, MEMS Oscillators, Resettable fuses, Ceramic Disc Caps, ……etc)*
  - *Some technologies forbidden for space (Al electrolytic caps, Quartz oscillators, SCR Thyristor…… etc.)*

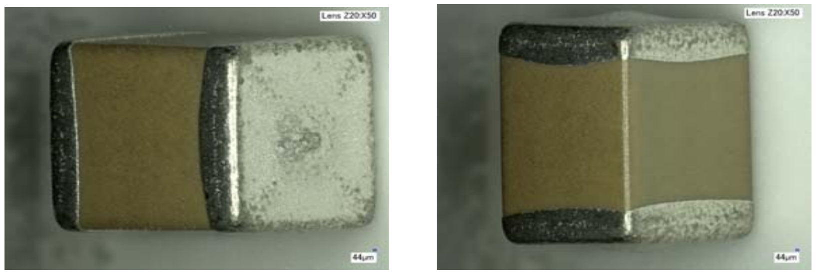
WP1 Component Selection

- **Three AEC-Q Component Families Selected**
- **Active & Passive EEE Components**
- **Procured (via distributors) from Large Manufacturers:**
  - *Low Noise Operational Amplifier, AEC-Q100, TSSOP-14 Package*
  - *High Speed Silicon Switching Diode, AEC-Q101*
  - *Ceramic Capacitor, AEC-Q200, 1210, Type II Dielectric, 4.7µF, 50V, X7R*
- **Three Lots (different date code) of Each Family Procured**

Op-Amp (lot 1816) – Top & Bottom Views



Diode (lot 1829) – Top & Bottom Views



Capacitor (lot 1927) – End & Side Views

WP2 AEC-Q vs Space

- **Test methods comparison between AEC, ESCC, MIL, ECSS-Q-ST-60-14 and NASA GSFC PEM-INST-001 as applicable for microcircuits (AEC-Q100), discrete semiconductors (AEC-Q101), and passive devices (AEC-Q200)**
- **Also comparison for Diodes & LEDs (AEC-Q102), MEM sensors (AEC-Q103) and MCM (AEC-Q104) are included.**
- **Detailed comparison for Qualification / LAT of AEC standard and ECSS-Q-ST-60-14, NASA GSFC PEMS-INT-001, ESCC / MIL as applicable**

ABV	STRESS TEST	TEST METHOD		
		AEC Q200	ESCC 3001 to ESCC 3012 ESCC 3501 ESCC 4001 to ESCC 4009 ESCC 3201	MIL-PRF-55681; MIL-PRF-55365; MIL-PRF-83421; MIL-PRF-83401; MIL-PRF-55342; MIL-PRF-23648; MIL-PRF-14409; MIL-PRF-27; MIL-PRF-21038; MIL-PRF-3098; MIL-PRF-28861
AN	Acoustical noise	–	–	MIL-PRF-810 TM 515
AS	Acceleration Sensitivity	–	–	MIL-PRF-3098 Para.4.10.14.2
AS	Thermal frequency hysteresis	–	–	MIL-PRF-3098 Para.4.10.15
AT	AXIAL THRUST	–	ESCC 3010 Para. 8.13	–
BF	Board Flex	AEC Q200-005	–	–
BH/LVHT	Biased Humidity / Low Voltage Humidty Test	MIL-STD-202 TM 103	Generic ESCC3009 Para. 8.2 MIL-STD-202 TM 103	MIL-STD-202 TM 103
BLT	Beam Load Test	AEC-Q200-003	–	–
BURNIN	Burn-in Voltage Conditioning for MIL Capacitor. Power Conditioning for Resistors. Ageing for quartzs	–	IEC 384-1 Clause 4.23 (capacitors) ESCC 3501 (quartzs) IEC 115-1 Clause 4.25 (resistors) MIL-STD-202 TM 108 (inductors)	MIL-PRF-55681 Para. 4.8.3 MIL-STD-202 TM 108 MIL-PRF-27 Para. 4.7.5 MIL-PRF-3098 Para. 4.10.27
CAN	Constructional Analysis	–	ESCC 21001	–
CD	Corona Discharge	–	–	MIL-prf-27 Para. 4.7.14
CHAR	Characterization	AEC Q003	ESCC spec	–
COLD	Cold Test	–	IEC 68-2-1 Test Aa	–
CS	Climatic Sequence	–	IEC 384-1 Clause 22	–
CSAM	C-Mode Surface Acoustic Microscope	–	ESCC 25200	–
CT	Corrosion Test (hermetic devices only)	–	IEC 68-2-11 Test Ka	–
DHA	DAMP HEAT ACCELERATED	–	IEC 68-2-30 Test Db	–
DHSS	DAMP HEAT STEADY STATE	–	IEC 68-2-3 Test Ca IEC 68-2-72 Test Cab	–
DISC	Dissipation Constant (thermistors)	–	ESCC 4006 Para. 8.12	MIL-PRF-23648 Para. 4.8.10 MIL-PRF-28861 Para. 4.6.4.2
DPA	Destructive Physical Analysis	–	ESCC 21001	MIL-STD-1580 MIL-PRF-28861 Appendix B (EMI filetrs)
DPAMLCC	Destructive Physical Analysis. SMD Ceramics	EIA-469	ESCC 21001 ESCC 23400	–

WP3 Test Programme

Physical Analysis

- **Detailed Construction Analysis (CA) 5 samples x 3 lots x 3 types:**
  - *External Visual Inspection.*
  - *Dimensional Measurement.*
  - *Radiographic Inspection & CT-Scan.*
  - *SAM (plastic-encapsulated components).*
  - *Marking Permanence (active components).*
  - *EDX Analysis of termination finish.*
  - *Solderability Test (SAC305 & Sn63Pb37).*
  - *Termination Strength Test.*
  - *Chemical de-cap (active components).*
  - *Internal Visual & SEM Inspection (active components).*
  - *Ball Shear Test (active components).*
  - *Glassivation Integrity Test (active components).*
  - *Cross-sectioning.*
  - *SEM Measurement of internal dimensions.*
  - *EDX analysis of all materials.*
  - *Determination of Tg & Outgassing for plastic-encapsulated components (active samples).*
  - *Determination of CTE for all component types.*

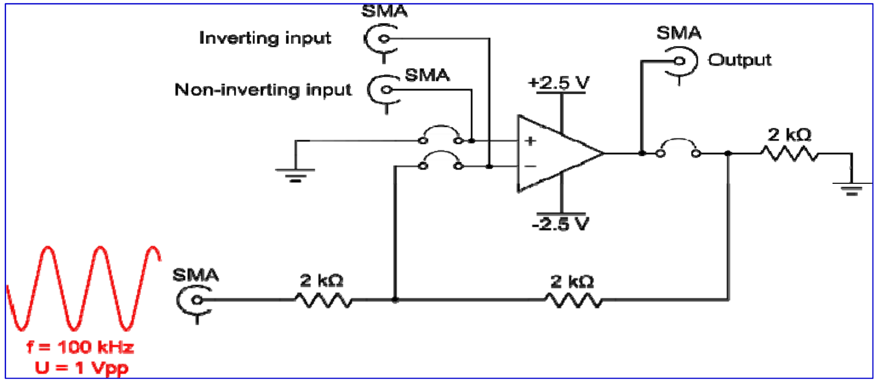
Environmental Stress Tests

- **Temperature Humidity Bias (THB) Test – 10 samples x 3 lots x 3 types (1,000 hours, 85°C / 85% RH).**
- **Temperature Cycling Test – 10 samples x 3 lots x 3 types:**
  - *Active Components mounted on FR4 PCB and tested to Mil-Std-883, TM1010, Condition B (+125 ℃, -55 ℃, 15min dwell, 10sec transfer,500 cycles).*
  - *Capacitors mounted on polyimide & tested between 125 ℃ & - 55 ℃ with change rate of 4 ℃/min, 15min dwell, 500 cycles.*
- **High Temperature Operating Life (HTOL) – 10 samples x 3 lots x 3 types (1,000 hours at 125°C with bias).**
- **Pre & Post Stress Inspections:**
  - *External Visual Inspection.*
  - *SAM Inspection for plastic (active) samples.*
  - *Electrical test at ambient (~22 ℃), low (-55 ℃) & high (+125 ℃) temperatures.*
  - *Failure Analysis (if required).*

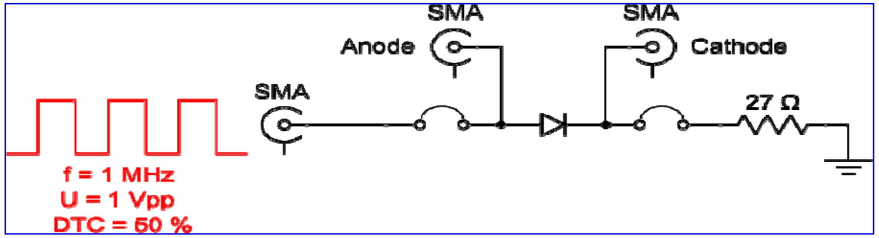
WP3 Test Programme

Biasing & Electrical Parameter Measurement

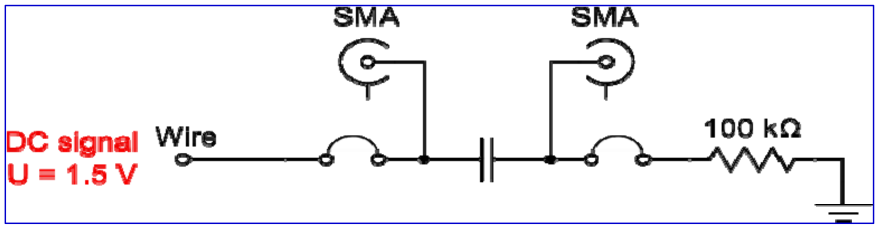
- **Op-Amp Components:**
  - *Input Offset Voltage* — (V_{io})
  - *Input Offset Current* — (I_{io})
  - *Common Mode Rejection Ratio* — *(CMRR)*
  - *Supply Voltage Rejection Ratio* — *(SVR)*
  - *Source Current* — (I_{source})
  - *Sink Current* — (I_{sink})
  - *Gain Bandwidth Product* — *(GBP)*
- **High Speed Diode Components:**
  - *Forward Voltage Drop* — (V_f) *@ 1, 10, 50, 100, & 150mA.*
  - *Forward Current* — (I_f)
  - *Reverse Breakdown Voltage* — (V_{br})
  - *Transition Capacitance* — (C_t)
  - *Reverse Recovery Time* — (T_{rr})
- **1210, 4.7µF Ceramic Capacitors:**
  - *Capacitance* — *(C) @ 1MHz.*



Op-Amp Biasing During Stress Tests



Diode Biasing During Stress Tests

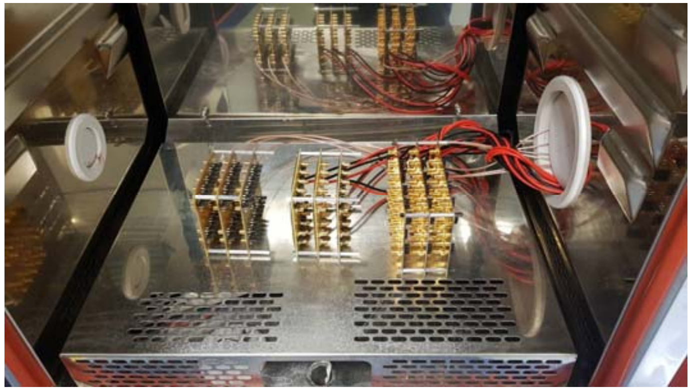


Capacitor Biasing During Stress Tests

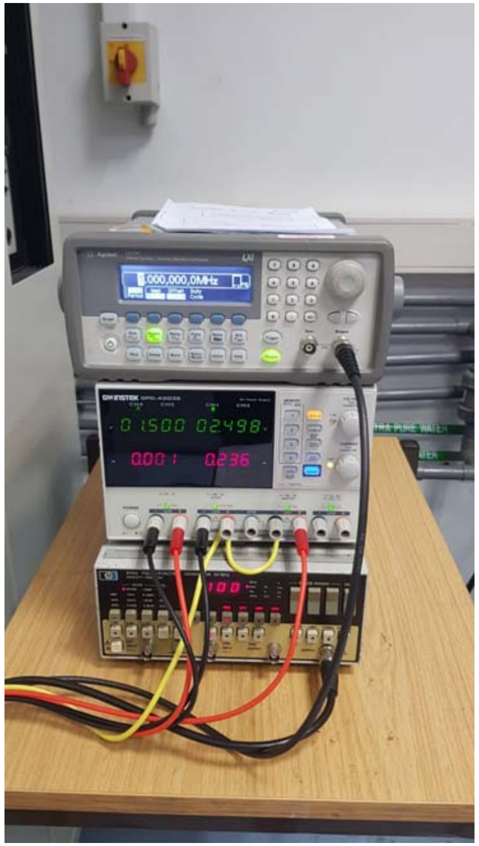
WP3 Test Programme

THB Test

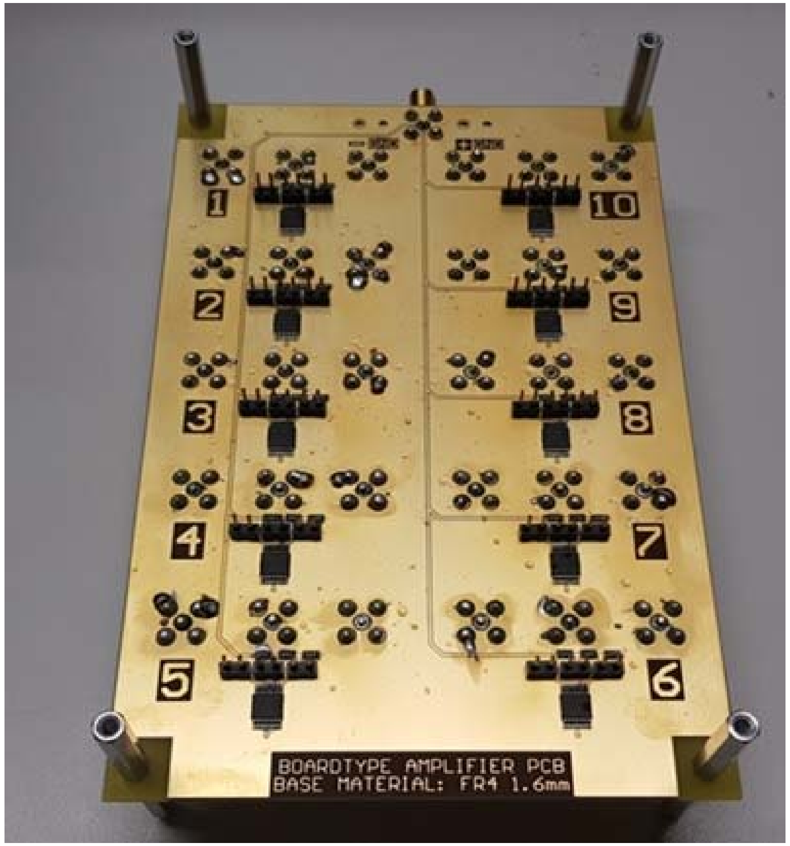
Test Chamber – Weiss Technik Wk 11/80



10 units per PCB x 3 component types x 3 lots



Bias set-up

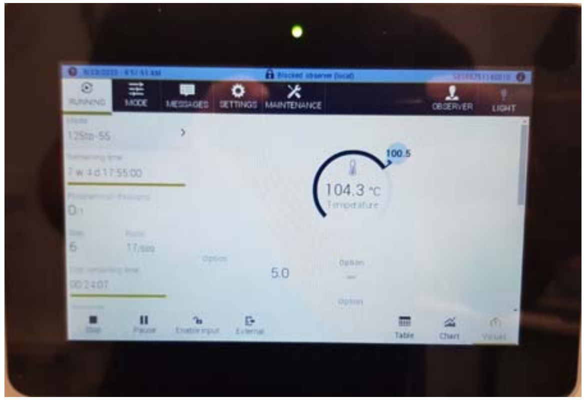


Individual FR4 Test PCB (St Micro Op-Amp)

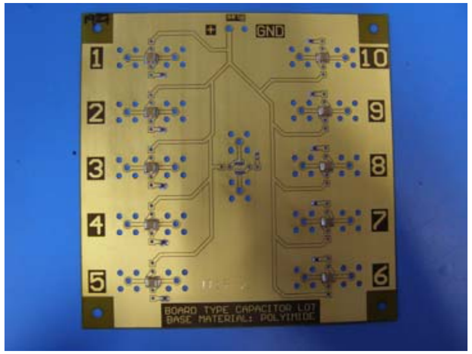
WP3 Test Programme

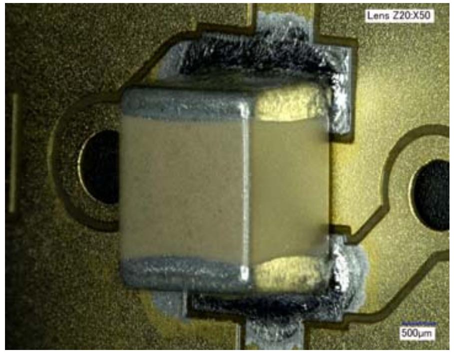
Thermal Cycling

Active Component TC Test
Votsch VT7012/S2
Dual Chamber System

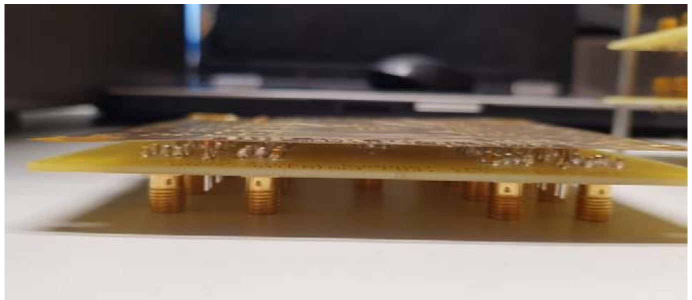


Capacitor TC Test
Votsch LabEvent T40/70/5
Single Chamber System





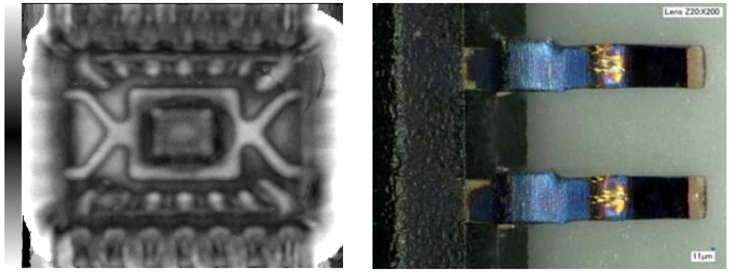
Individual Polyimide Capacitor Test PCB



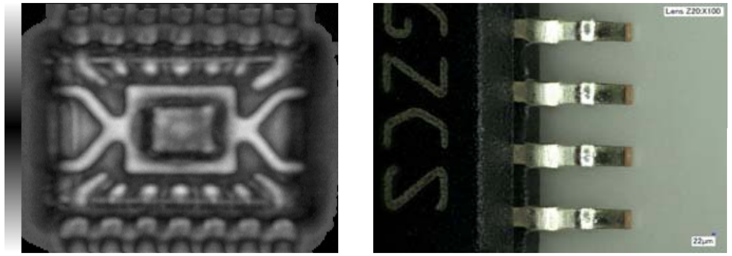
Capacitor Test PCB Support Structure

WP3 Test Results (CA)

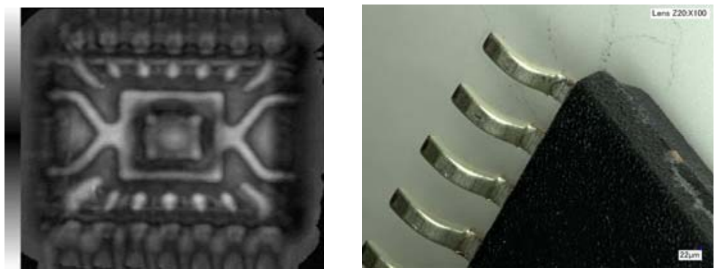
Operational Amplifiers



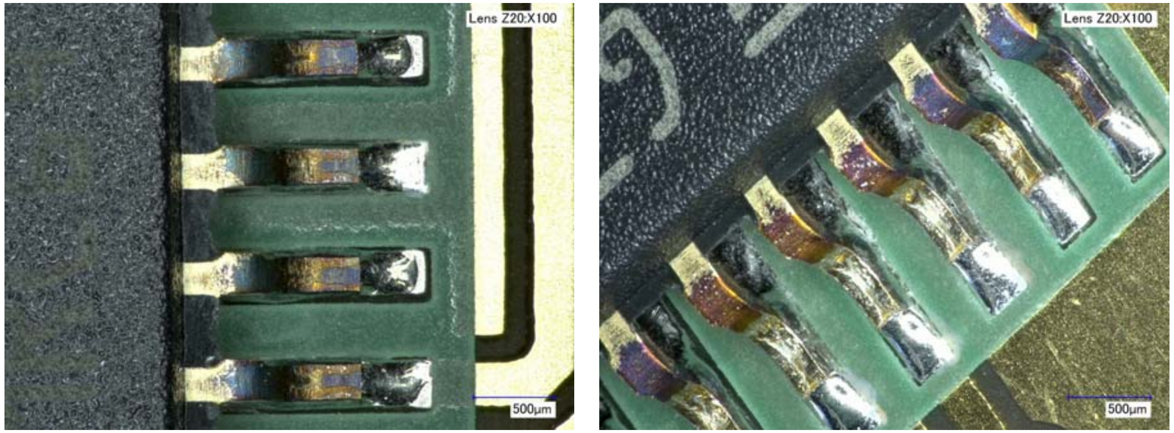
Op-Amp (1647)



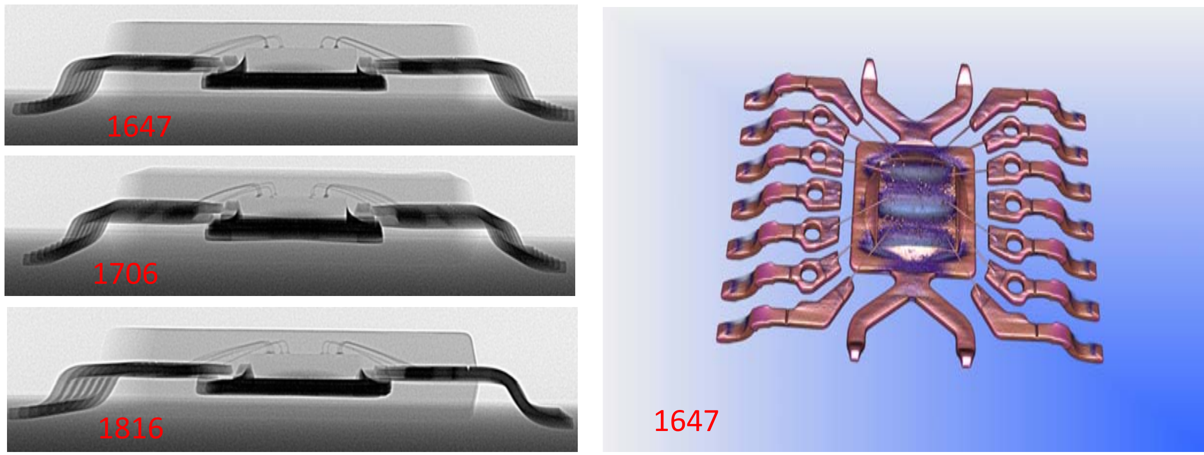
Op-Amp (1706)



Op-Amp (1816)



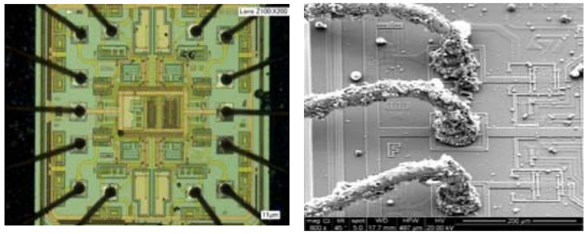
Op-Amp (1647)



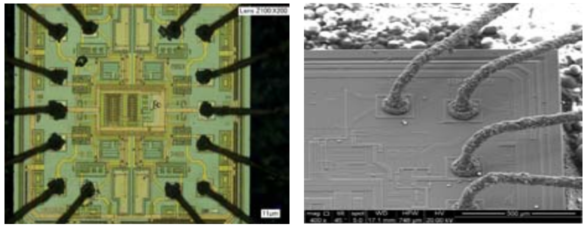
Radiographic Inspection - Op-Amp

WP3 Test Results (CA)

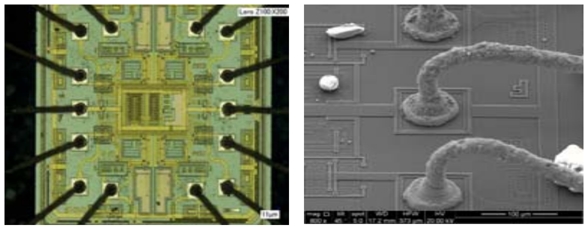
Operational Amplifiers



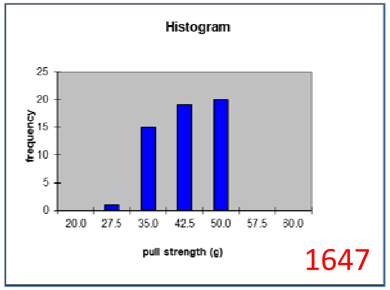
Op-Amp (1647) – Cu wires

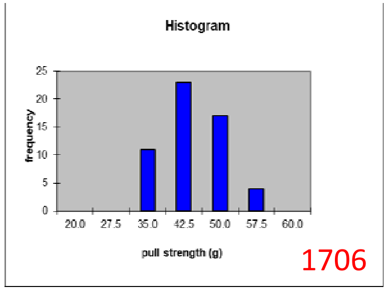


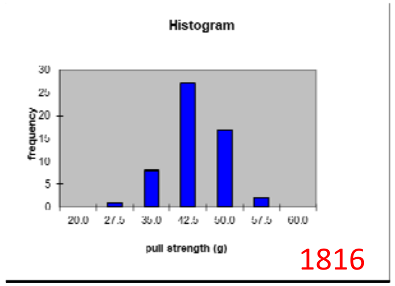
Op-Amp (1706) – Cu wires



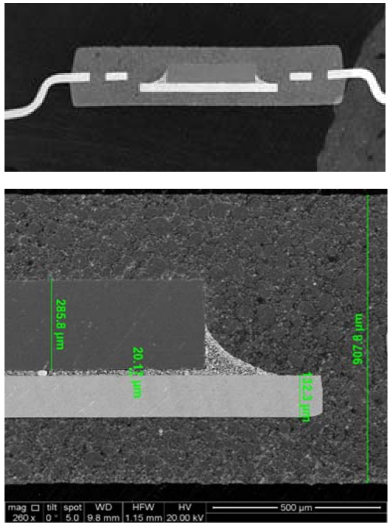
Op-Amp (1816) – Cu wires







Ball Shear Test Histograms - Op-Amp



Cross-sectioning

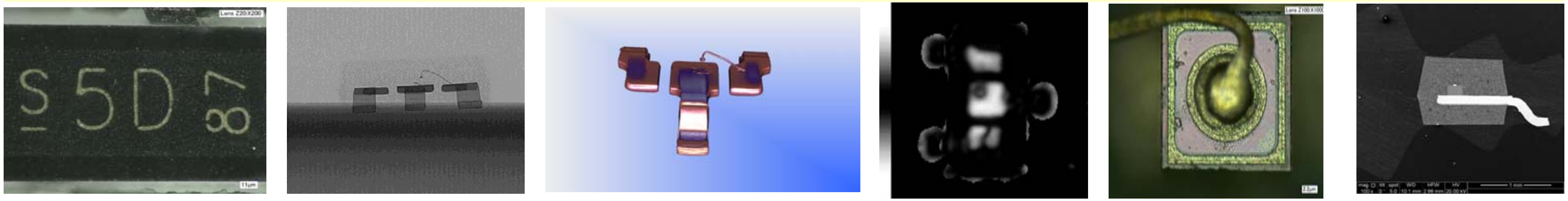
Part Type	Component		
	1647	1816	1706
Die	Si	Si	Si
Die Paddle Bulk	Cu, Fe	Cu, Fe	Cu, Fe
Die Attach	Ag, C, O	Ag, C, O	Ag, C, O
Plastic	Si, C, O	Si, C, O	Si, C, O
Plastic filler particle	Si, O	Si, O	Si, O
Die paddle Plating	Ag, Ni, Cu	Ag, Ni, Cu	Ag, Ni, Cu
Lead Plating	Ag Ni, Cu	Ag Ni, Cu	Ag Ni, Cu
Wire Bond	Cu	Cu	Cu

Materials Analysis

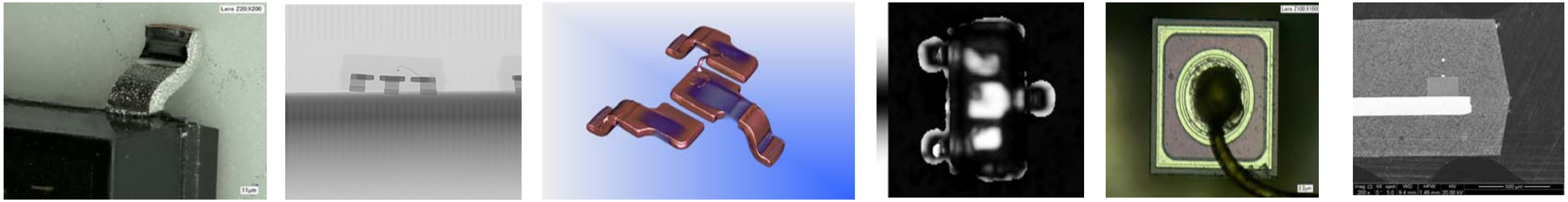
WP3 Test Results (CA)

High Speed Diodes

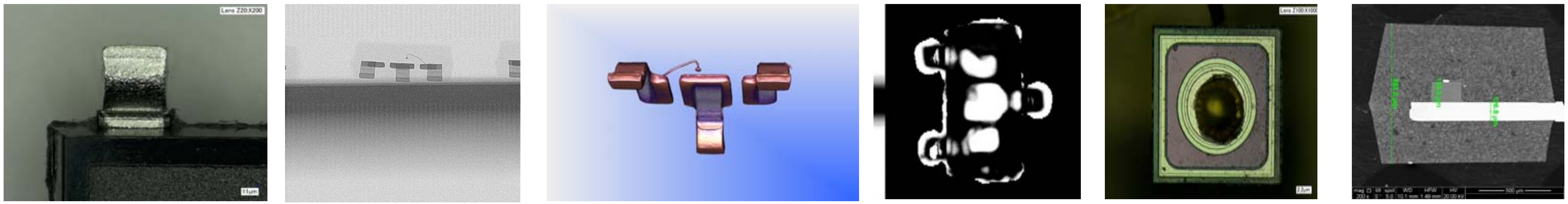
External Visual → X-ray → CT-Scan → SAM → Internal Visual → X-section



Diode (1536)



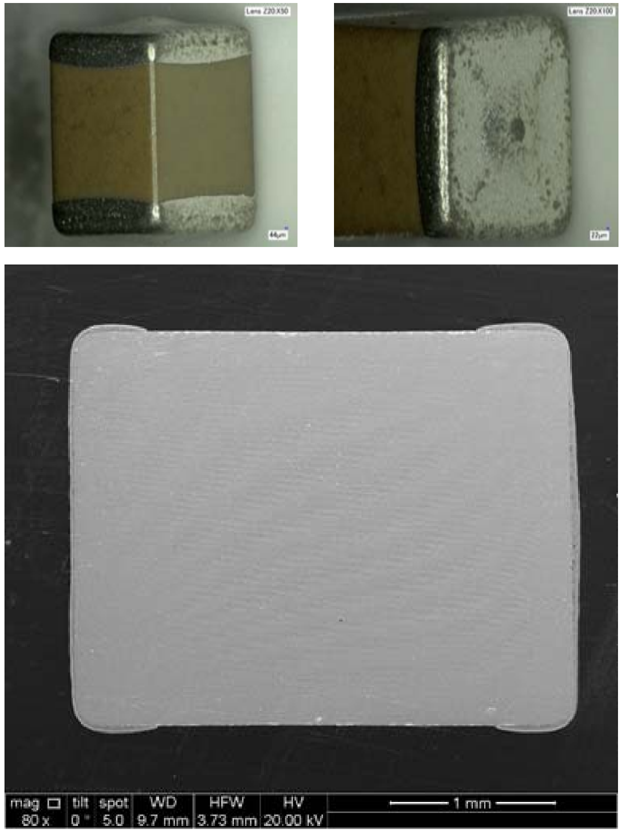
Diode (1829)



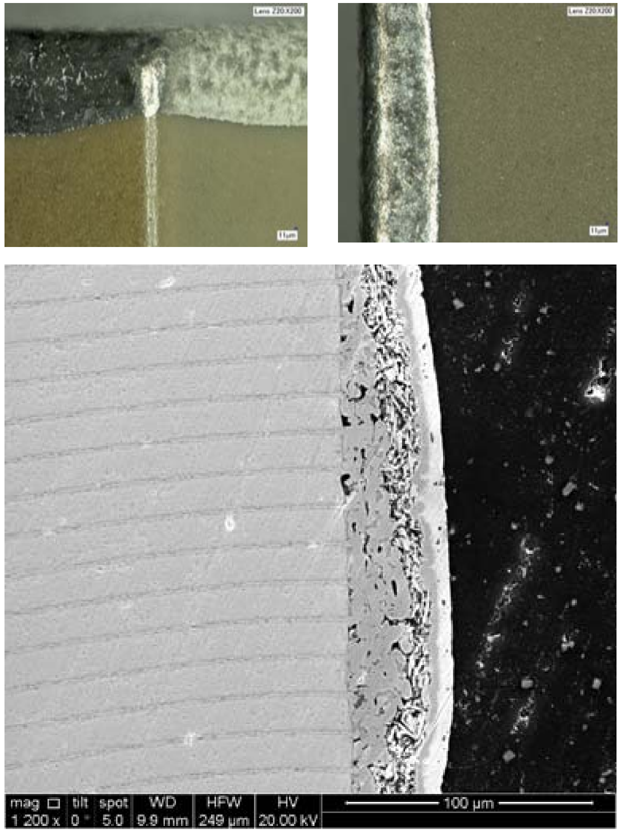
Diode (1831)

WP3 Test Results (CA)

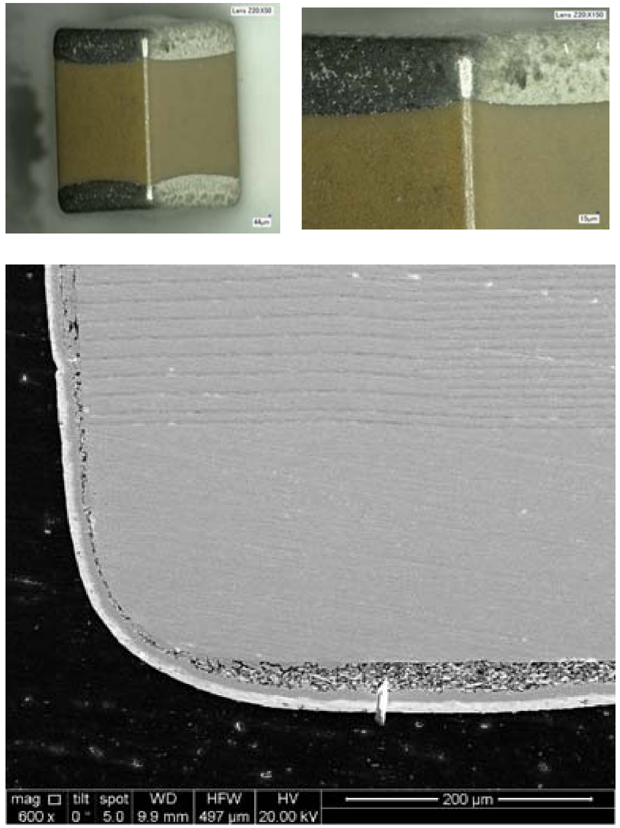
Ceramic Capacitors



Capacitor (1820)



Capacitor (1927)



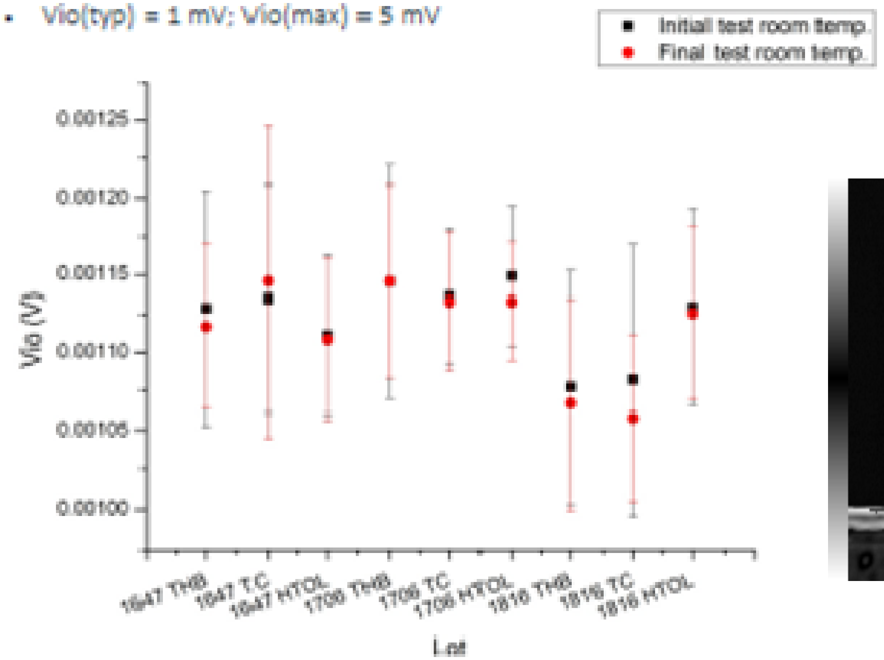
Capacitor (1937)

WP3 Test Results (Reliability)

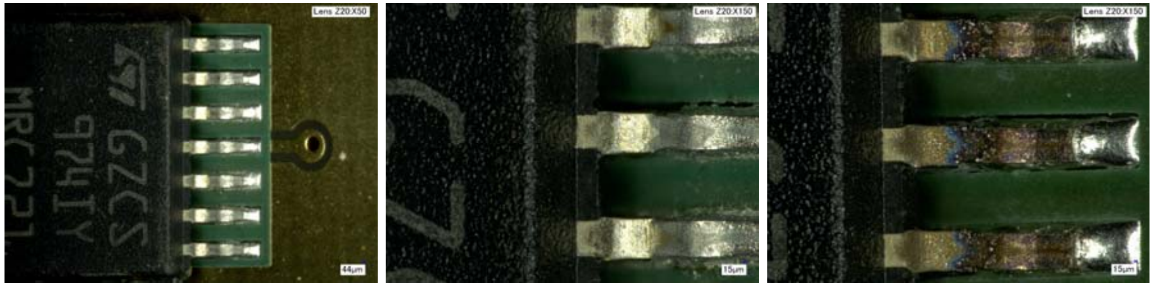
Operational Amplifiers

Amplifier lot test – Input offset voltage – room temperature

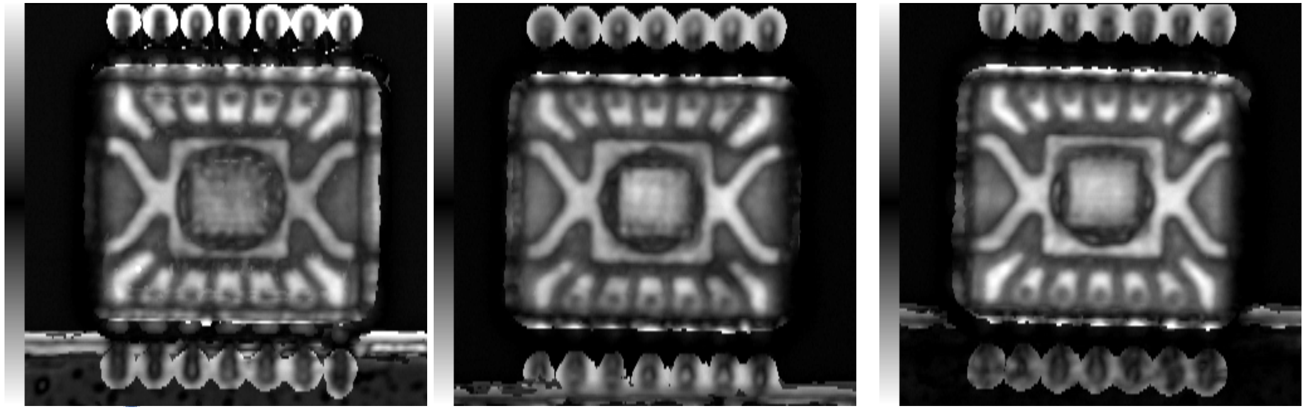
- Vio(typ) = 1 mV; Vio(max) = 5 mV



Example Electrical Test Results (V_{io}) pre & post stress.



Post Stress High Magnification Inspection – No Sn Whisker Growth Evident



1647 1716 1816

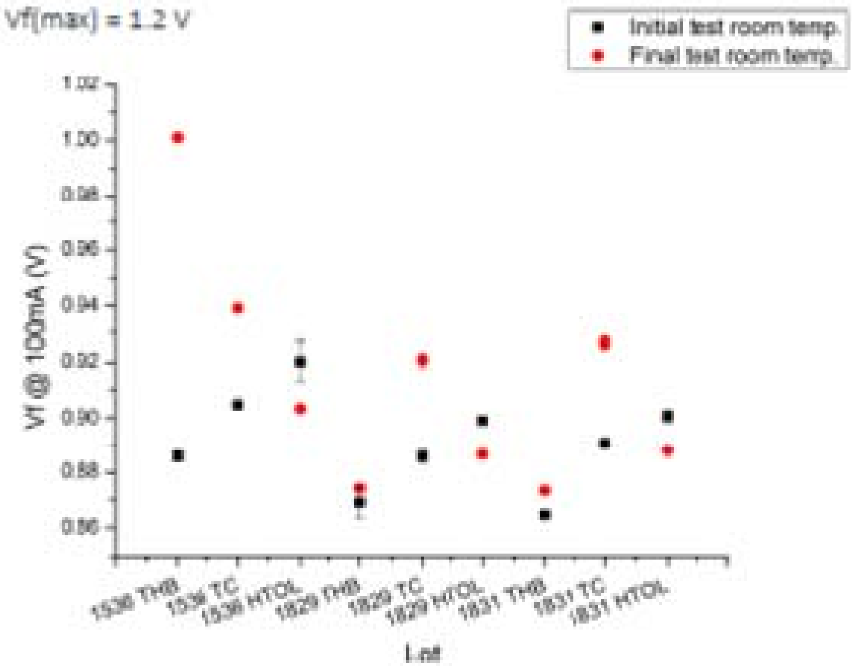
Post Stress (Thermal Cycling) SAM Imaging – No Delamination

WP3 Test Results (Reliability)

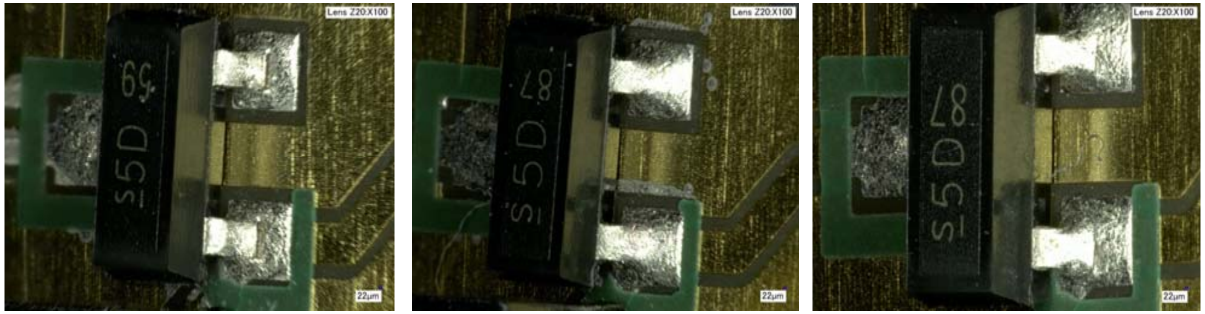
Diodes

Diode lot test – Forward voltage at 100mA – room temperature

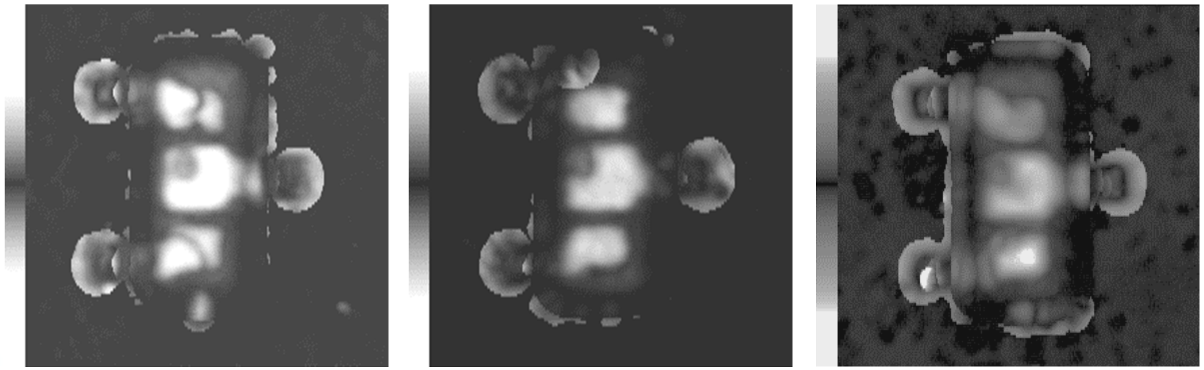
- Vf(max) = 1.2 V



Example Electrical Test Results (V_f @ 100mA) pre & post stress.



Post Stress High Magnification Inspection – No Sn Whisker Growth

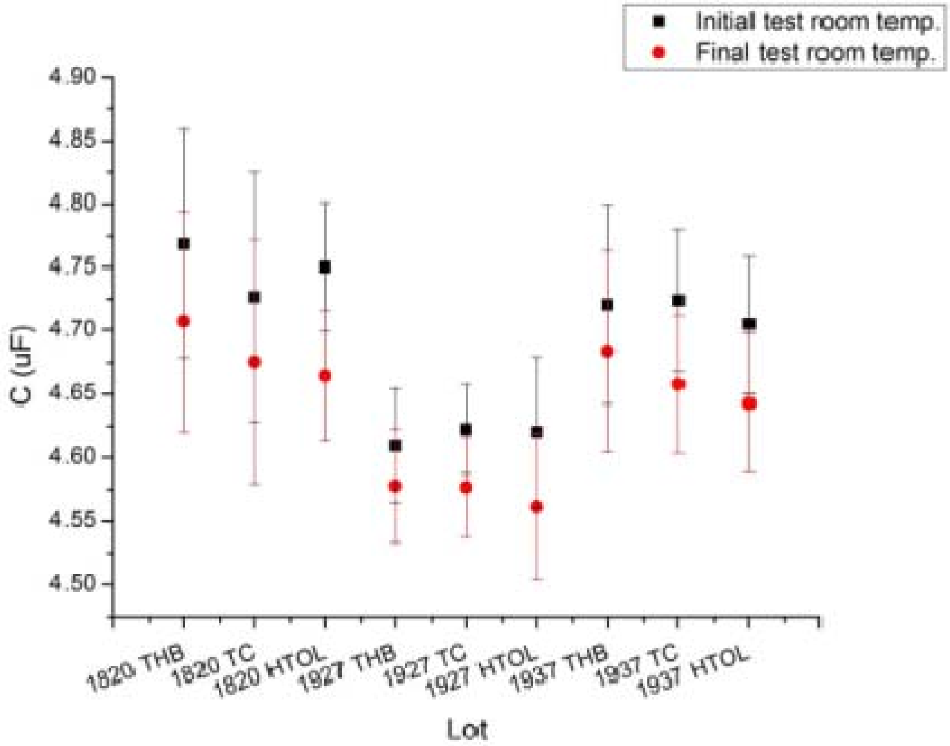


Post Stress (Thermal Cycling) SAM Imaging – No Delamination

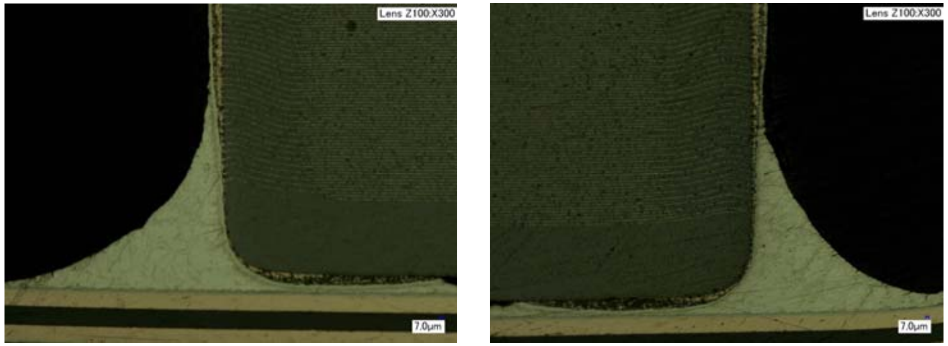
WP3 Test Results (Reliability)

Capacitors

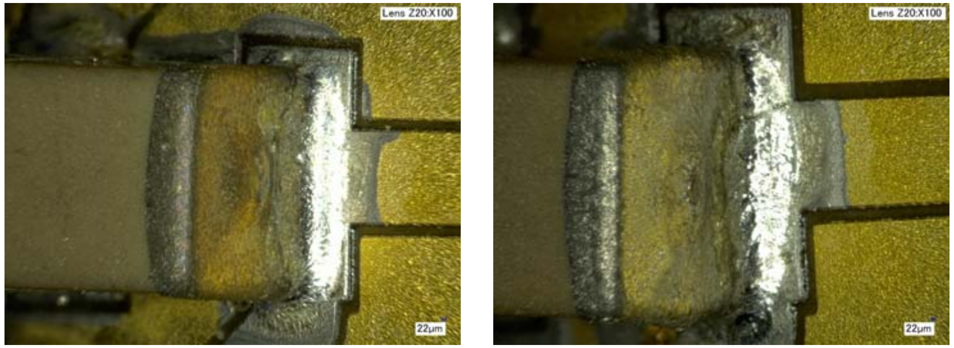
- C = 4.7uF +-10% allowed; Cmax = 5.17uF , Cmin = 4.23uF



Capacitance measurements pre & post stress test



Capacitor Cross-sections following Thermal Cycling



Inspection following HTOL & THB

Preliminary Conclusions

- **Three lots of each of three components families (Low noise operational amplifier, high speed diode & ceramic capacitor) procured & tested.**
- **No lot-to-lot variation (materials, dimensions or quality of construction).**
- **Consistent lot-to-lot CTE, Tg & Outgassing results (confirms materials / process).**
- **Initial concern on discoloured lead finish in oldest lot of op-amps, however:**
  - *Lot performed well in solderability tests (SAC305 & Sn63Pb37).*
  - *Soldered easily to test boards, no joint failures, no observable Sn-whisker growth.*
  - *Similar performance in electrical / reliability test to other lots.*
- **No failures occurred in "delta test" reliability campaign (THB, Temp Cycling & HTOL).**
- **Only minor electrical parameter drift observed following reliability campaign:**
  - *In some cases, improvements in performance observed following stress.*

Preliminary Conclusions

- **Promising results indicate a potential for use of AEC parts in space, but:**
  - *Findings are specific to the 3 component families evaluated.*
  - *May not be representative of other EEE components families or manufacturers.*
  - *More complex component types (e.g. large-area plastic encapsulated ICs) may perform differently.*
- **AEC parts manufactured in high volumes & supplied through networks of distributors:**
  - *Very difficult to obtain detailed information on individual lots.*
  - *Storage, handling, shipping may be less well controlled than for space-grade components.*
- **AEC qualified parts not rad-hard:**
  - *Suited only to low radiation space applications (unless tested / verified).*
  - *Radiation test campaign outside scope of this project.*

Recommendations

- Procure recent lots (DC<3 years), store in controlled conditions (ideally N_2).
- Conduct periodic visual inspection on stored samples.
- Carry out detailed CA, materials analysis, Tg, CTE, etc. on samples of new lots to ensure similarity with previous lots.
- Verify the manufacturer's AEC qualification data (could be as old as 10 years +).
- For grade-1 applications, full qualification needed on 1st lot (AEC-Q parts), then periodic test (e.g. every 2 years life test).
- For grade-2 & 3 mission applications, CA only (unless AEC qualification data is very old).
- SnPb re-tinning may not be required for some applications, (JESD-201 class 2 recent data & other measures such as coatings, barrier layers, etc..)

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