PASSIVE COMPONENT EMBEDDING IN PRINTED CIRCUIT BOARDS FOR SPACE APPLICATIONS

2ND SPACE PASSIVE COMPONENT DAYS (SPCD), INTERNATIONAL SYMPOSIUM, 12-14 OCTOBER 2016, ESA/ESTEC, NOORDWIJK, NL

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PROJECT GOAL

Investigate the suitability of embedding passive components in printed circuit boards for space applications

- Overview of available technologies for component embedding
- Assessment of the AT&S ECP® technology
- Evaluation of reliability of passive component embedding
- Realization of a functional demonstrator
- Procedures for procurement and qualification of PCBs with embedded components for space applications

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TECHNOLOGY OVERVIEW

Component embedding vs surface mounting

- 👍 Reduced volume and weight
- 👍 Increased electrical performance
- 👍 Larger design freedom
- 👍 Elimination of solder joints
- 👍 Better mechanical protection
- 👍 Lower board complexity = higher yield
- 👎 Additional design effort
- 👎 Longer time to market due to prototyping requirements
- 👎 Impossibility of rework or repair
- 👎 Reduction in yield and throughput of the printed circuit board with embedded components
- 👎 No existing qualification and procurement procedures

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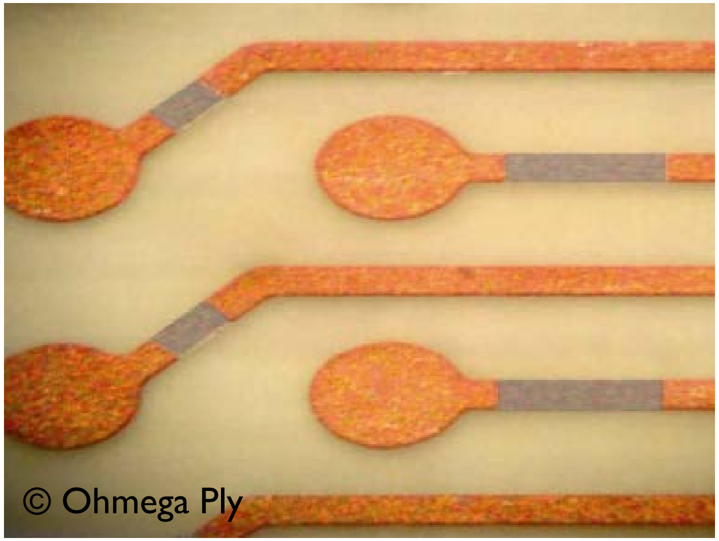
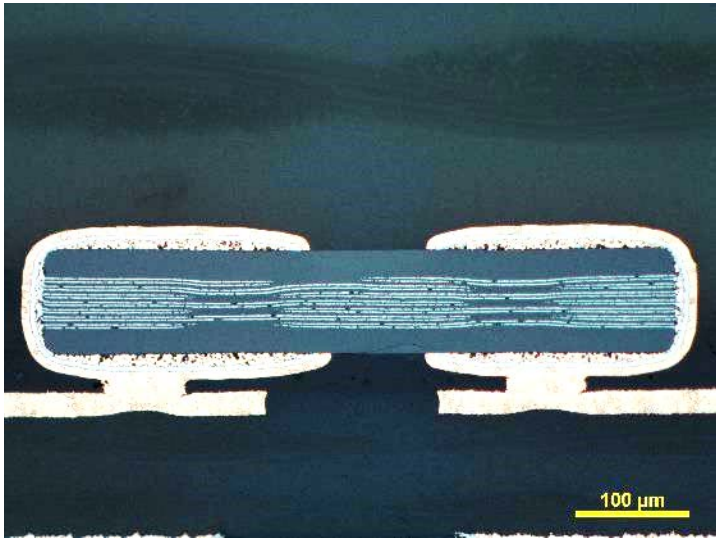
TECHNOLOGY OVERVIEW

Passive component embedding technology overview

- Creating passive components in-situ: "*formed passives*"
  - Printed thick film technology (👍 cost, manufacturability; 👎 tolerances)
  - Resistive and capacitive laminates (👍 performance; 👎 values, design)
- Embedding discrete passives into PCB: "*placed passives*"
  - (👍 miniaturization, values, performance; 👎 complex process)





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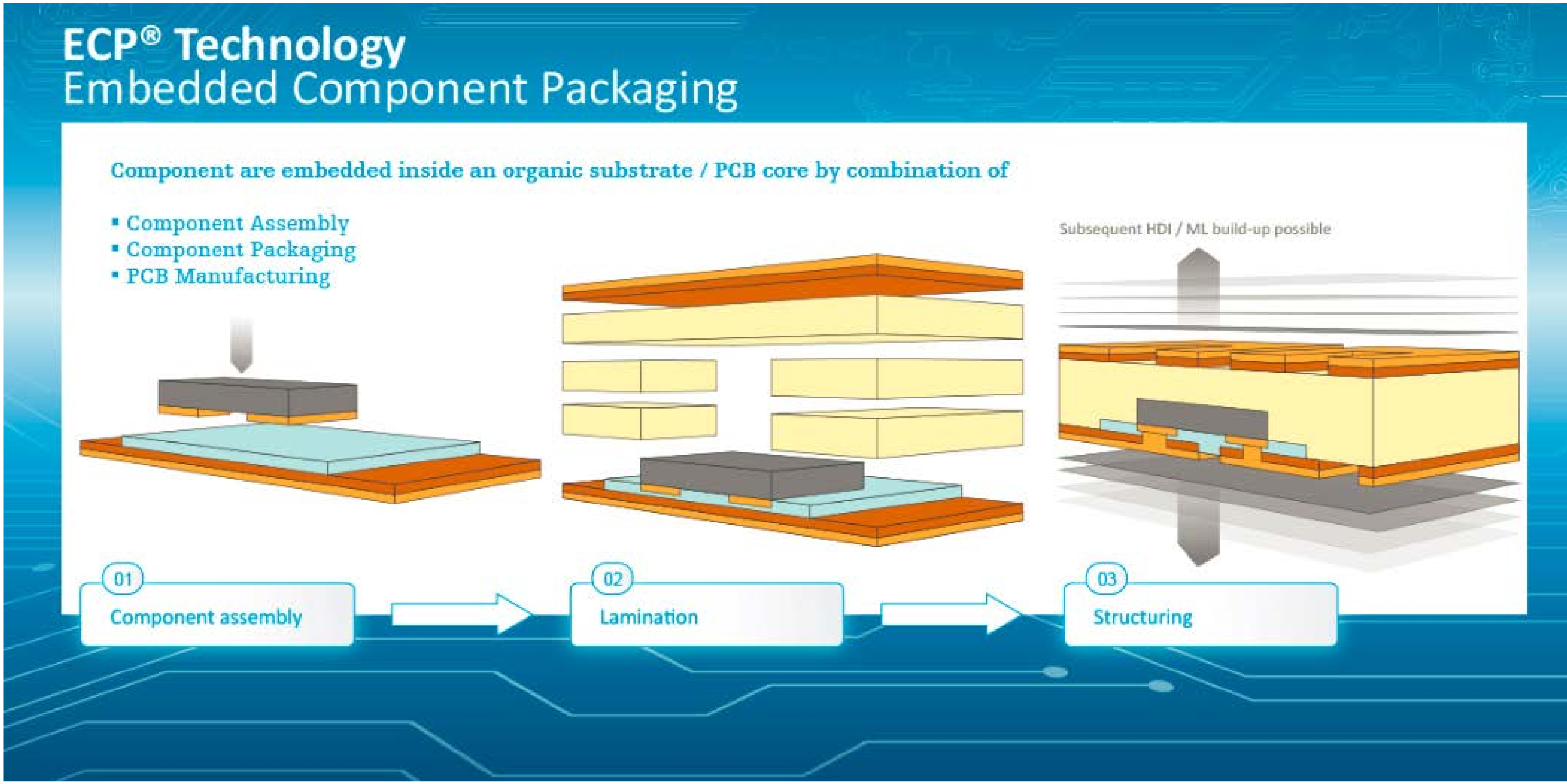
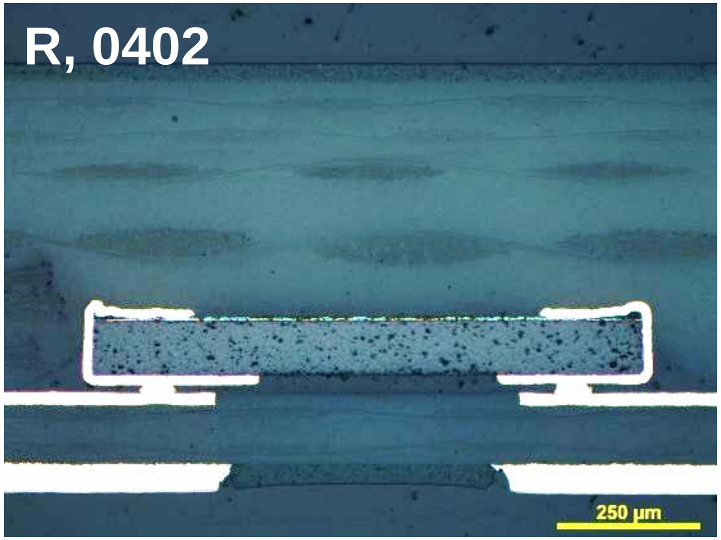
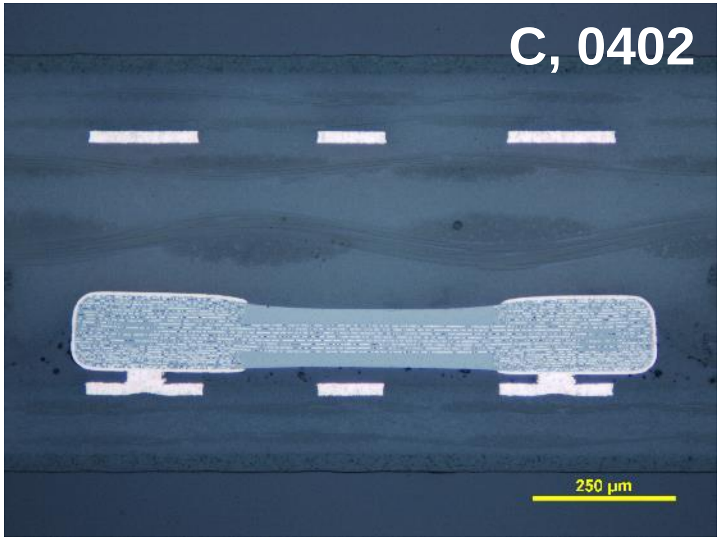
EMBEDDED COMPONENT PACKAGING TECHNOLOGY

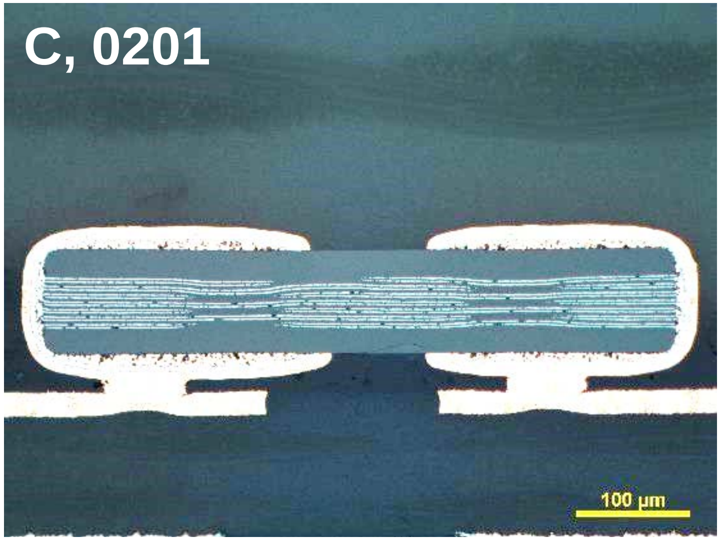


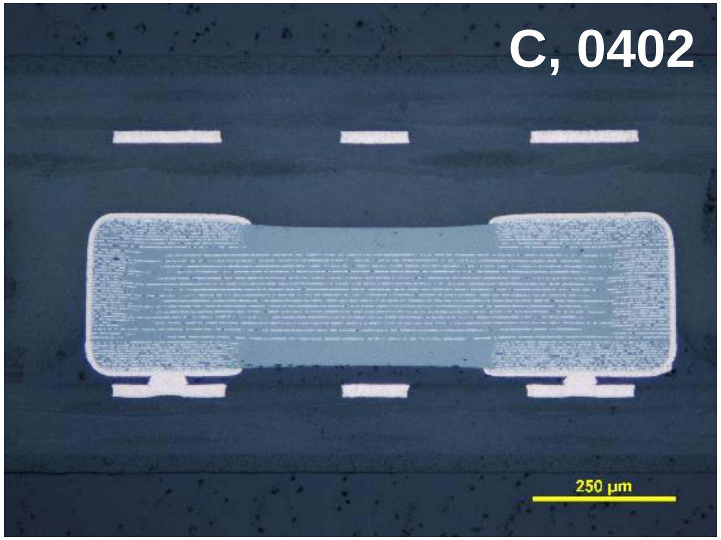
- Embedding of both active and passive components
- Embedded core can be integrated in various PCB build-ups
- Component thickness and pad metallization to be adapted

EMBEDDED COMPONENT PACKAGING TECHNOLOGY









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EMBEDDED COMPONENT PACKAGING TECHNOLOGY

Available components for embedding

- Resistors (Panasonic, KOA Speer)

Size	Voltage (V)	Power (W)	Tolerance	Operating temperature	TCR
01005	*??*	*0.03*	*1 %, 5 %*	*-55 °C to 125 °C*	*200-300 ppm/°C*
0201	25	0.05	1 %, 5 %	-55 °C to 125 °C	200-300 ppm/°C
0402	50	0.06 – 0.1	1 %, 5 %	-55 °C to 125 °C	100-200 ppm/°C

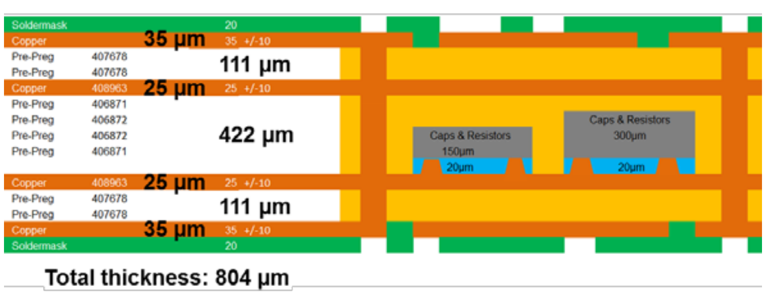
- Capacitors (AVX, Murata, TDK)

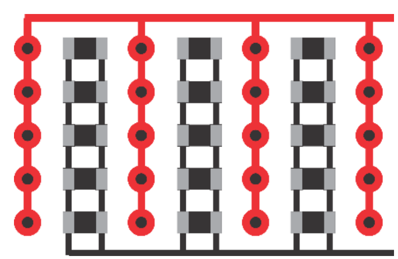
Type	Size	Range	Voltage (V)	Tolerance	Thickness (µm)	TCC
C0G	0201	1 – 100 pF	10 – 50	5 %	150 – 330	30 ppm/°C
X5R	0201	0.1 – 10 nF	2.5 – 50	10 – 20 %	110 – 330	±15 %
X5R	0402	1 – 1000 nF	2.5 – 50	10 – 20 %	110 – 330	±15 %
X7R	0201	0.1 – 10 nF	2.5 – 25	10 %	150 – 330	±15 %
X7R	0402	1 – 10 nF	6.3 – 25	10 %	150 – 330	±15 %

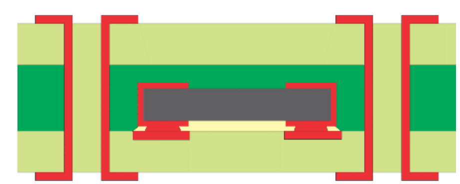
TEST BOARD

Board Type I

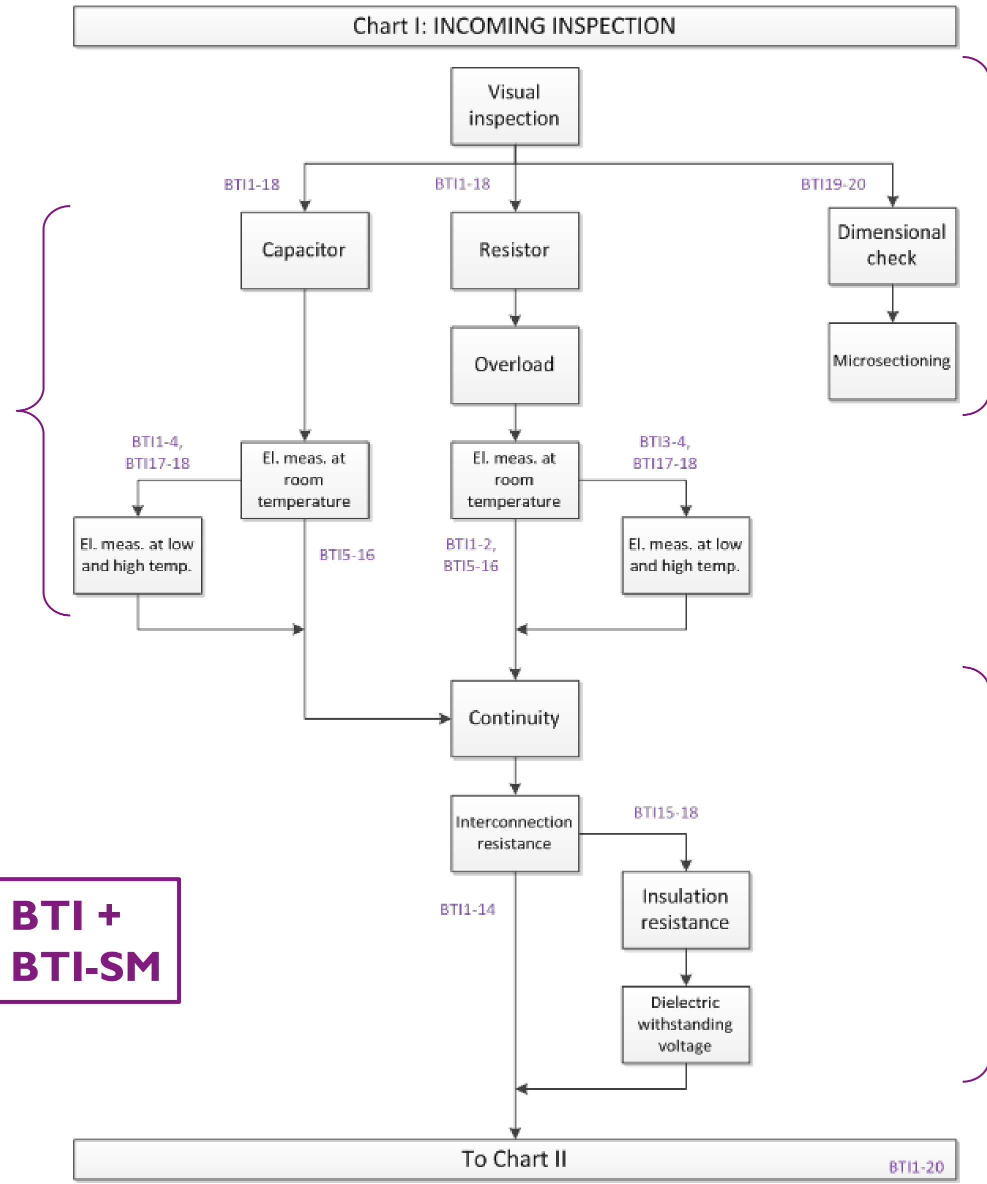
- Board level reliability and component characterization
- Components selection based on availability and BTII
  - 33 Ω, 0402 / 10 kΩ, 0402 / 10 kΩ, 0201 / 1 MΩ, 0201 from Panasonic
  - Murata 10 pF & 100 pF (0201, 150 µm), AVX 10 nF (0402, 300 µm, 16 V to 50 V and 150 µm, 6.3 V) and Murata 100 nF (150 µm, 6.3 V)
- Test structures
  - Probe pad test structure for electrical measurement of components
  - Disk, comb and tree test pattern for interlayer and intralayer insulation
  - Daisy chains (0-ohm resistors) for continuity and interconnect resistance
  - Interconnect stress test (IST) patterns on separate coupon







EVALUATION TEST PLAN



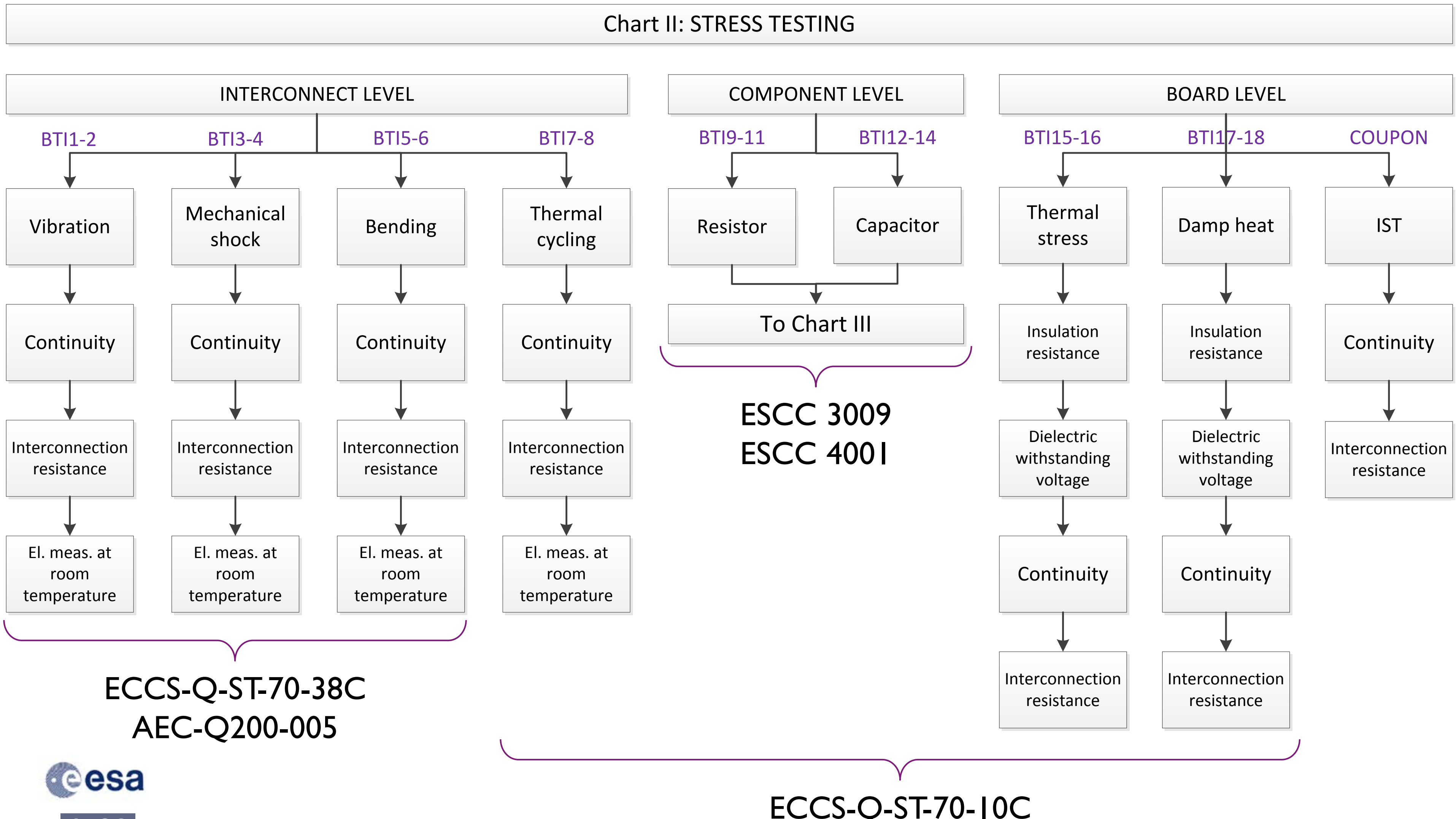
ESCC 3009
ESCC 4001

ECCS-Q-ST-70-10C
ESCC 3009 & 4001

ECCS-Q-ST-70-10C

20x BTI +
10x BTI-SM

EVALUATION TEST PLAN



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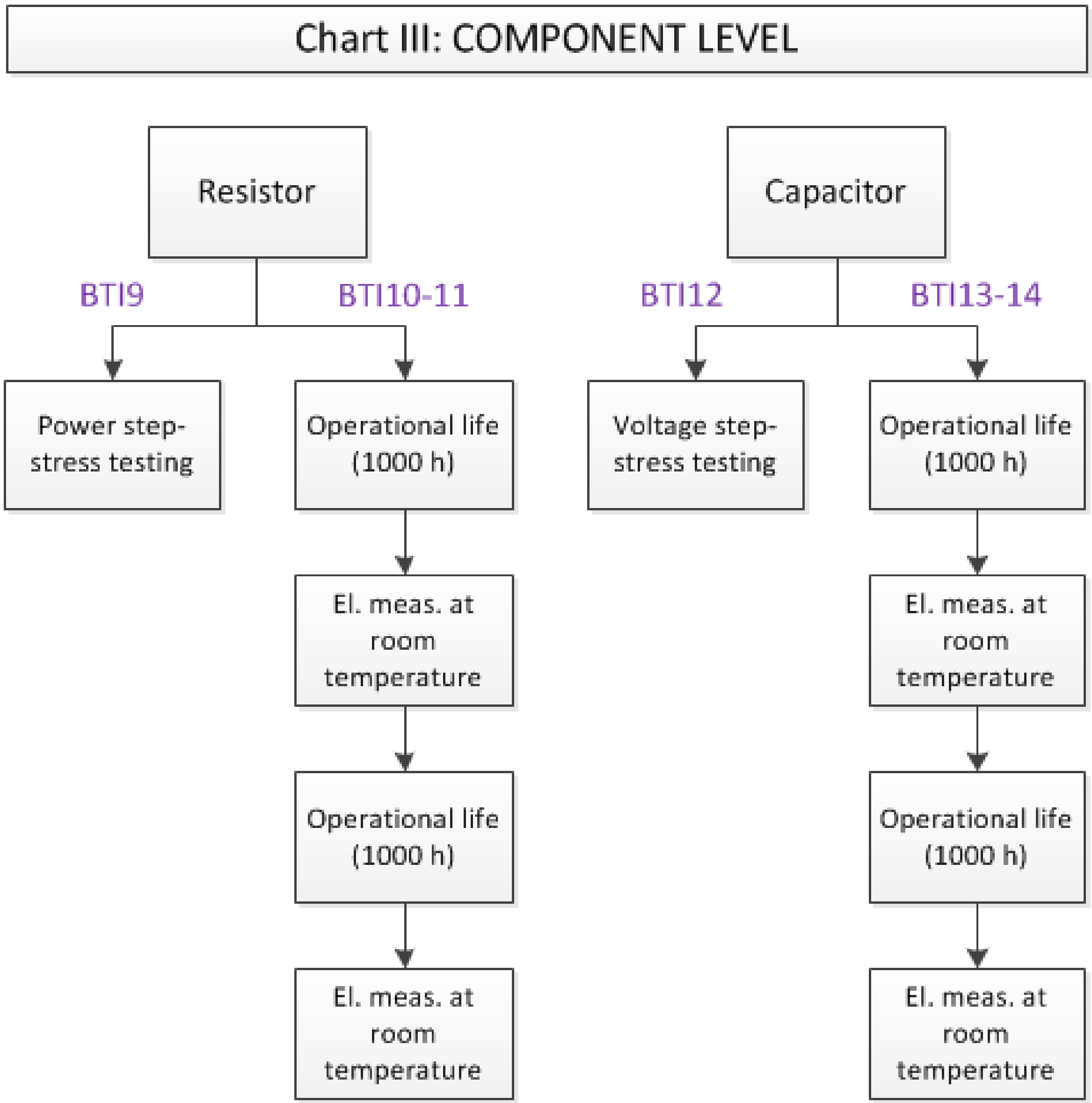
EVALUATION TEST PLAN



TEST RESULTS

Test	Type	Resistor	Capacitor	0-ohm resistor	Board
Component values	Embedded				n.a.
	Surface-mount				n.a.
Overload	Embedded		n.a.	n.a.	n.a.
	Surface-mount		n.a.	n.a.	n.a.
Board insulation resistance	Embedded	n.a.	n.a.	n.a.	
Board dielectric withstanding voltage	Embedded	n.a.	n.a.	n.a.	
Vibration	Embedded				n.a.
	Surface-mount				n.a.
Mechanical shock	Embedded				n.a.
	Surface-mount				n.a.
Bending (AEC-Q200)	Embedded				n.a.
Thermal cycling	Embedded				n.a.
Thermal stress	Embedded			n.a.	
Damp heat	Embedded			n.a.	
IST	Embedded	n.a.	n.a.		n.a.
Operating life	Embedded			n.a.	n.a.
	Surface-mount			n.a.	n.a.

TEST RESULTS

Component performance

- Resistors are within spec for 5 % tolerance, outside spec for 1 % tolerance
- Capacitors are within spec for capacitance, loss factor, insulation resistance and voltage proof testing
- Resistor operating life time (2000 hours, 70 °C with power cycling)
  - 0402 embedded resistors perform slightly worse than SMT resistors
  - 0201 embedded resistors started failing after 512 hours
- Capacitor operating life time (2000 hours, at 85 °C and 2x V_R)
  - Decrease in capacitance is larger for the embedded components compared to their surface-mount equivalents
  - X5R capacitors out of spec after 1000 hours of testing

More detailed test results were presented at EMPS-7, Portsmouth, UK, on 13 and 14 April 2016 (http://emps.port.ac.uk/)

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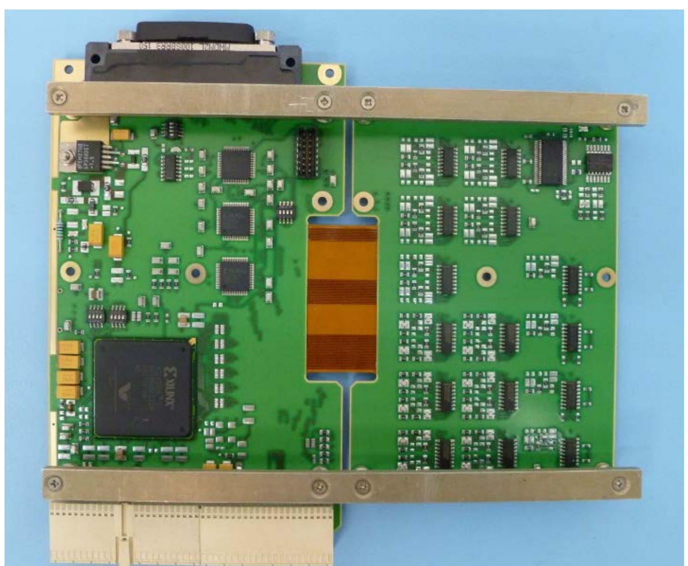
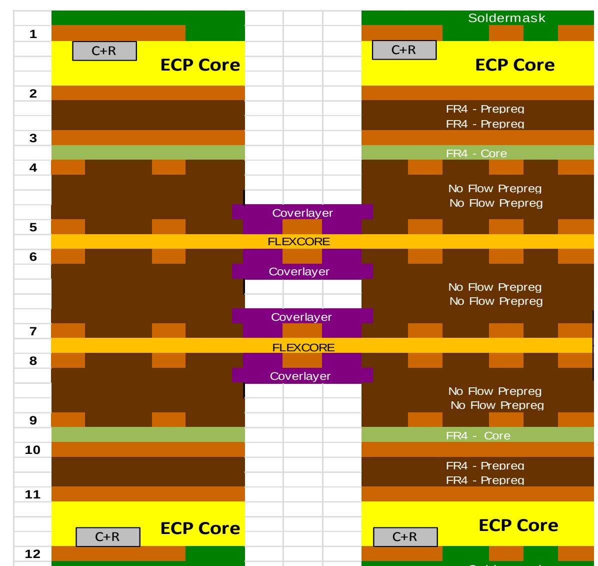
FUNCTIONAL DEMONSTRATOR

Spacecraft Interface Module (SIM)

- Proven flight board developed and tested in-house at QinetiQ Space for various missions (IXV, Proba-2 and Proba-V)
- Redesigned for the use of embedded passives by AT&S
  - Layout and dimensions of the board are not changed
- Twelve layer rigid-flex construction with two embedded cores





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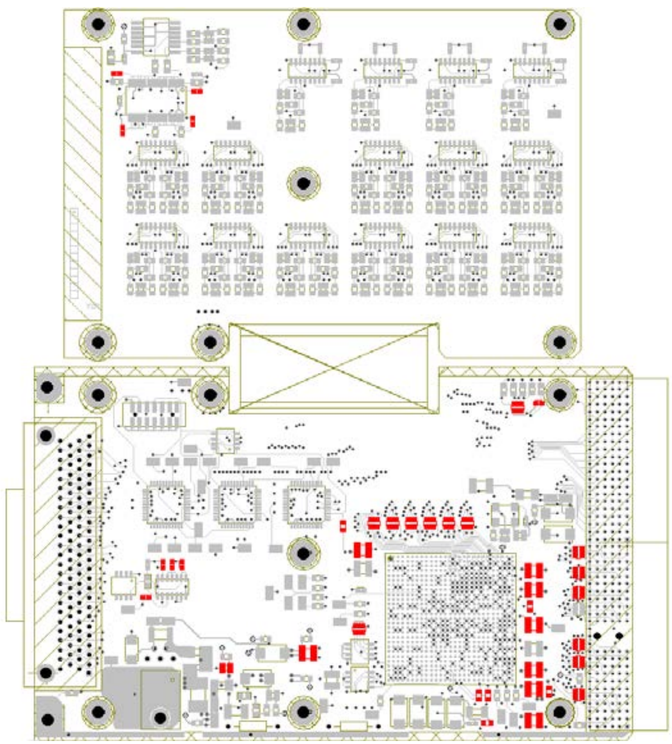
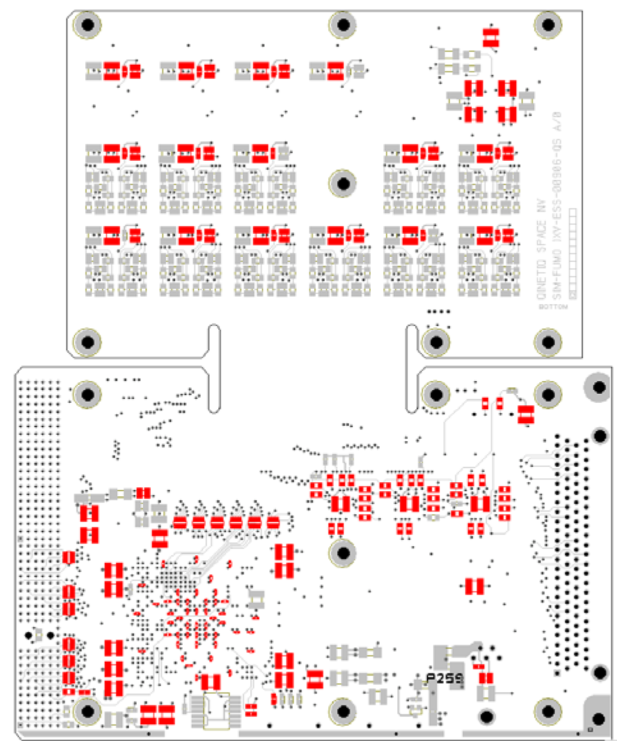
FUNCTIONAL DEMONSTRATOR

Test results

- Initial electrical tests, FPGA tests and functional tests passed
- Performance is on par with the standard SIM-FUMO board, despite non-optimized layout





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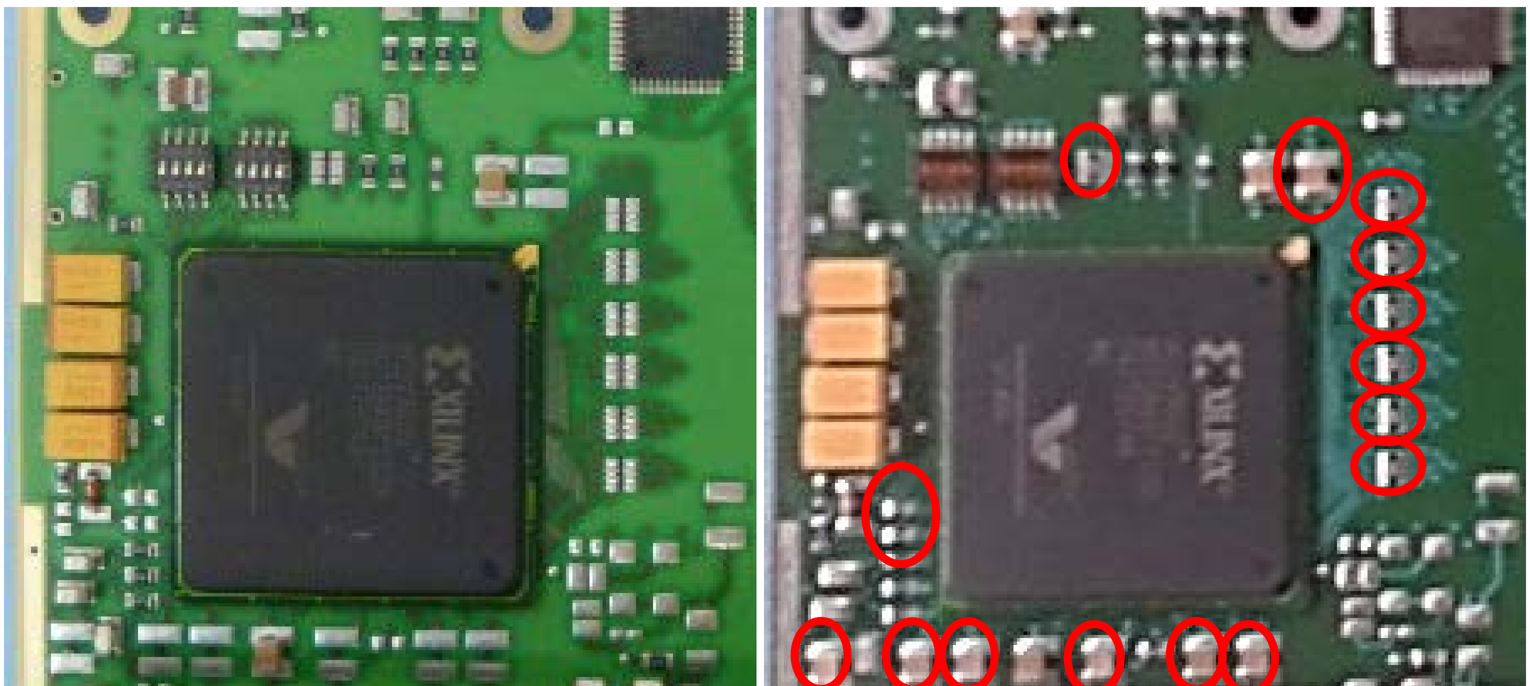
FUNCTIONAL DEMONSTRATOR

Embedded component area gain

- 44% of all capacitors and 20% of resistors replaced
  - Smaller size with lower voltage and power rating used
  - Proper redesign would possibly reduce board size by factor of 2



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SUMMARY

Status of passive component embedding

- Performance of embedding technology is at high level
  - Board Type II performed on par with its SMT counterpart
  - No failure observed in interconnection to component (except for IST)
- Embedding has minor impact on components
  - Component performance is adequate, except for 0201 resistors
  - Operating life time does not match space requirements
- Available components are limitation for space applications
  - Range of available values is limited, no European supply chain, voltage and temperature ratings not sufficient for derating
  - Qualification testing and lot screening need to be upgraded to ESCC requirements and better matched with embedded technology
- General considerations
  - Testing of PCBs with embedded component is challenging
  - No automated design flow for space PCBs with design rule checks
  - No repair possible

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