Electronic Assembly for use in Space Hardware

Carole Villette

17th of February 2022

Carole Villette, Materials Engineer, ESA ESTEC

Materials and Processes Section (TEC-MSP)

Structures, Mechanism & Materials Division (TEC-MS)

- Degree in Materials Sciences
- Ph.D. in Material Sciences
- Experience in TAS-F
  - Materials engineer specialized in Metallurgy
- Experience at ESA :
  - Materials engineer specialized in electronic assembly for 20+ years – supporting ESA's space projects

ESA-ESTEC team in charge of Electronic Assemblies

TEC-M (T. Henriksen)

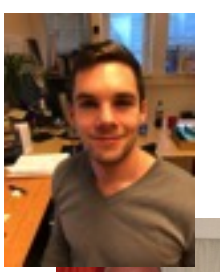
TEC-MS (T. Ghidini)

TEC-MSP (Th. Rohr)

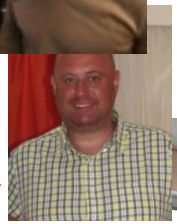
Assembly: C. Villette

G. Corocher

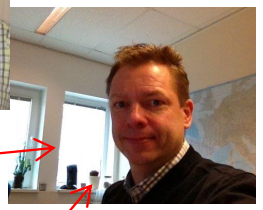
E. Peraud



- N. Beadle (100%)



- R. Dohmen (20%)



- D. Adams (on demand)

PCB:S. Heltzel

J. Hokka

-R. Dohmen (80%)

ECSS related to electronic assemblies

ECSS-Q-ST-70-07: Wave soldering

ECSS-Q-ST-70-08: Hand soldering of through hole connection

ECSS-Q-ST-70-18: RF cables assemblies

ECSS-Q-ST-70-26: Crimping

ECSS-Q-ST-70-28: Repair and modification on PCBs

ECSS-Q-ST-70-30C: Wire warp

ECSS-Q-ST-70-38C Rev 1: SMT soldering

ECSS-Q-AS-20-30: Harness manufacturing and control

- ECSS-Q-ST-70-07, ECSS-Q-ST-70-08 and ECSS-Q-ST-70-38 are under merge to issue the ECSS-Q-ST-70-61

ECSS-Q-ST-70-12: Design of PCB

ECSS-Q-ST-70-60: Procurement and qualification of PCB

ECSS content related to electronic assemblies

- ✓ -Materials to be used
- ✓ -Processes to be used

} Industry to choose the configuration } -Preferred combination to be used

- ✓ -Design to be used (PCB, Assembly, thermal, mechanical…)
- ✓ -Workmanship criteria

- ➢ Electronic Assembly verification
- ➢ PCB qualification
- ➢ Operators and Inspectors training

Different types of electronic assemblies

-Connection made by using solder on PCB or wiring (07, 08, 28, 38)

-Connection made by using crimping (26)

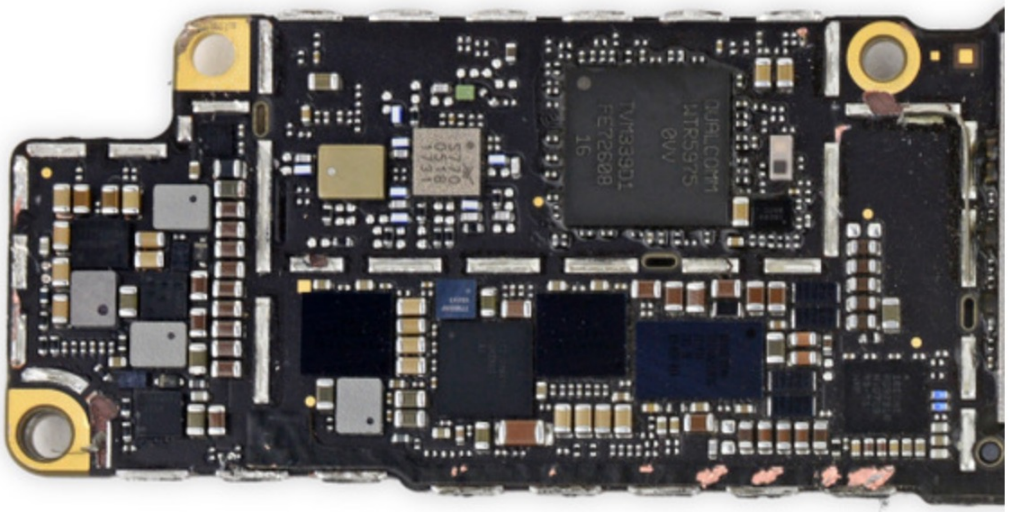
-Connection made by using wire warping (30)

- Connection by using cable connections and connectors, harness connection (08, 26, Harness)

-Connection made by using solderless connection

Connection made using solder

Electronic assembly



Connection made using solder

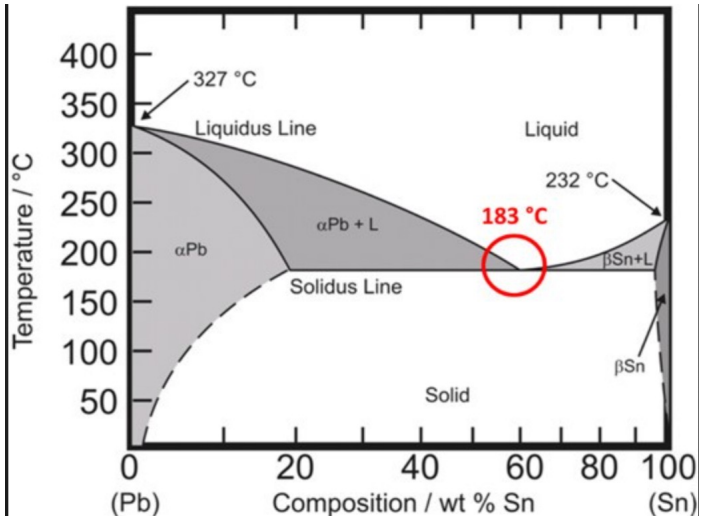
Common Interfaces

-Printed Circuit Board plating:	-Component termination: See ESCC23500	-wires
• Copper (Cu) with Tin lead (Sn60Pb40) • Copper with lead free finish (RoHs compliant): ENIG/ ENEPIG/ Gold	• Tin lead • Gold plating: degolding and pretining prior assembly using tin/lead solder • Silver plating: • COTS (pure tin,…)	• Silver • Pure tin

Connection made using solder: Phase diagram

Type of solders:

Commonly used: Sn63Pb37



Alternative: Tin/Lead/Silver alloy:Sn62 Pb36 Ag2

High temperature solder: Tin/silver alloy :Sn96Ag4

Low temperature solder: Indium/Lead: In/Pb

Connection made using solder: Assembly method

Automatic assembly (Collective soldering)

- Vapour Phase (usually 215C)
- Convection reflow (min 12 degree above solder melting point)
- Wave soldering (235 °C to 275 °C)

Local assembly

- Assembly by hand (240-340C with exception of 380 for PTH with copper plane)
- Selective wave soldering (max 300C)
- Local hot air (Repair station)

Connection made using solder: Substrates commonly called Printed Circuit Board

Qualification status of PCB

Responsible in ESA: Stan Heltzel

Stan.heltzel@esa.int

- Design in compliance with the ECSS-Q-ST-70-12C.
- Manufacture and procurement in compliance with the ECSS-Q-ST-70-60C

Status on: https://escies.org/webdocument/showArticle?id=798&groupid=6

PCB/substrates materials: Polyimide/ Epoxy HTg/ low CTE such as thermount 85NT RF substrates (Duroid, TMM10i,…)/ Ceramic. New commers Megtron, Ventec VT901

Connection made using solder: Printed Circuit Board

Rigid PCB

-Single sided

-Double sided

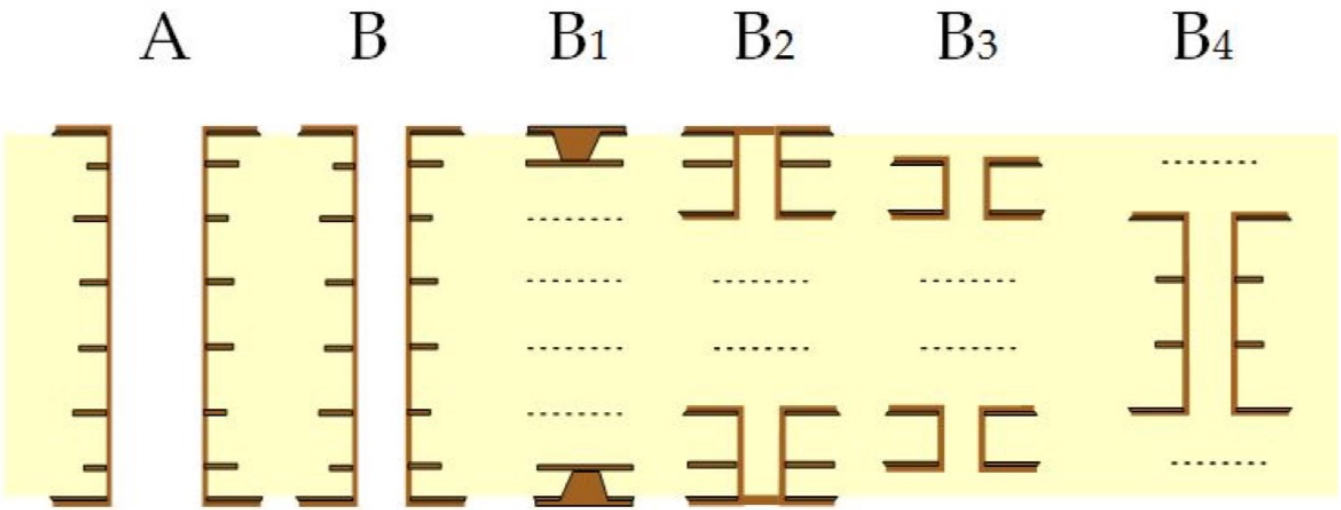
-Multilayer (A/B)

-Sequential (A/B/B2/B3/B4

-Micro vias (A/B/B1/B3/B4)

-Patch boards for

Modifications (single sided)



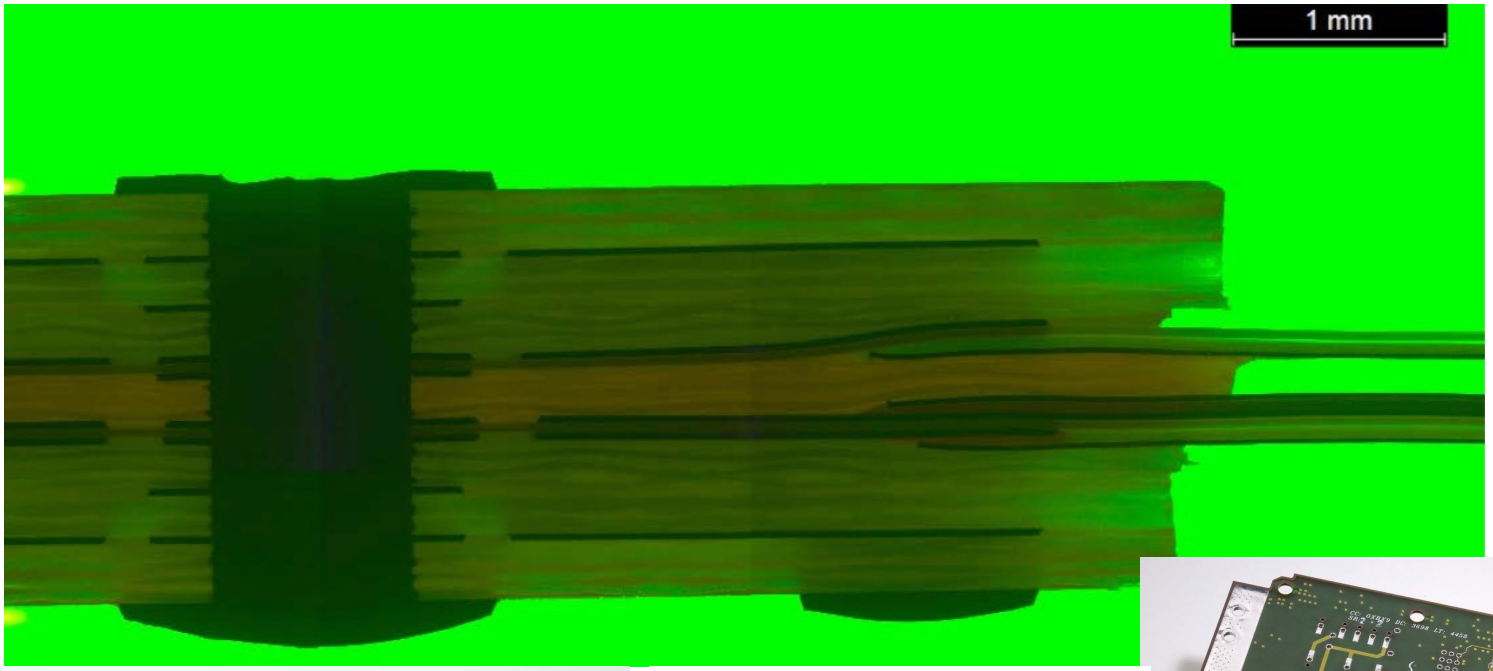
A = PTH
B = through-going via
B_1 = microvia
B_2 = blind via
B_3, B_4 ... B_n = buried vias

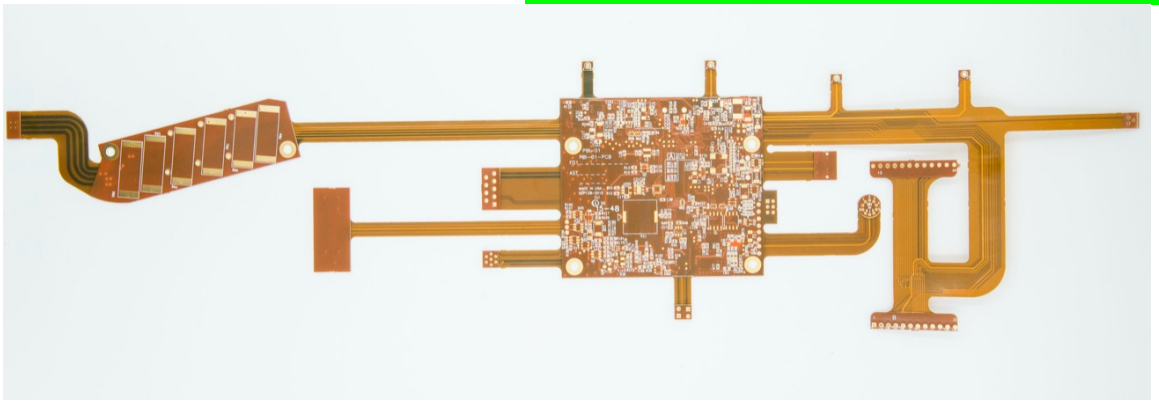
Connection with solder: Printed Circuit Boards

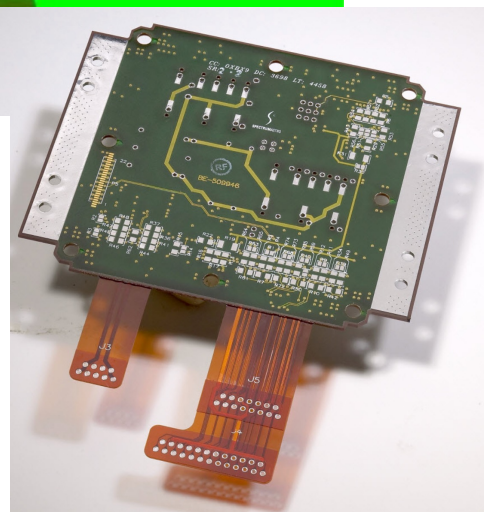
Rigid/flex PCB

-Rigid/flex

-Flexible PCB

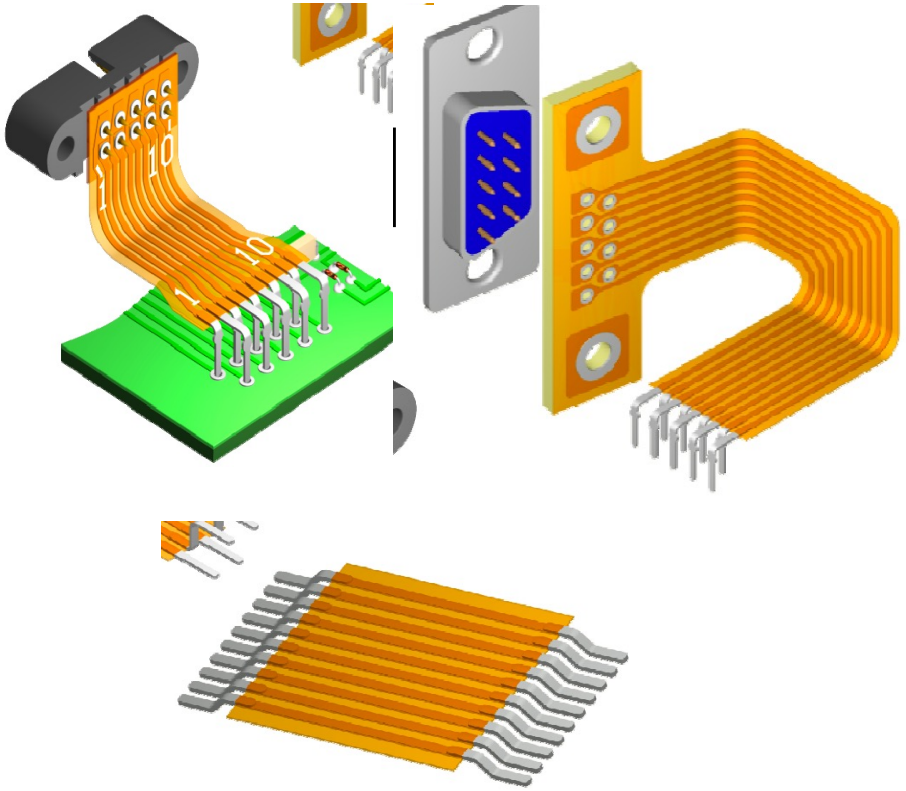


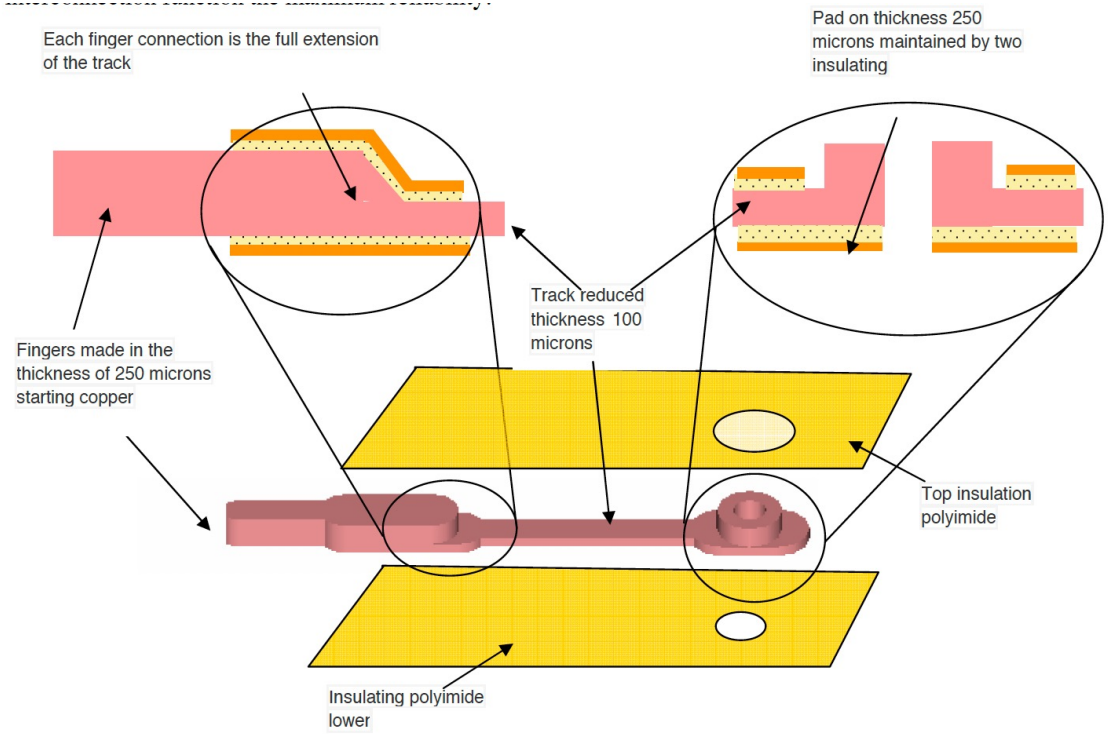




Connection with solder: Printed Circuit Boards

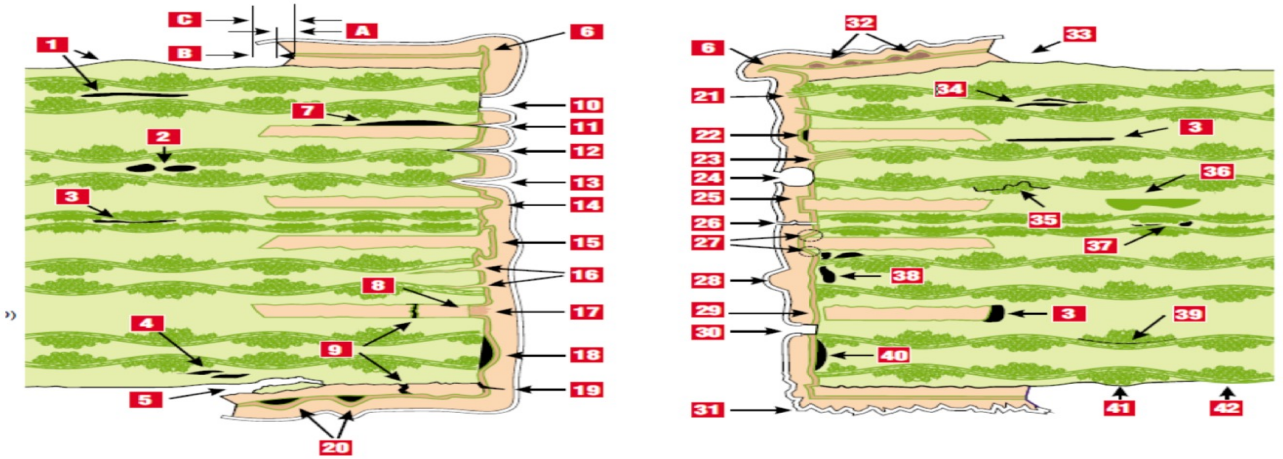
Sculptured flexible





Connection made using solder: Printed Circuit Board

Possible defects in PCB



A Undercut
B Outgrowth
C Overhang

1 (Resin) Blistering
2 Laminate Void
3 (Resin) Delamination
4 Lifted Land Crack
5 Pad Lifting
6 Burr
7 Pink Ring
8 Negative Etchback
9 Foil Crack
10 Void (PTH)
11 Wedge Void
12 Glass Void
13 Microvoid (Glass)
14 Arrow Heading
15 Nail Heading
16 Drilling Cracks
17 Innerlayer Burning (ICD)
18 Pull Away
19 Corner Crack
20 Blistering

21 Glass Fiber Prostitution
22 D-Effect
23 Wicking
24 Void (Metal Resist)
25 (Positive) Etchback
26 Barrel Crack
27 Shadowing
28 Nodule
29 Rest Smear (ICD)
30 Void (Resist Residues)
31 Burned Plating
32 Starburst
33 Pad Rotation
34 Resin Crack
35 Crazing
36 Foreign Inclusion
37 Prepreg Void
38 Pocket Void
39 Measling
40 Resin Recession
41 Glass-Weave Texture
42 Glass-Weave Exposure

Originally designed by
Viasystems Mommers BV, Netherlands

Reviewed by BTT-PTH
Atotech Deutschland GmbH, Berlin

More detailed information in the ECSS-Q-ST-70-60

Regular ECSS theory training made on the standard by Hytek

Connection made using solder: Printed Circuit Board

Possible defects in PCB (ECSS-Q-ST-70-60)

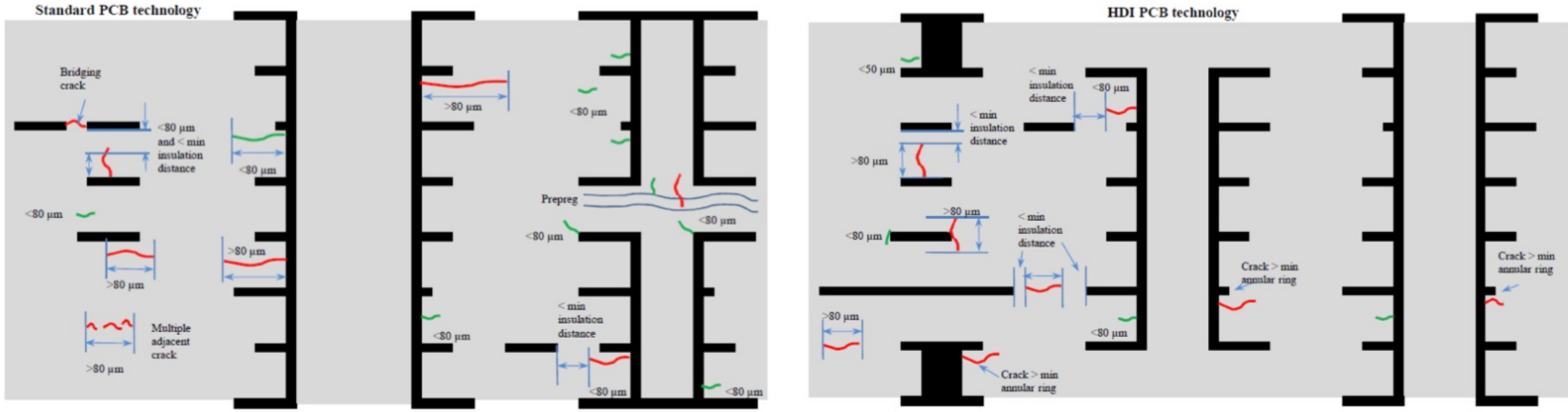


Figure 10-47: Acceptable (green) and non-acceptable (red) dielectric cracks

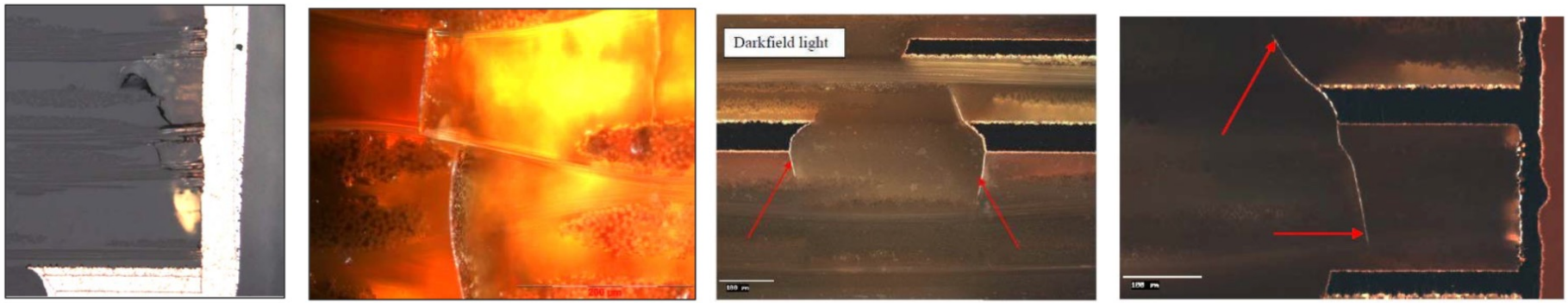
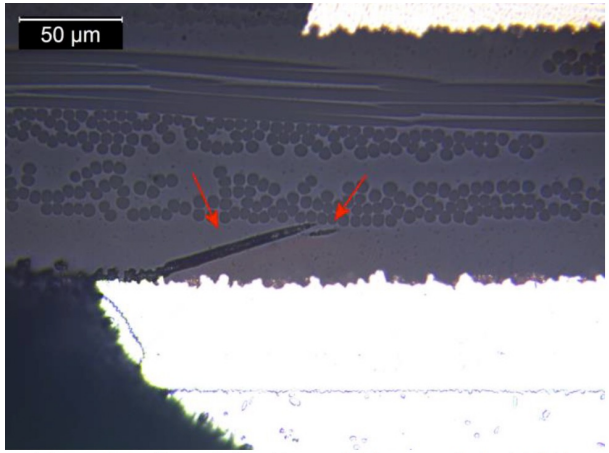


Figure 10-48: Examples of laminate cracks

Connection made using solder: Printed Circuit Board

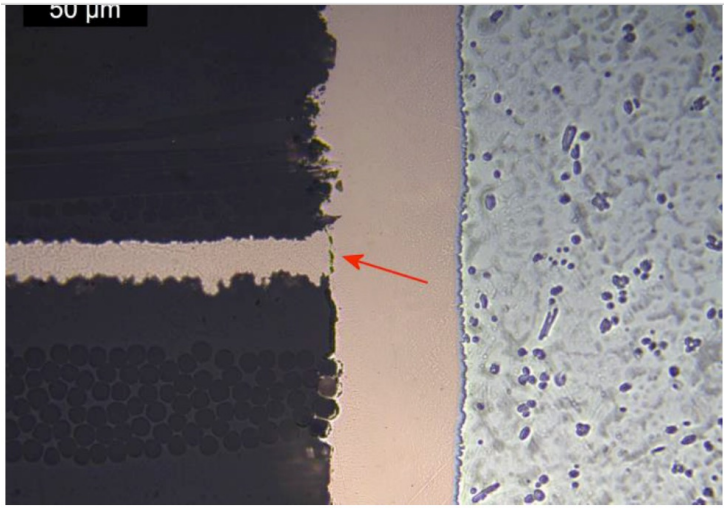
-Pad lifting



Termination 2 bottom LH, crack in PCB

Eccessive Soldering temperature

-Interconnection defect



Connection made using solder: Printed Circuit Board

-Qualification of PCB remains mandatory to ensure reliable hardware

- ECSS Qualification in compliance with the ECSS-Q-ST-70-60
- Project qualification by means of a group 6 and IST test.

❖ Failure in PCB are not visible and may degrade with the time of the mission to result to failure (ground test, mission)

-Double source recommended

- Citretec recent fire. One ESA Approved PCB manufacturer less that will results to heavy impact on procurement and cost for qualification
- In the past Cirep, Printca

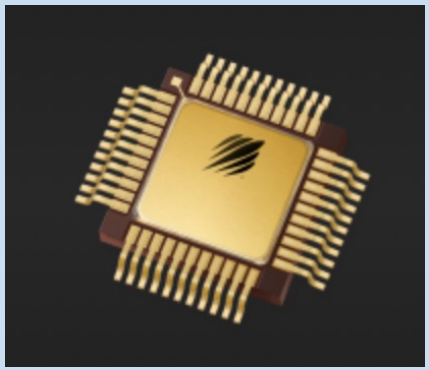
Soldered connections

- **Assemblies made using Surface Mount Technologies**
  - Leaded or leadless components
    - Leaded components will have some more stress relaxation during the environmental test due to the presence of stress relief.
    - Leadless components can suffer of reduced stress relaxation and develop cracks in the solder joints and in package itself

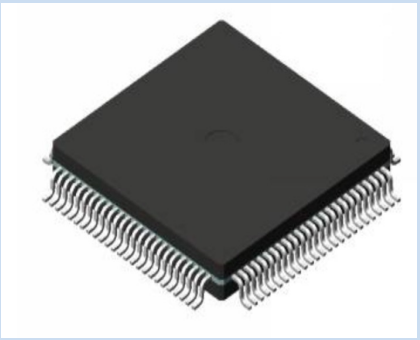
Soldered connections. Surface Mount Technologies

Leaded devices

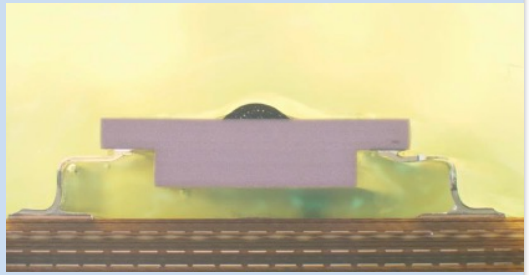
Top attachment



Middle attachment



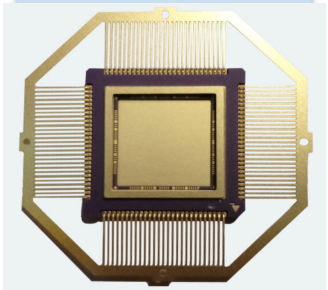
Bottom attachment

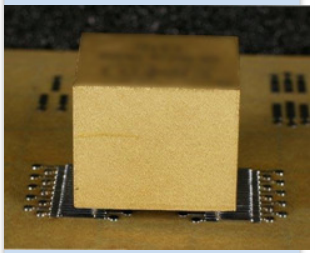


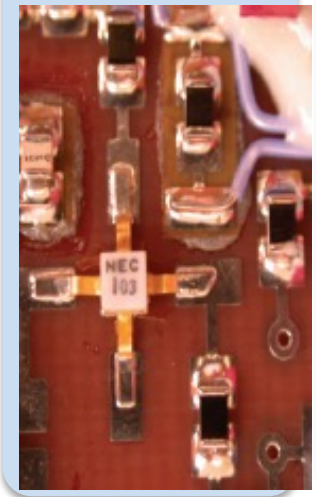
Soldered connections. Surface Mount Technologies

Leaded devices

Flat pack







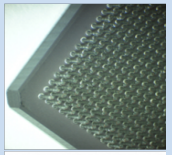
L inwards

Gull wing

J leads

Area Array Device

CGA



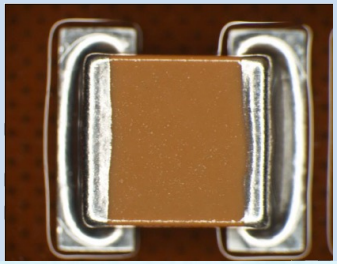
BGA

LGA

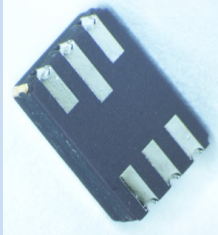
Soldered connections. Surface Mount Technologies

Leadless devices

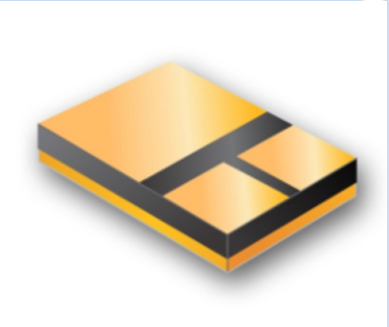
Chips

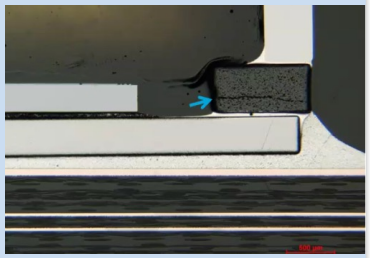


Castellation

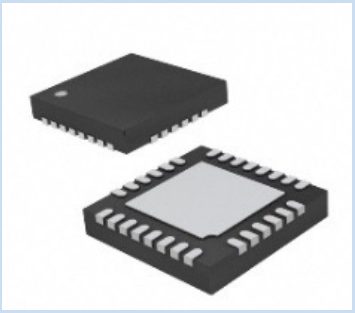


Bottom cases





QFN

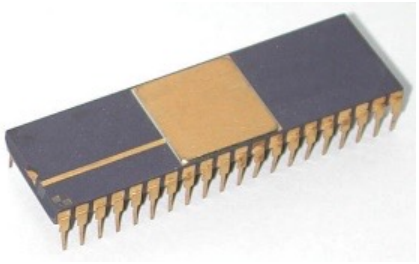


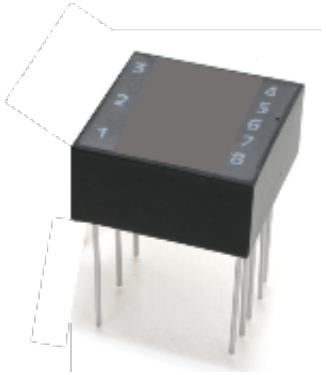
Soldered connections

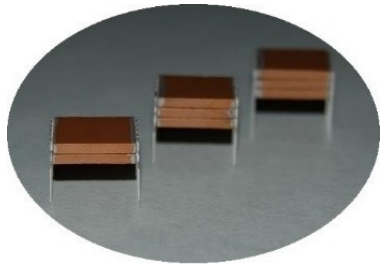
Assemblies made using Through Hole Technology

- With stress relief

- Without stress relief



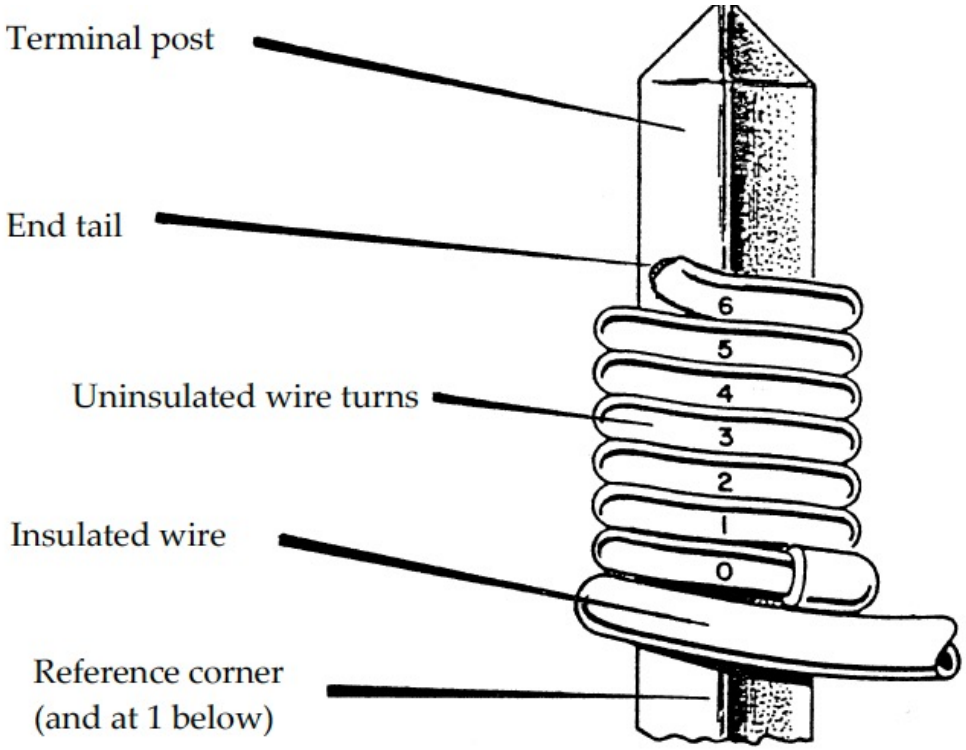




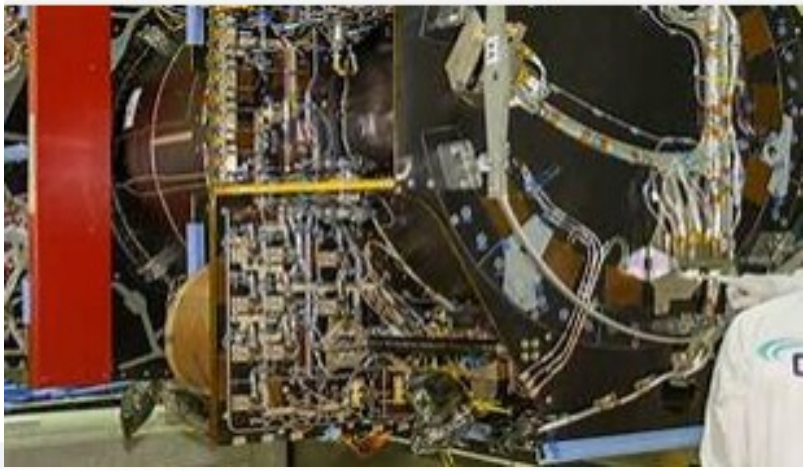
Connection made using crimping (ECSS-Q-ST-70-26)

Barrel (lug, splice,…) association with wires

Connection made using wire warping (ECSS-Q-ST-70-30)



Connection made by using Harness connection



Connection made by using solderless connection

Spring contact:

Advantage: Possible to mate and demate with reduced damaged on the PCB.

Drawback: Limited experience on such assemblies

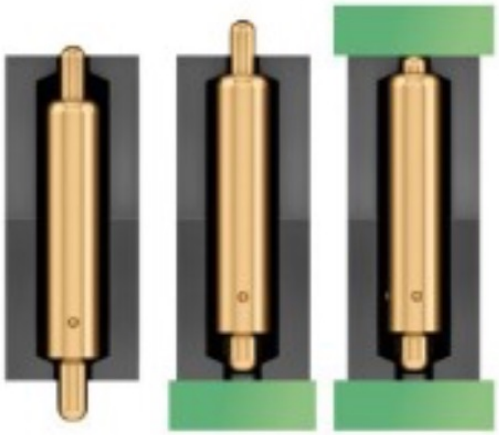
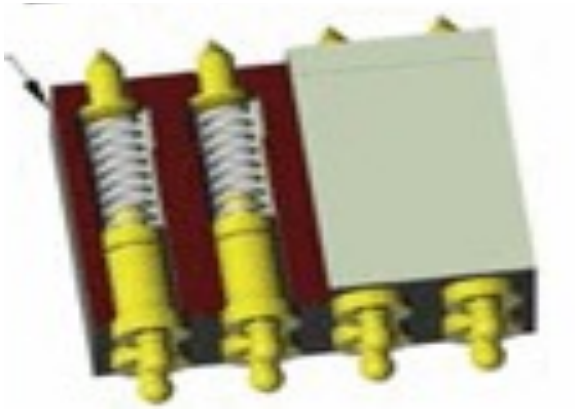


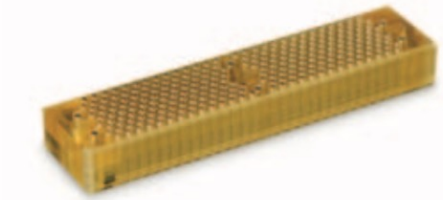
Figure 2a: Cross Section of Two-Piece Housing with Floating Probe



Stacking Connectors

Spring Probe Interposers

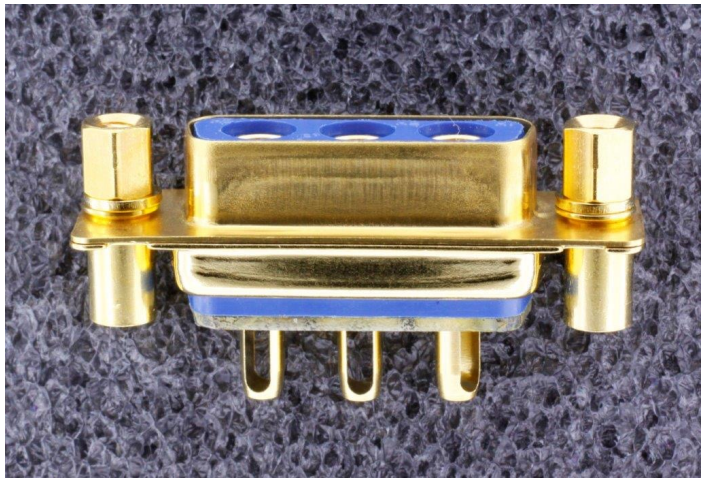
- ESCC 3401/076 approved
- Z-Axis interconnects with solderless contacts
- High density button contact
- Design flexibility



Connection made by using solderless connection

Press fit connection

Not yet qualified for ESA programms that requires high reliability but on evaluation



Mechanical and thermal constrain

Why soldered connections of electronic assembly fail?

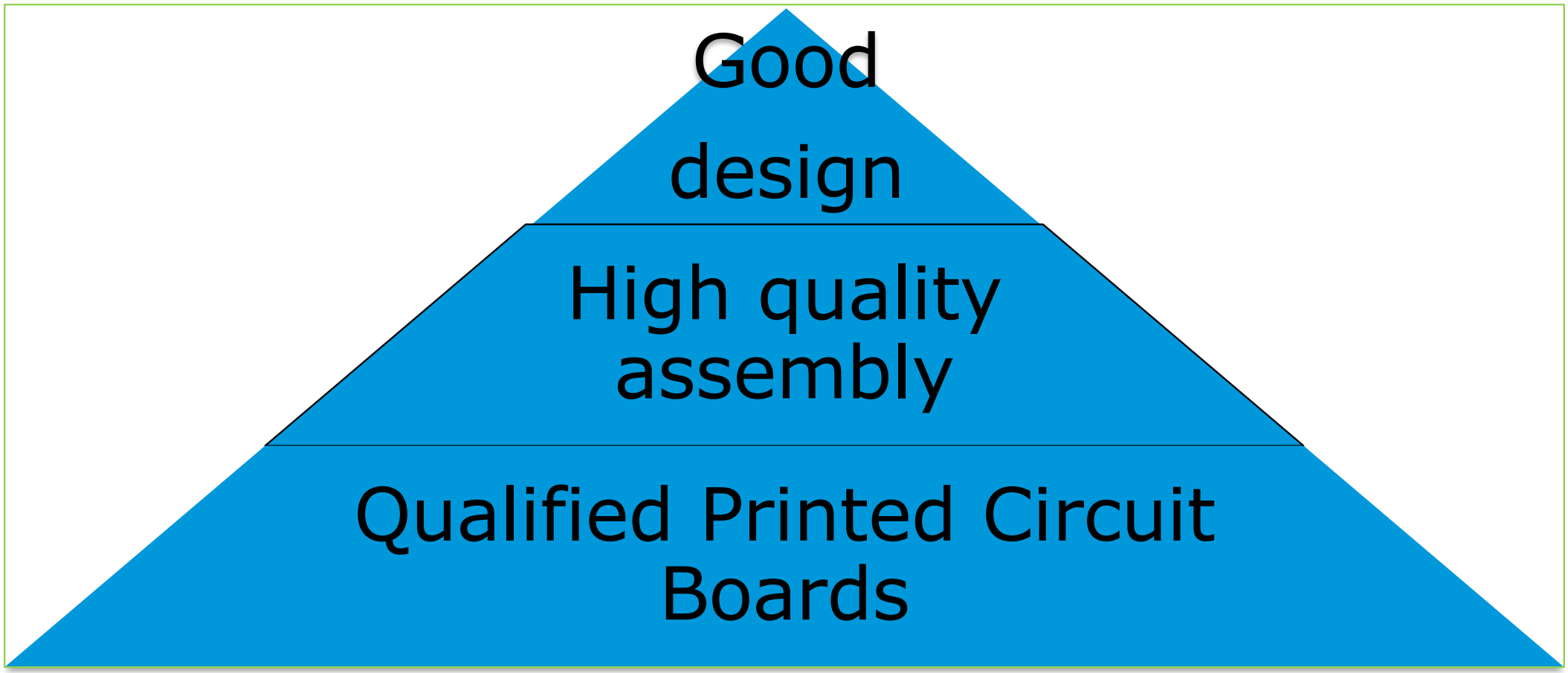
Electronic assemblies are exposed to stresses during their life.

- **Mechanical loading: vibrations (eg Launch) and shock (solar panel deployment)**

- **Thermal stresses : due to difference in CTE of the materials involved in the assembly during thermal cycling (AIT, Ground testing, mission,..)**

Accumulation of these stresses can eventually lead to failure of the connections.

Reliable assemblies



Good design

- PCB design in compliance with ECSS-Q-ST-70-12

- Assemblies in compliance with ECSS-Q-ST-70-07/08/18/26/28/30/38

- CTE mismatch limited between Components and substrate (See list of sensitive parts)

- Reduced mechanical stress
  - Use of stiffener
  - Use of local mechanical fixation
- Reduced thermal excursion when possible
  - Good thermal design at system level
  - Use of PCB with thermal drain and assemblies with thermal bonding or thermal heat sink (coolers, thermal finger, …)

High quality assemblies

- ✓ Reliable components.
  - ➢ Qualified parts
  - ➢ COTS are newly introduced due to high performances and low cost (radiation sensitivity, plating, miniaturization, new packaging such as QFN…)

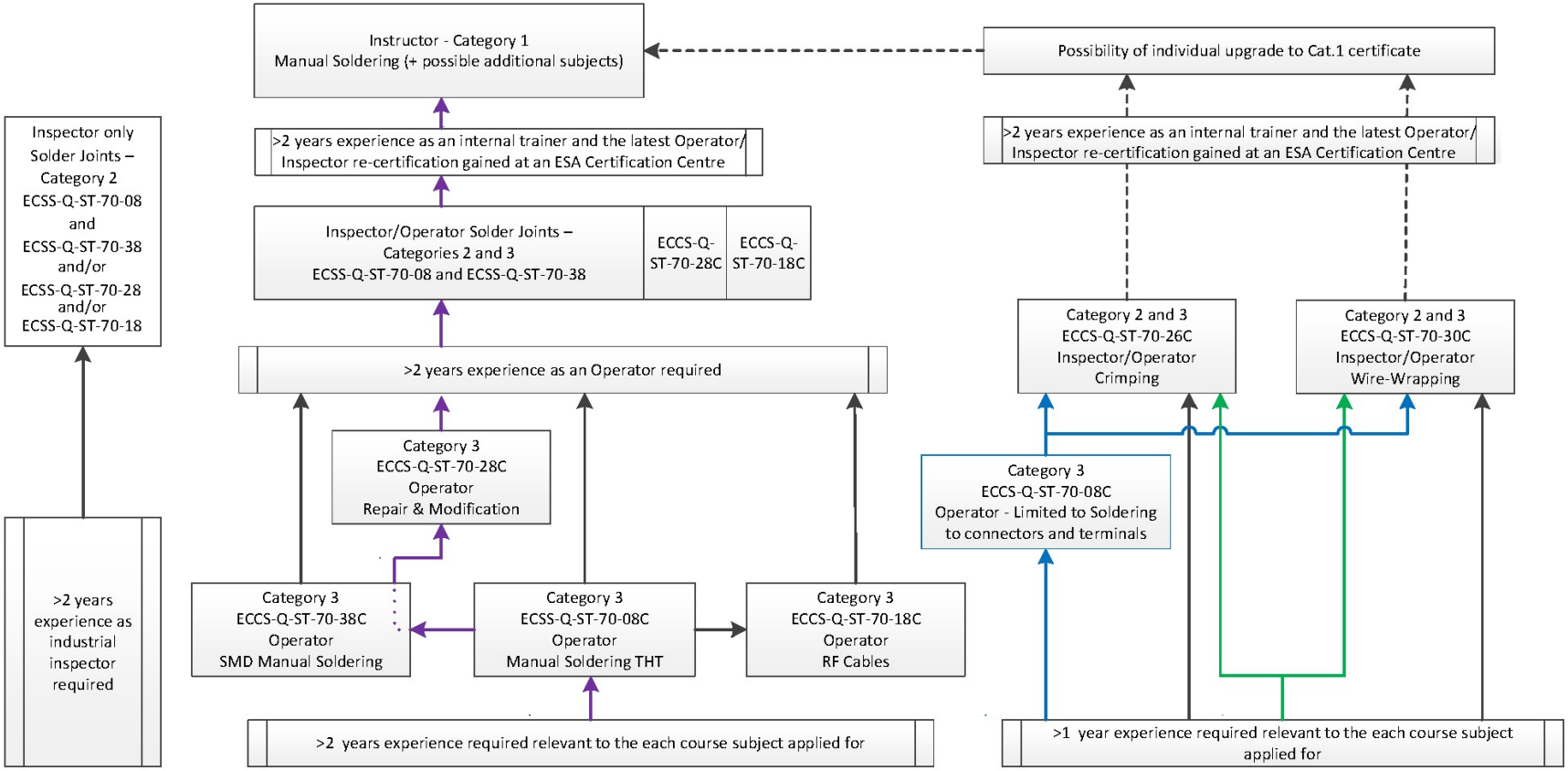
- ✓ Stress relief implemented (leads, Low CTE mismatches between component and PCB)

- ✓ Qualified materials (solder, PCB, plating of PCB and parts, conformal coating)

- ✓ Reproducible procedures
  - •Verified assemblies
    - ✓ verified in compliance with Applicable ECSS
- ✓ Certified operators

  Companies trained and certified and ESA skills certification schools

High quality assemblies: ESA skills certification School



Attendance-only courses for delegates who do not meet entry requirements are possible.

High quality assemblies: ESA skills training School

-ASTA in UK

-IFE in Germany

-ZVE in Germany

-IIS in Italy

-IS in France

-Hytek in Denmark

-SWI in Switzerland

-Renex in Poland to be concluded

High quality assemblies:

- ✓ Assembly verification
- ✓ Audit of the assembly line
- ✓ Approved PID

(See ESA Approved Summary Tables)

- ✓ Assembly of sensitive devices (see https://escies.org/webdocument/showArticle?id=981 MOM ESA-TECQTM-MO-1143 Issue 1)

- ✓ Assembly MPCB to be organized in compliance with the ESA memo ESA-TECMSP-MO-018430

Qualified PCB

- ✓ Qualification of PCB made in compliance with the ECSS-Q-ST-70-60
- ✓ Audit of the PCB lines
- ✓ PCB approval sheet part 1 shall be submitted prior to the PDR and subject to approval during MPCB.
- ✓ The procurement authority shall complete a PCB approval sheet part 2 for each individual PCB type in conformance with requirement G.2.1b of the DRD in Annex G of ECSS-Q-ST-70-60C
- ✓ PCB approval sheet part 2 shall be submitted prior to the CDR and subject to approval during general MPCB.

Review and assessment of the assembly status

-During development at Company

Completed by Assembly verification in close relation with the Agency

-EQSR

-PDR

-CDR

-MPCB for PCB compliance

-Assembly MPCB

Assembly Approval status reviewed during MPCB (See https://escies.org/webdocument/showArticle?id=981

-MRR

-Participation to NCRs, RFA, RFD, RFW

-Participation to MIPs

Different Working Group

PCB/Assembly CTB Working Group (chairman: Stan Heltzel)

-Bi yearly meeting to share the PCB quality defects, Improvements in materials used for PCB, Harmonization of PCB and assembly technology, Review of new developments, review of list of assembly sensitive parts, similarity rules in between PCB substrates.

-Splinter meeting for press fit connection

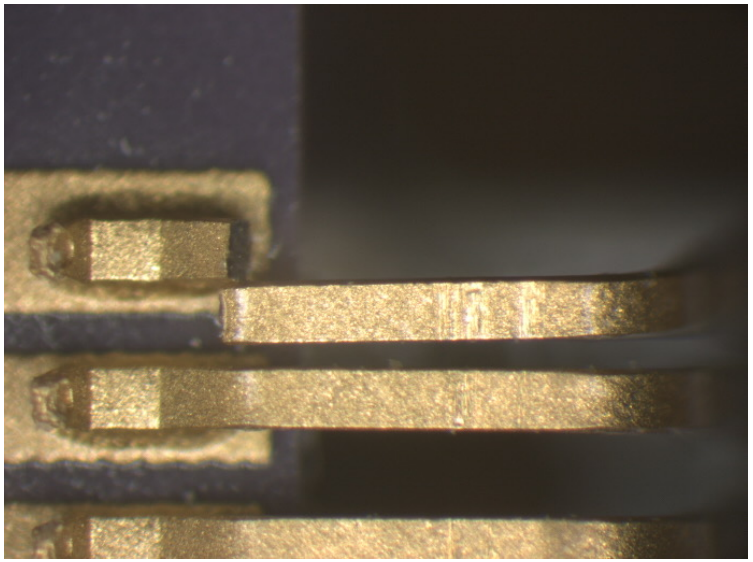
Lead free WG under MPTB (chairman: Gianni Corocher)

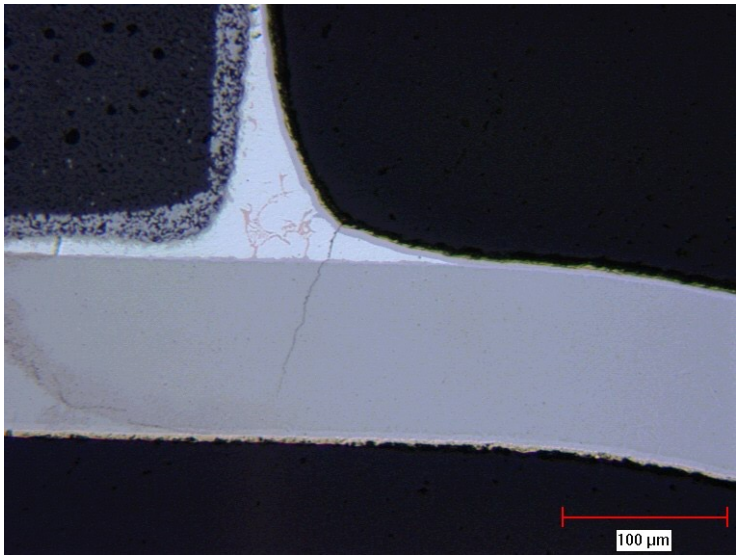
COTS Guidelines within ESA

Project classification and associated qualification requirements

Electronic Assembly failure mechanisms

Mechanical loading: vibrations and shock





Broken component terminations (visible or not)
Broken Adhesive (visible or not)

Electronic Assembly failure mechanisms

Mechanical loading: vibrations and shock

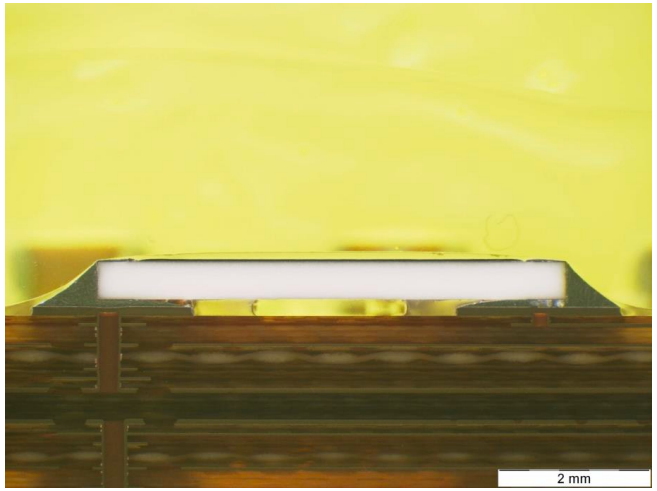
Corrective actions:

- Increase stiffness of the PCB by adding stiffener or reducing the surface of the stiffener window

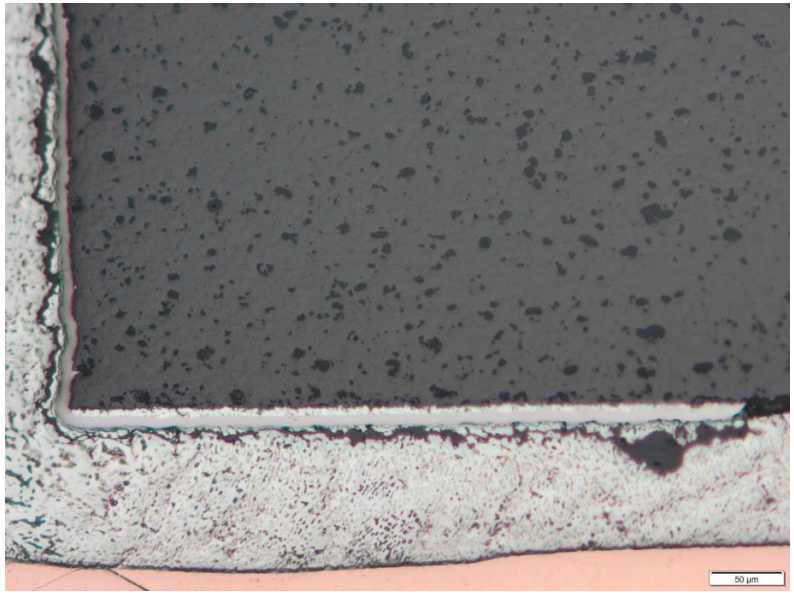
- Increase the mechanical bonding or staking of the component.

Electronic Assembly failure mechanisms

Thermal stresses : due to difference in CTE of the materials involved in the assembly



Chip resistance R2512



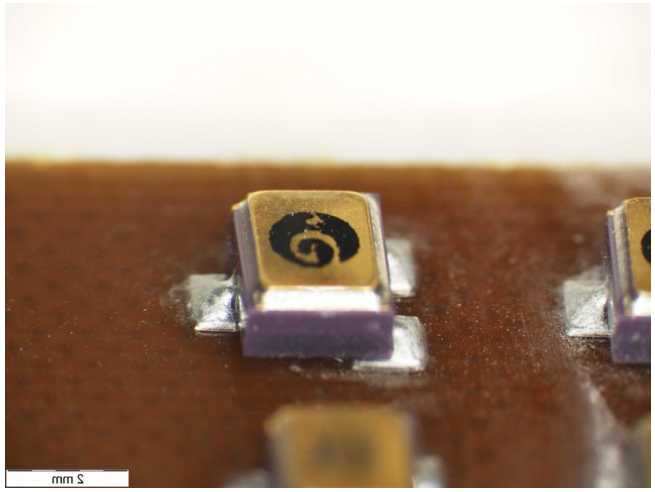
Crack in solder joint

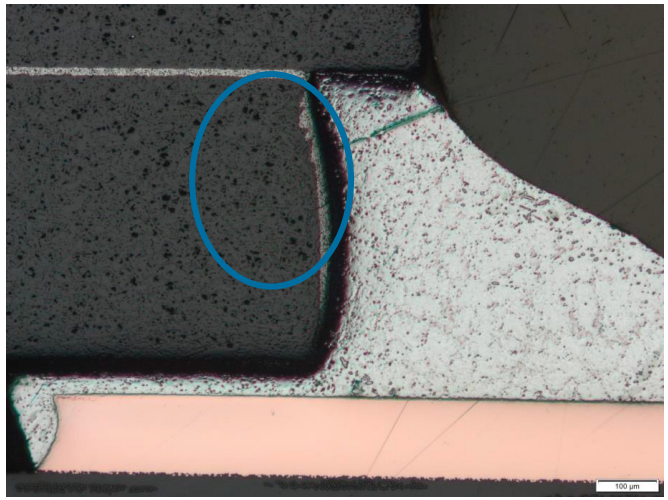
→ Design modification to avoid R2512

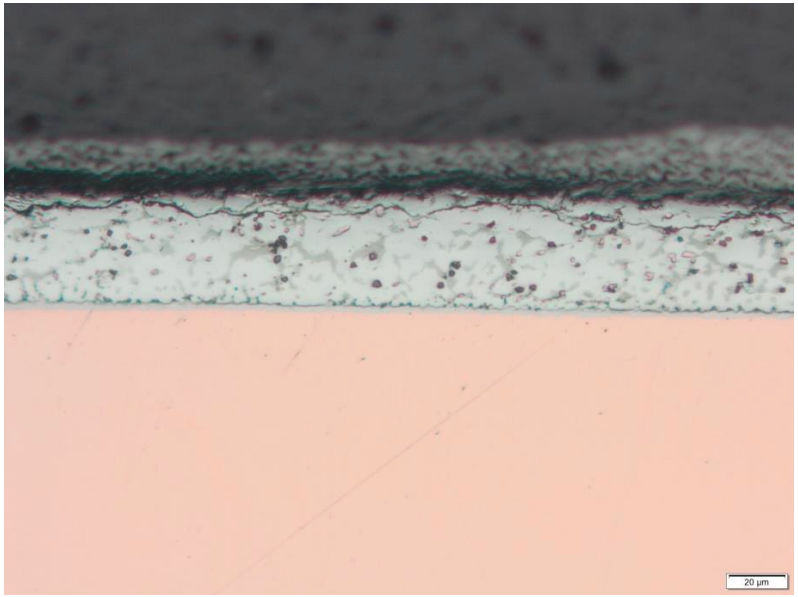
Electronic Assembly failure mechanisms

Thermal stresses : due to difference in CTE of the materials involved in the assembly

LCC3:



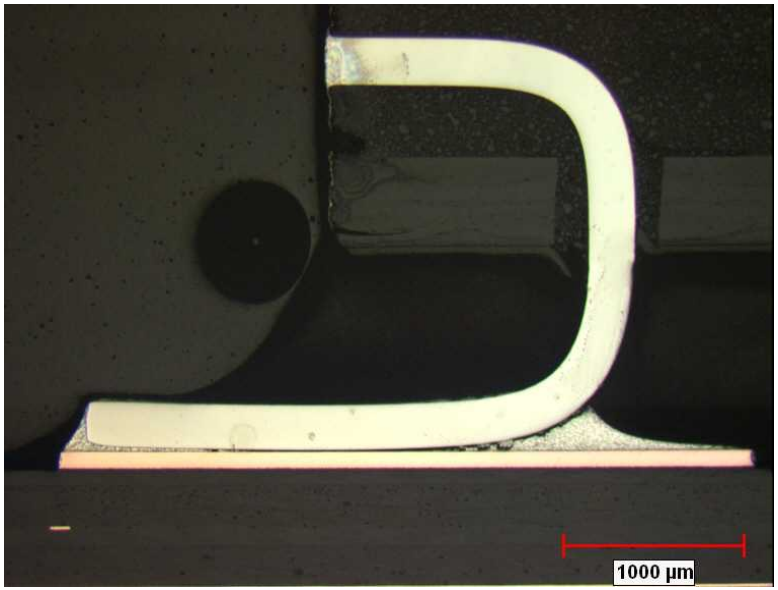


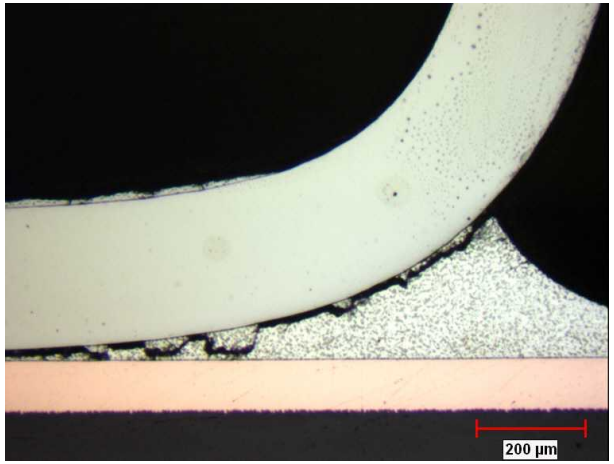


→ Assembly by hand using a solder stand off

Electronic Assembly failure mechanisms

Cracks in the solder joint due to poor design of components

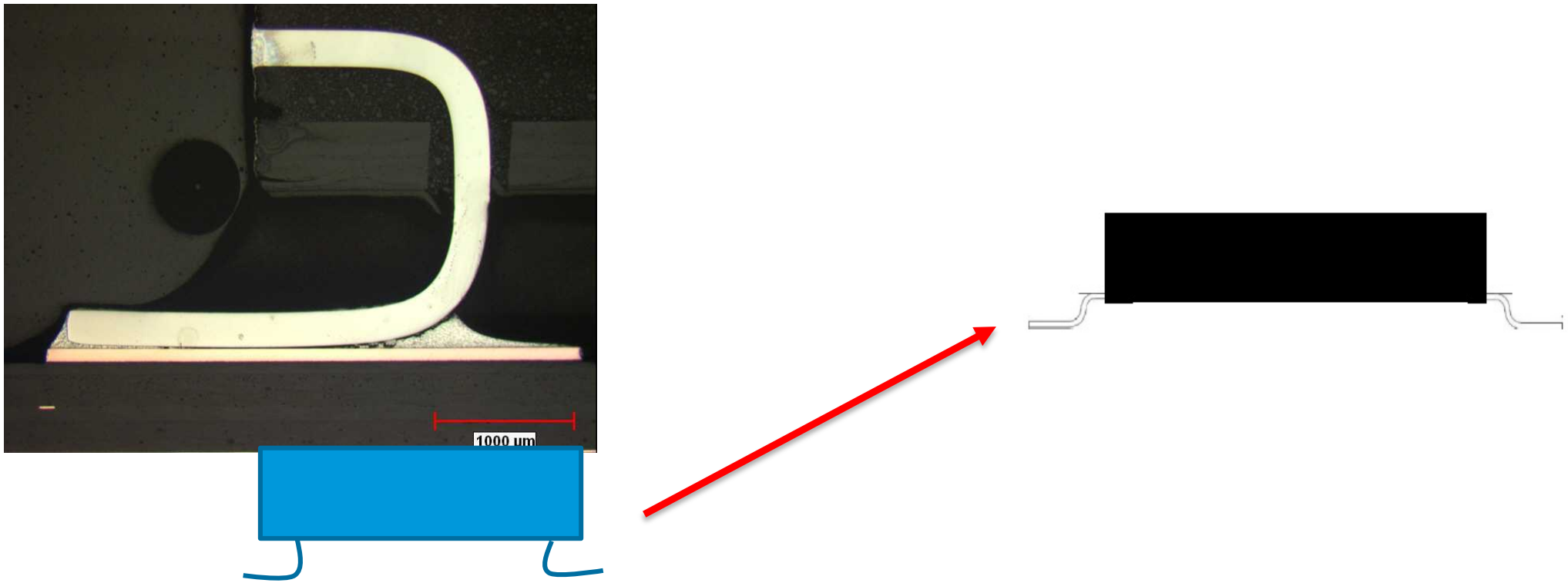




No stress relief

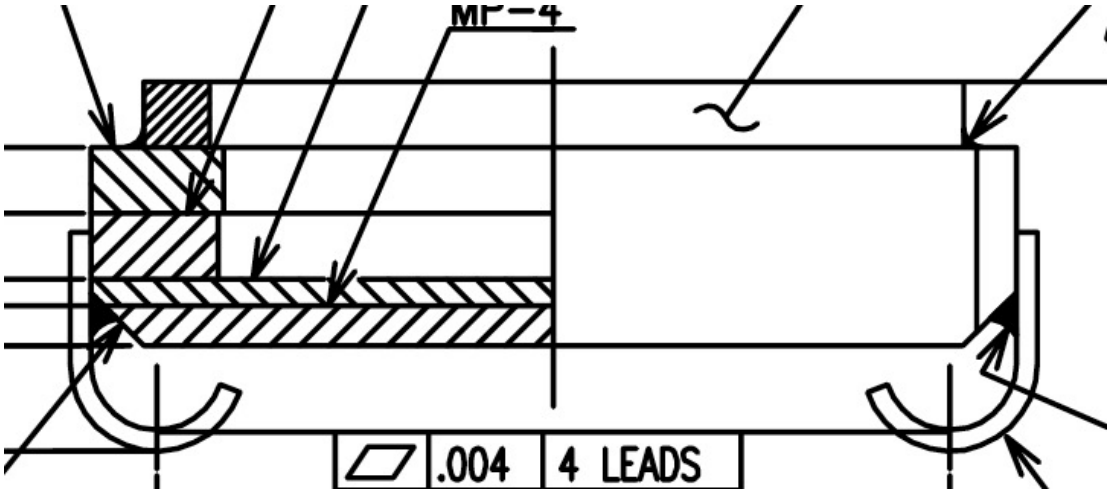
Electronic Assembly failure mechanisms

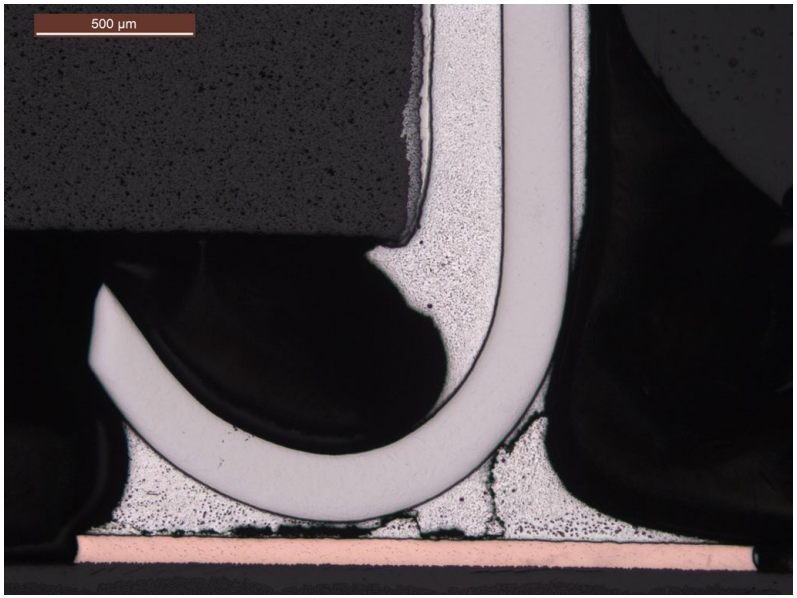
Component corrective action



Electronic Assembly failure mechanisms

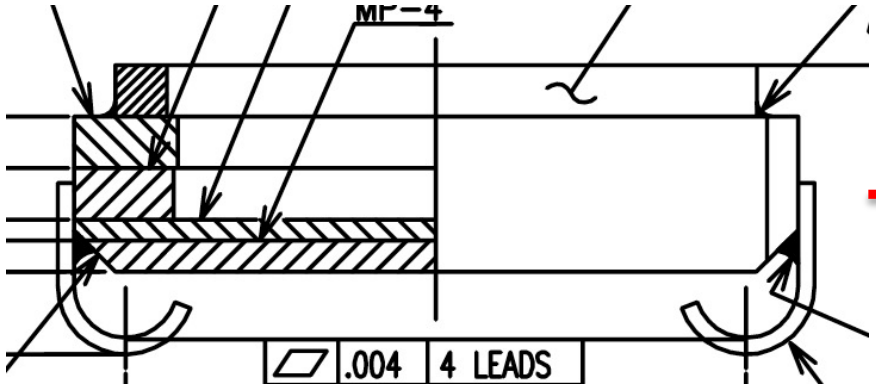
Cracks in the solder joint due to poor design of components

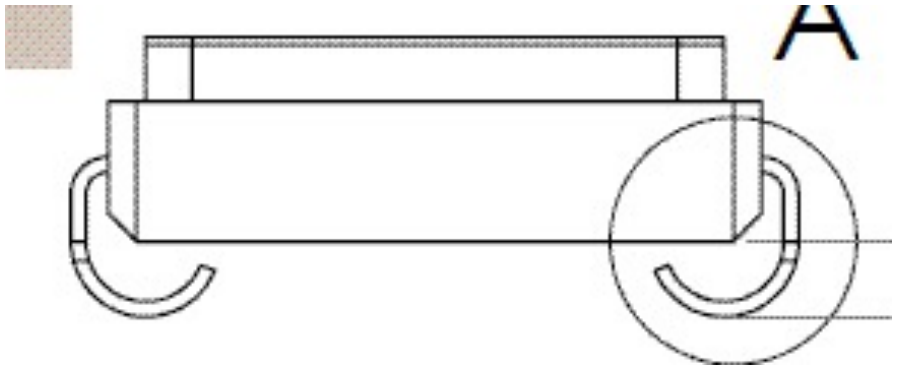




Electronic Assembly failure mechanisms

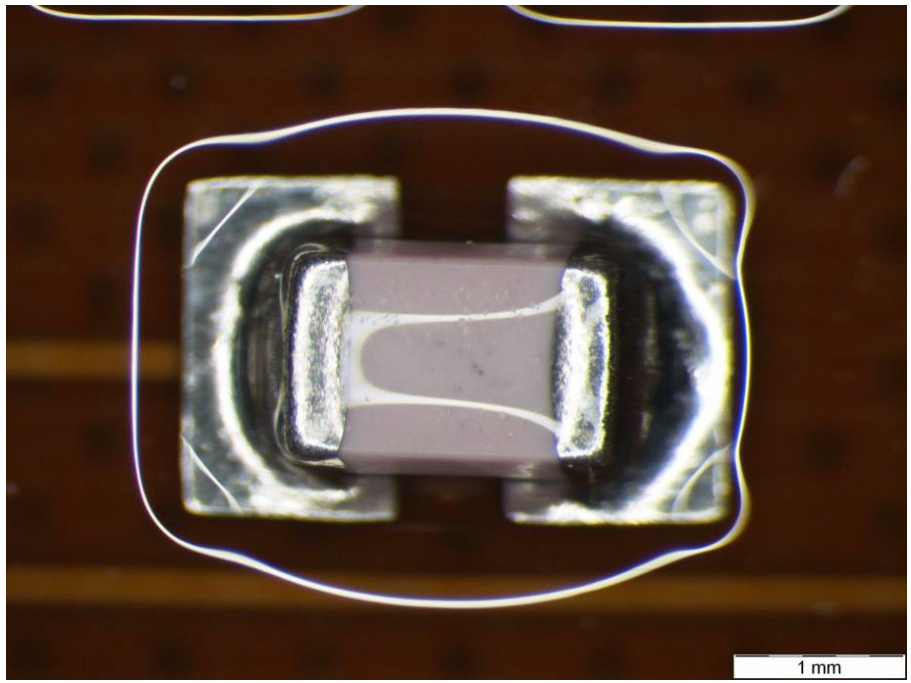
Component corrective action

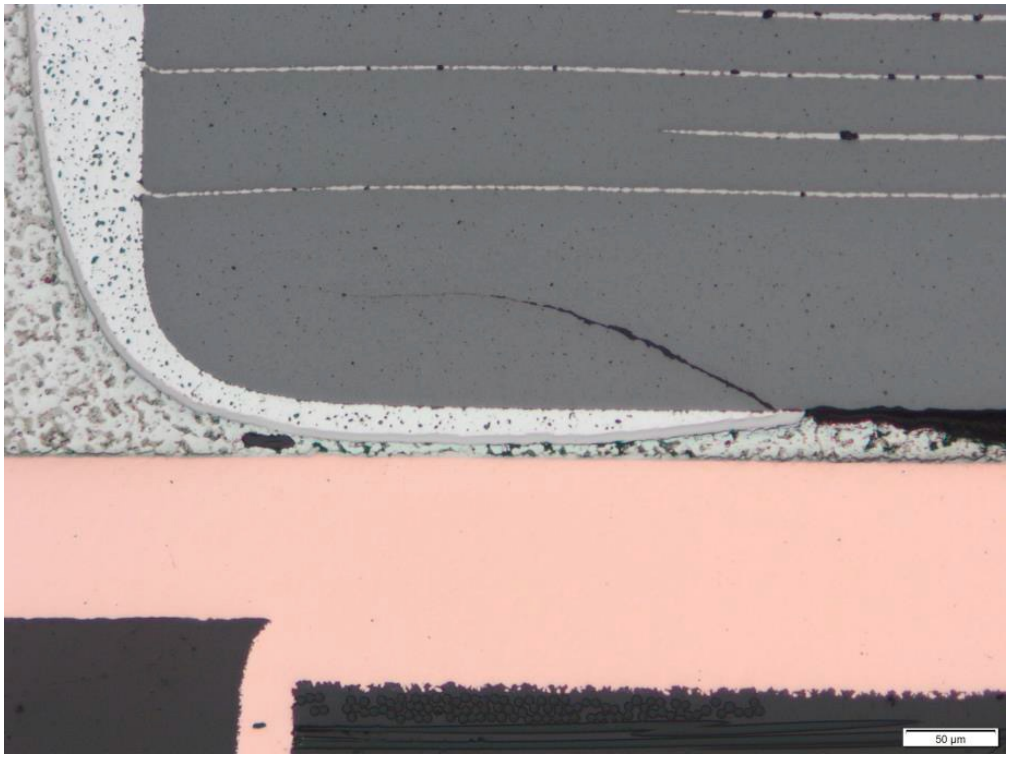




Electronic Assembly failure mechanisms

Thermal shocks during assembly by hand

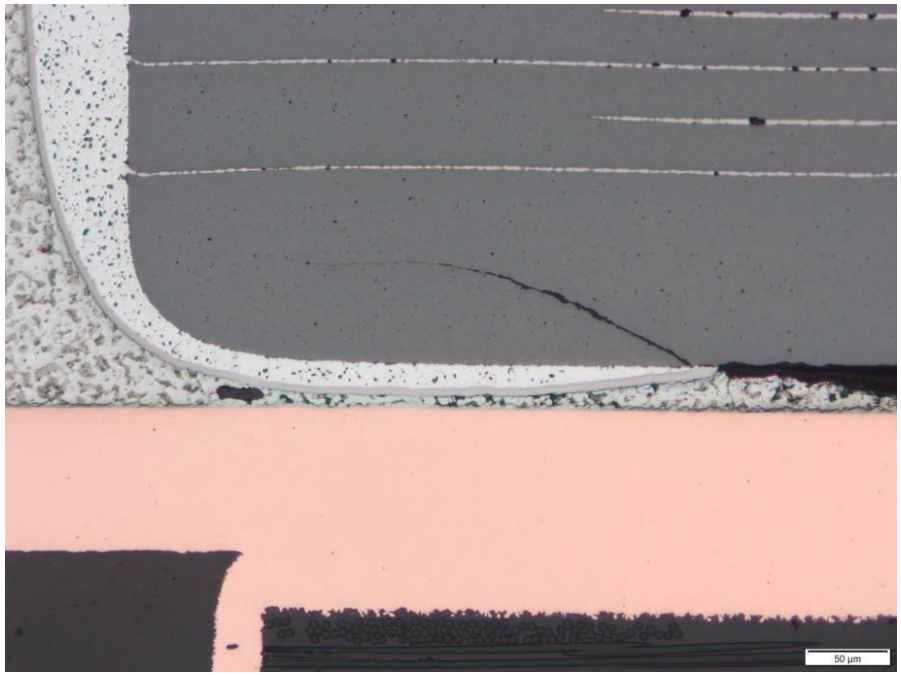


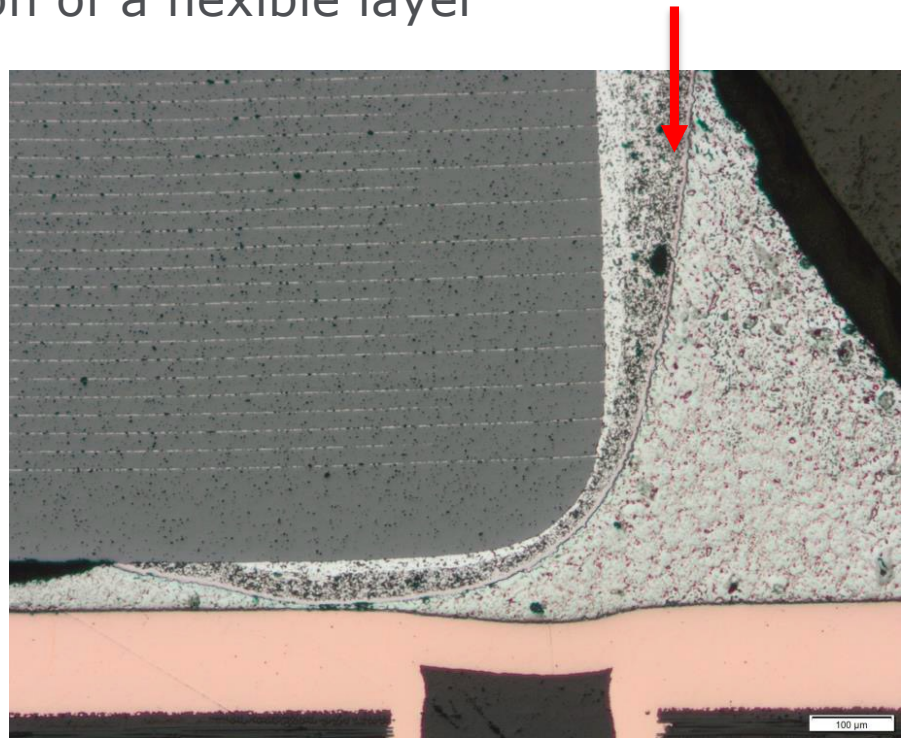


ESA-TECMSP-MO-022805

Electronic Assembly failure mechanisms

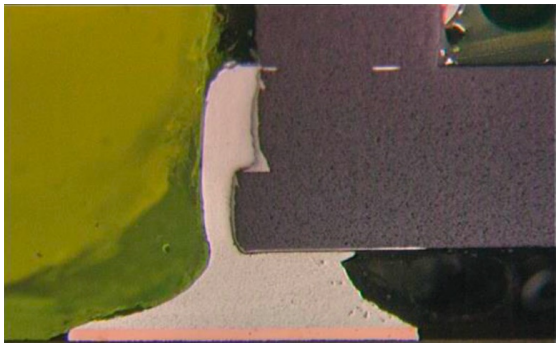
Thermal shock: Chip capacitors. Change of component built up to reduce thermal shocks and mechanical weakness. Addition of a flexible layer



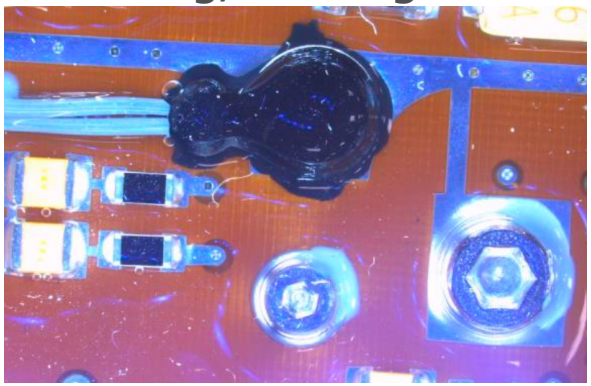


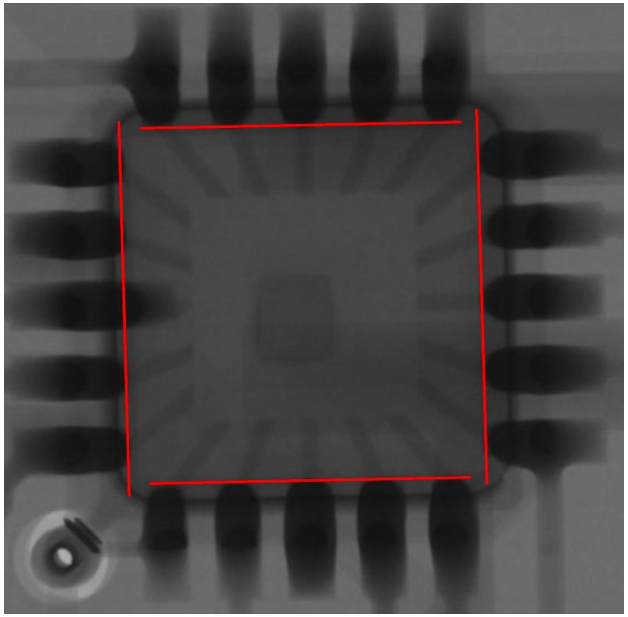
Electronic Assembly failure mechanisms

- Poor wetting due to excessive stand off



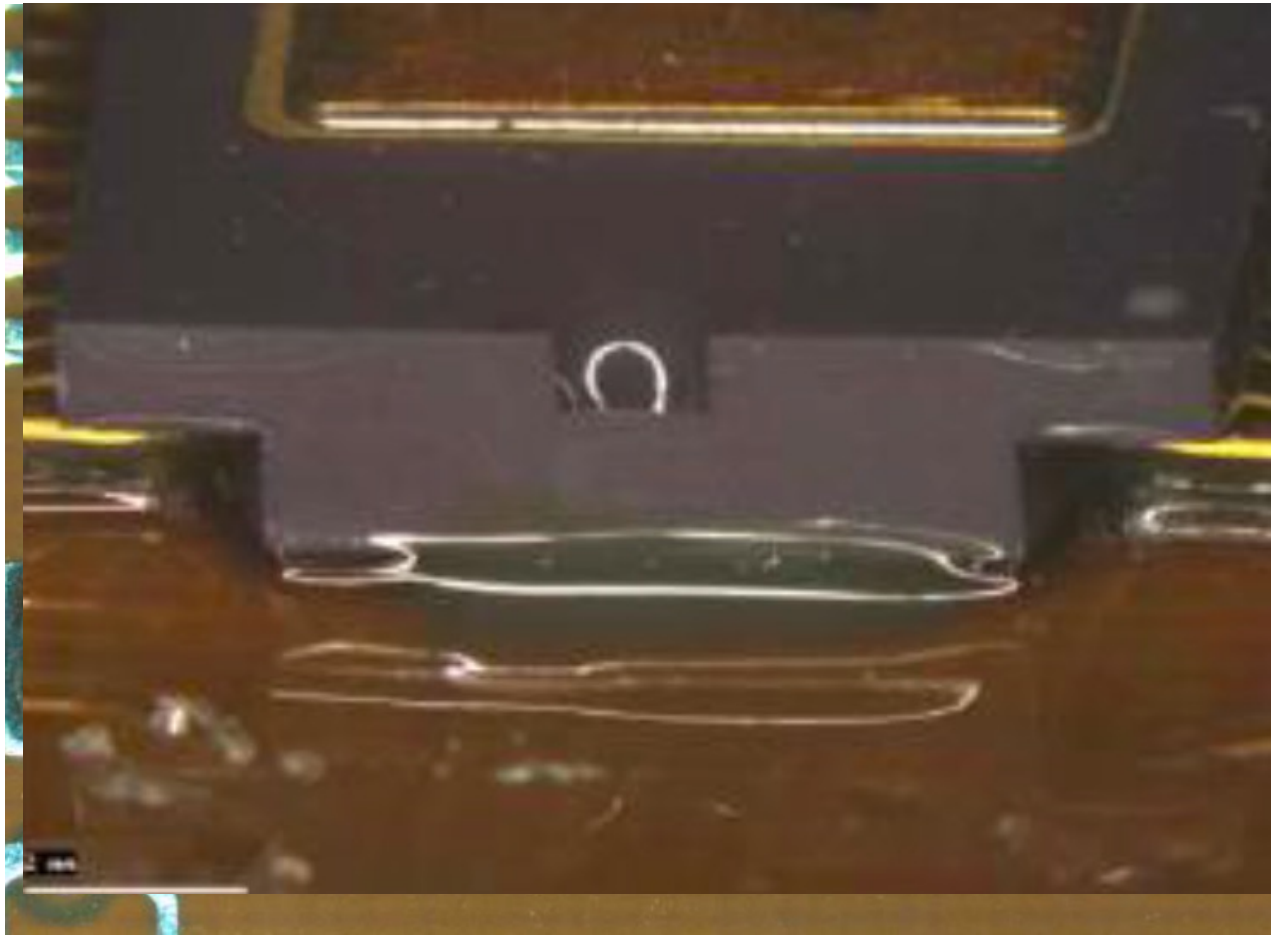
- Bonding/staking on fused tin lead



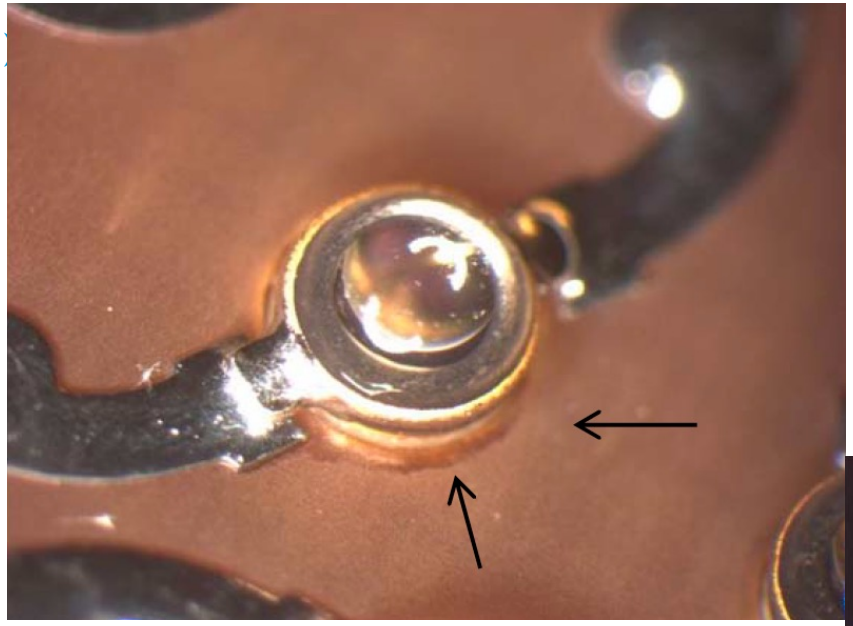


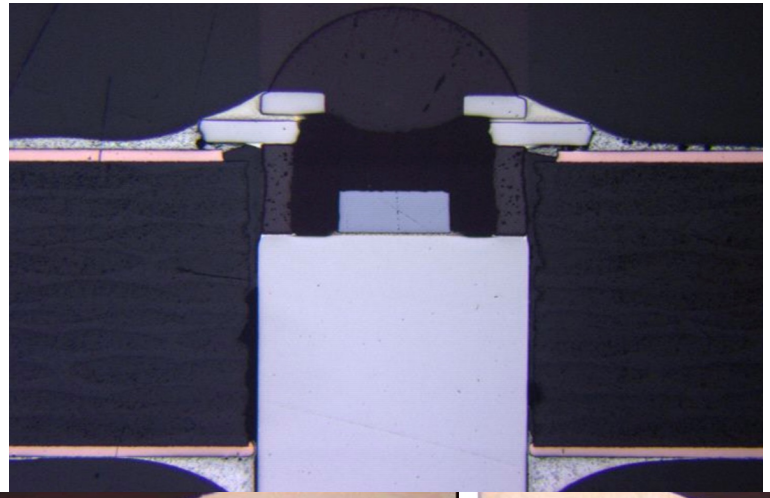
Electronic Assembly failure mechanisms

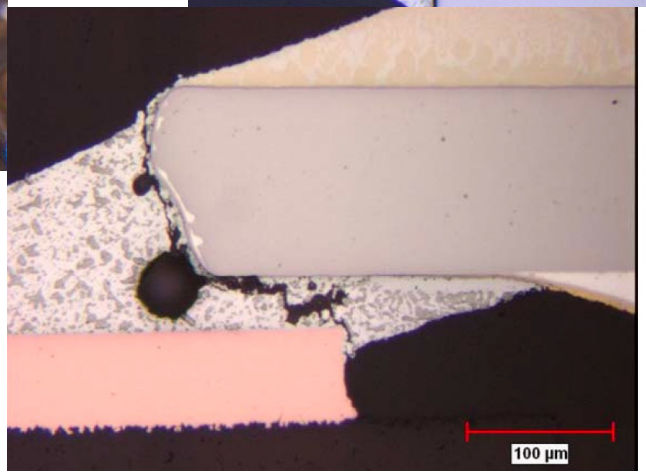
- Poor staking

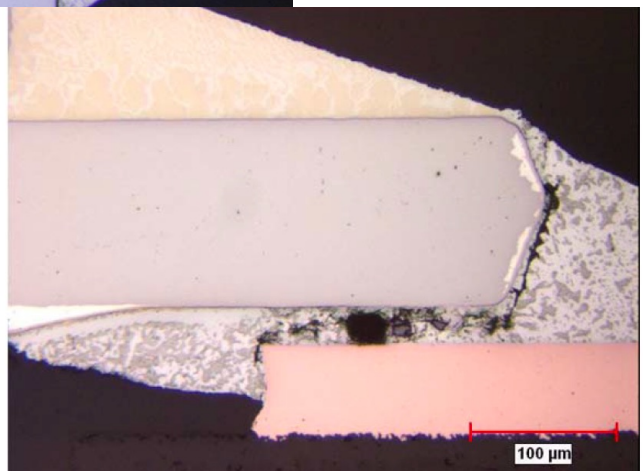


Electronic Assembly failure mechanisms



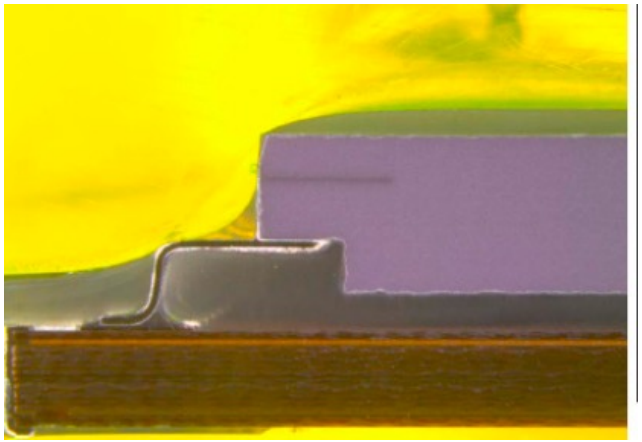


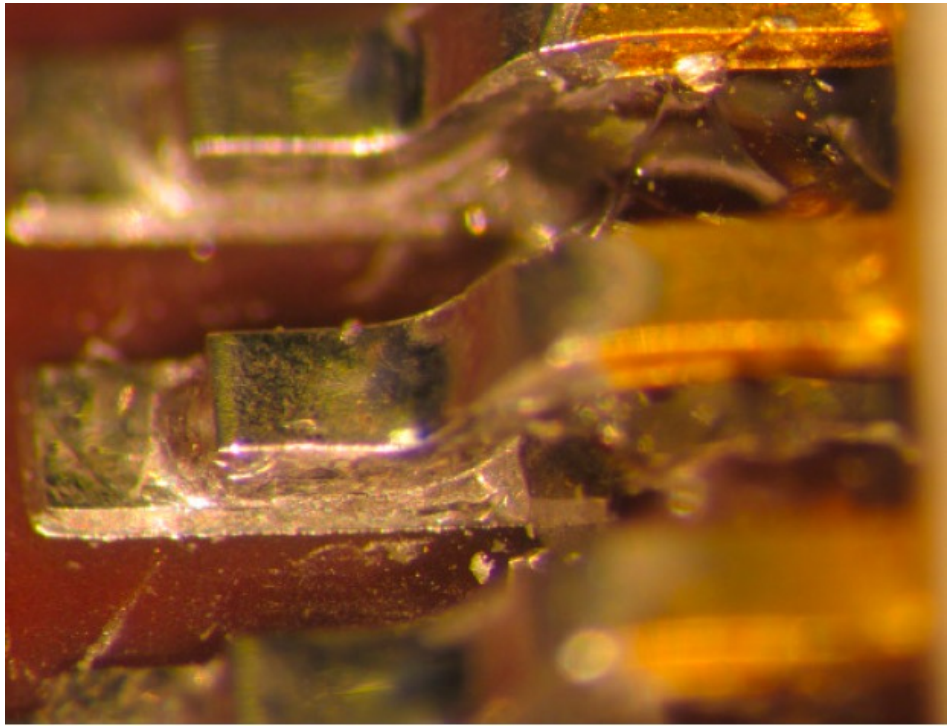




Electronic Assembly failure mechanisms

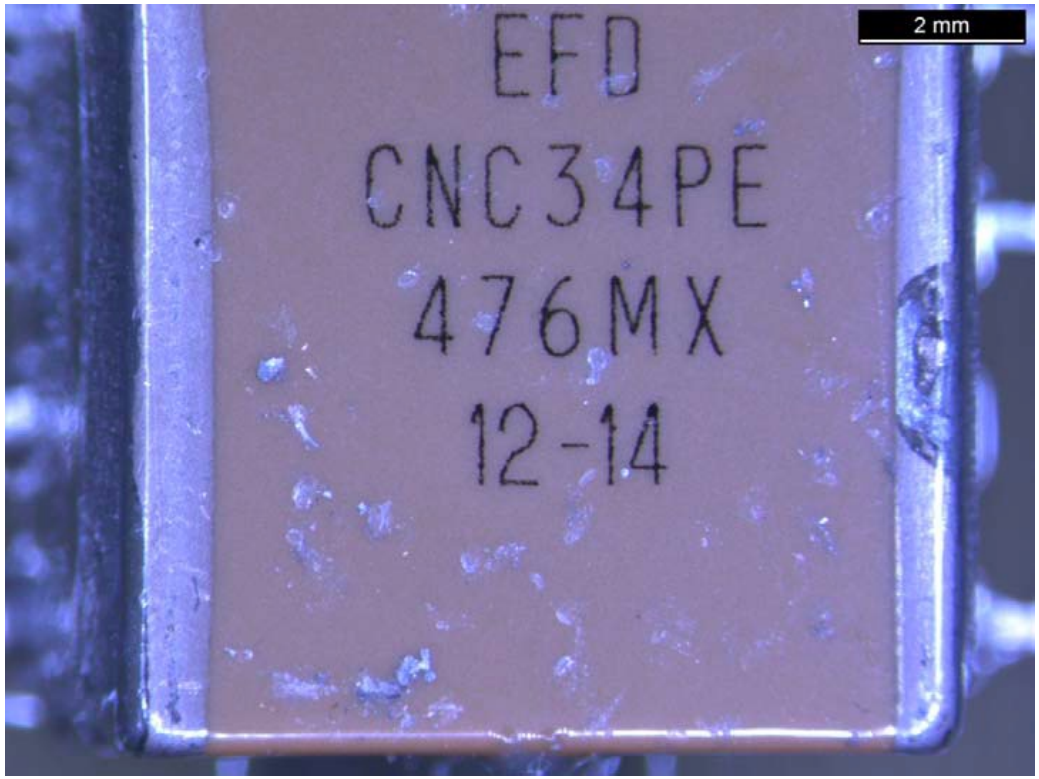
- Excess of conformal coating





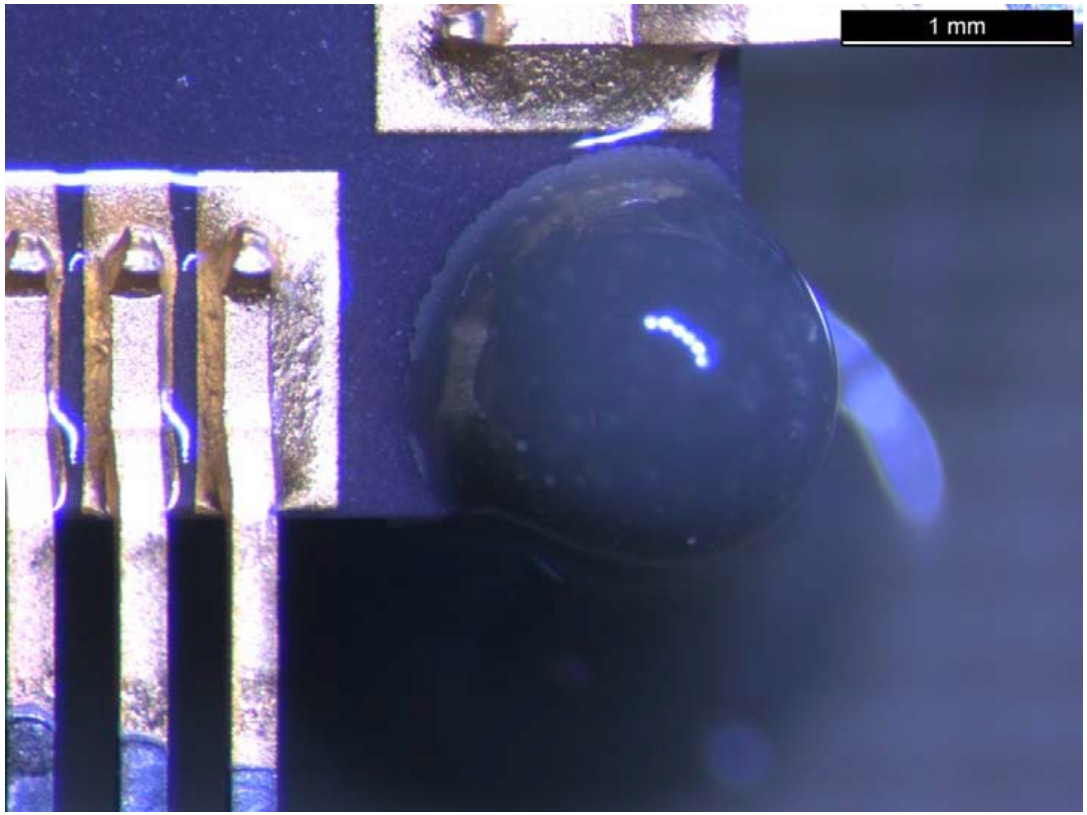
Electronic Assembly failure mechanisms

Contamination



Electronic Assembly failure mechanisms

Poor surface preparation



Electronic Assembly failure mechanisms

Nonconformance Report

NCR **Title** Anomalies during Vibration Test		
NC Item **Identification** Verification PCB	Sr-N°: 01	Drawing N° 11214-ASP-DD-10000B20
Next higher Assembly n.a.		Procedure N° TP 11214-1000_ASP_03 Issue 2
Subsystem n.a.	Model	Supplier n.a.
NC Observation Date: 13.09.12 Location: Diehl BGT Defence, Überlingen		NC detected during (Prod.-/Inspec. Step, Test, etc): Vibration Test

Description of Nonconformance

During Vibration Test, the following components left the PCB:

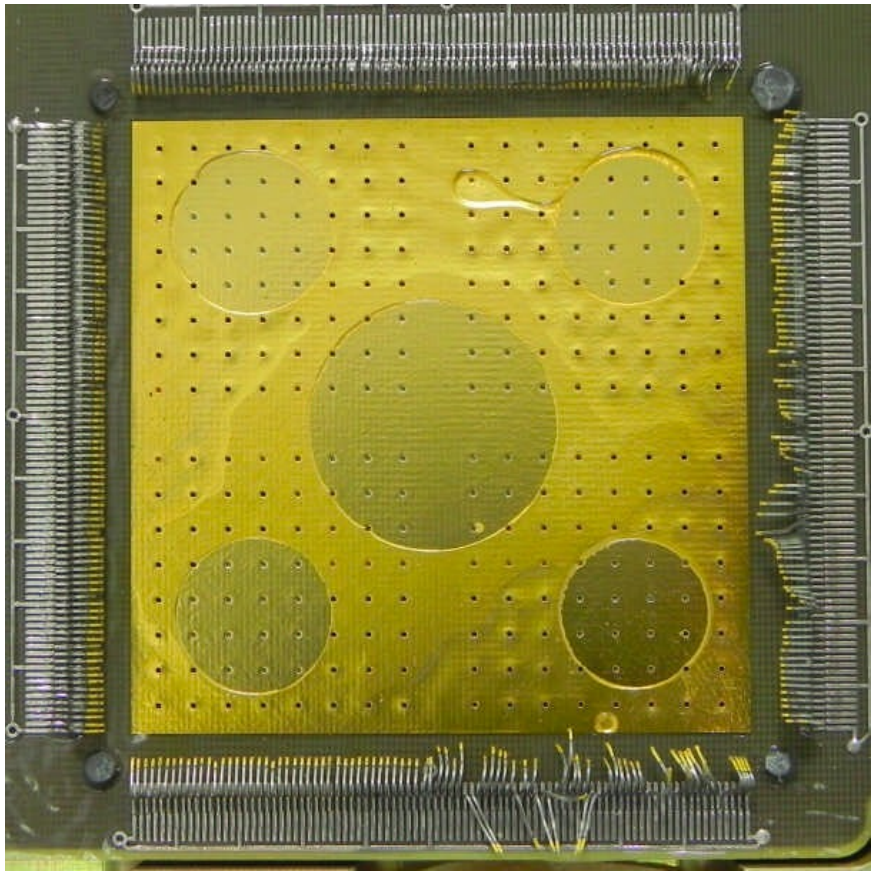
- All CNC34P, CNC53P, CNC56P and CDFP-28
- IC13 (1 of 3, CQFP-352)
- IC29 (1 of 3, CQFP-52)
- C125 (1 of 5, CTC21D)

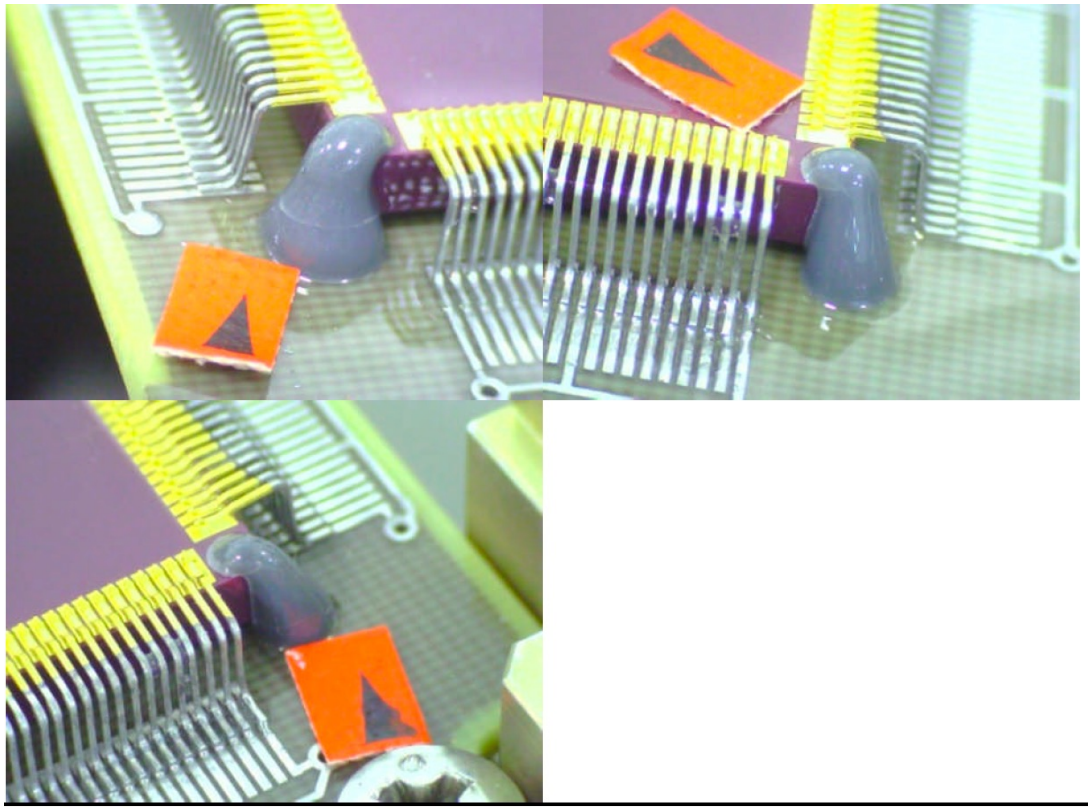
Some damages of adhesive were observed. Furthermore, some damages to other components, PCB and coating have been introduced by the components detached from the PCB. For details, refer to the following pages.

[redacted]

Internal NRB Dispositions **CNC capacitors:** Review bonding strategy and eventually update bonding procedure **CDFP-28:** Add adhesive to bond components to PCB	**Classification:** **Minor ❑ Major X** Verification

Electronic Assembly failure mechanisms

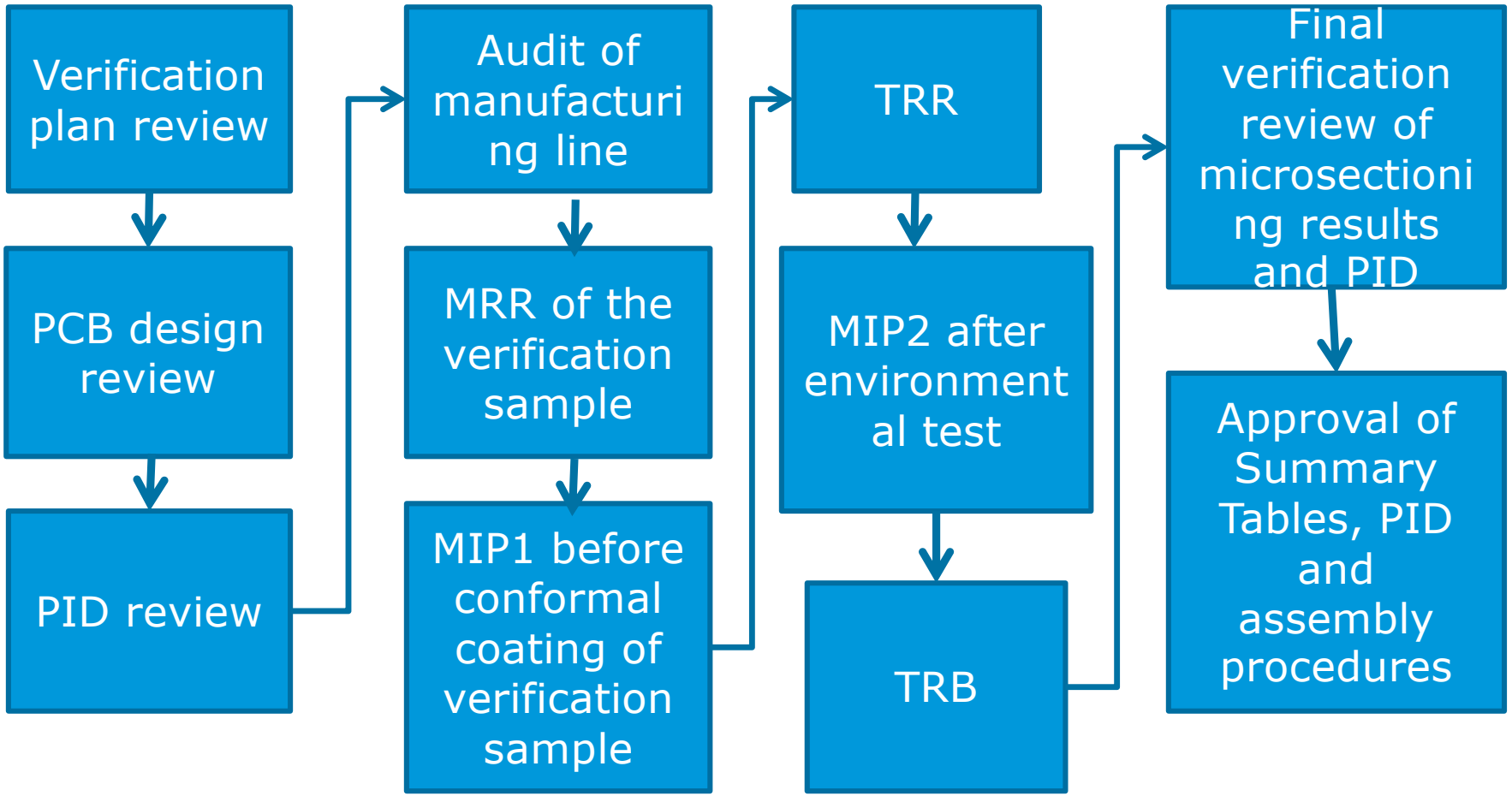




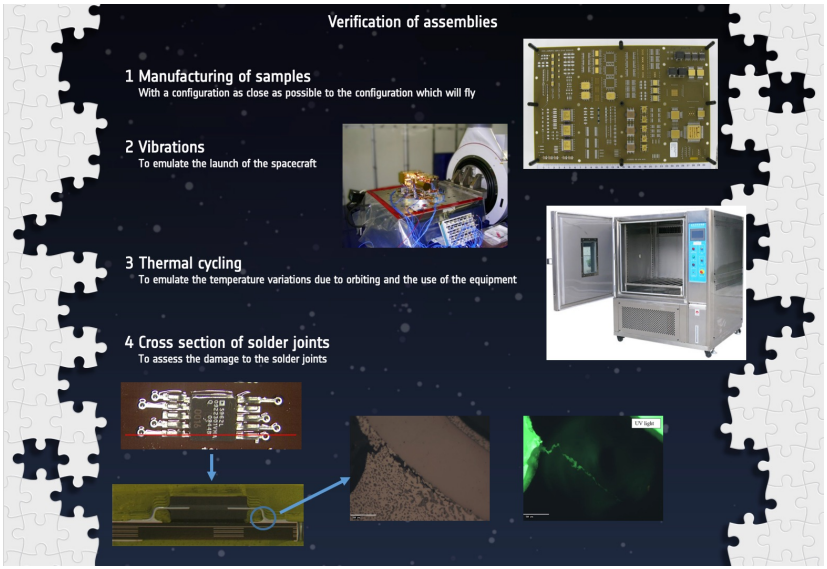
Assembly verification in compliance with the ECSS-Q-ST-70-08 and 38C

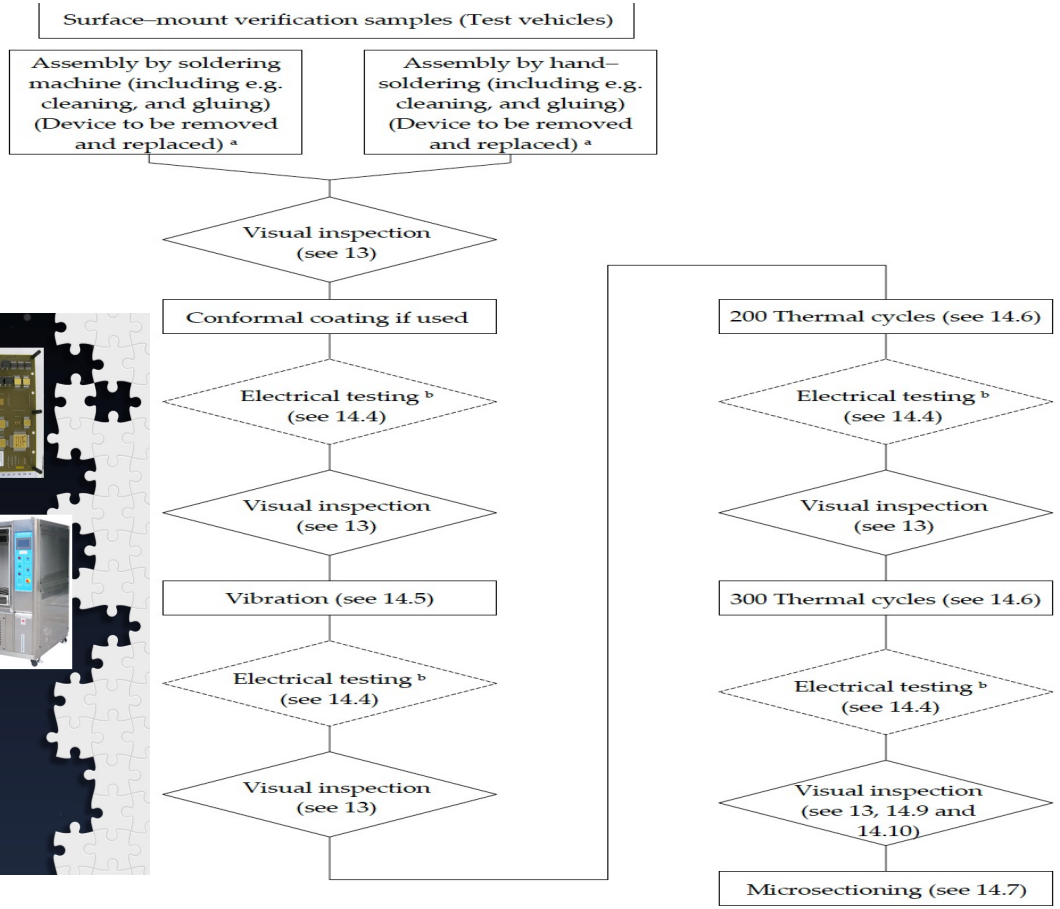
- Detect criticality of the assembly configuration
  - ✓ Design correction
  - ✓ Process correction
- Ensure that the assembly can withstand project environmental stresses
  - Space Rider (New requirementt due to re use of some equipments)
  - MTG (high vibration loads and Long Term Storage)
  - Metop SG (LTS and Long AIT testing- 1000 to 1500 On/Off during ground testing)
  - Launchers (reduced thermal stress due to short mission)

Assembly verification in compliance with the ECSS-Q-ST-70-38C



Assembly verification in compliance with the ECSS-Q-ST-70-38C





Assembly verification in compliance with the ECSS-Q-ST-70-38C

Around 60 companies ESA Approved for the assembly of electronic assemblies (list on escies).

Long process to be ESA Approved in compliance with the ECSS but ensure reduction of failure or increase reliability of the Electronic hardware

New challenges

- Re entry vehicules (Space rider)/ MSR (mechanical stress not limited at launch)
- COTS assembly
- Lead free assembly
- New Launcher generation

-3D printing of electronic hardware

- Integrated function in PCB (actually not much developped for space)
  - -Parts
  - -Thermal dissipation
  - -RF/Analog

-NeReduction of the cost of the assembly verification without impacting the reliability to keep European companies competitive

- Change in assembly verification process
- To use modelling to determine failure mode
- To developp an ageing model (NL against Engelmair or…)

- **Development of PCB and Electronic assembly harmonization plan**

New challenges

-To developp expertise in assembly domain in Industry

We need M&P engineers to provide technical support to their project

We need M&P engineers to participate to the new challenges

We need M&P enginners to provide technical support to manufacturing line

-To developp Cat 1 Instructor in Industry

To perform internal training in their own companies

-To developp tools such DMPL tools for which Assembly MPCB input could be treated off line by all parties and reduce the number of meetings

-Reduce the number of NCRs due to controled and well managed assembly line (Cost, delay,…)

-Participation of M&P to different step of a new product such as design review to verify assembly verification status

-Verify the assembly reliability by testing preferably after a technology development phace

-Maintain the list of ESA Approved Summary Tables

-Perform Assembly MPCB to demonstrate assembly verification

- Request to prime the thermal configuration of the equipment to calculate equivalent number of thermal cycles
- Calculate the ECSS equivalent number of thermal cycles to ensure compliance with your qualification
- Verify that the vibration levels of the project are covered by the assembly verification