EMBEDDED PASSIVE COMPONENTS: A WAY TO MINIATURIZATION

TRP CONTRACT NO. 400010974/13/NL/SFe

COORDINATED FINAL PRESENTATION DAYS
21-22 NOVEMBER 2016, ESA/ESTEC, NOORDWIJK, NL

MAARTEN CAUWE¹, GERHARD SCHMID², STEVEN DE CUYPER³, DENIS LACOMBE⁴

1. Center for Microsystems Technology, IMEC, Zwijnaarde, Belgium, Maarten.Cauwe@imec.be
2. AT&S, Leoben, Austria
3. QinetiQ Space, Kruibeke, Belgium
4. ESA (TEC-QTC), ESTEC, Noordwijk, The Netherlands
CONTENTS

▸ INTRODUCTION
▸ PROJECT GOAL
▸ TECHNOLOGY OVERVIEW
▸ ECP TECHNOLOGY
▸ FUNCTIONAL DEMONSTRATOR
▸ EVALUATION TEST PLAN
▸ SUMMARY AND OUTLOOK
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
- Impossibility of rework or repair
- Reduction in PCB yield and throughput
- No existing qualification and procurement procedures
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
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)
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

R, 0402

C, 0402

C, 0201

C, 0402
Available components for embedding

- Resistors (Panasonic, KOA Speer)

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

- Capacitors (AVX, Murata, TDK)

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Range</th>
<th>Voltage (V)</th>
<th>Tolerance</th>
<th>Thickness (µm)</th>
<th>TCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0G</td>
<td>0201</td>
<td>1 – 100 pF</td>
<td>10 – 50</td>
<td>5 %</td>
<td>150 – 330</td>
<td>30 ppm/°C</td>
</tr>
<tr>
<td>X5R</td>
<td>0201</td>
<td>0.1 – 10 nF</td>
<td>2.5 – 50</td>
<td>10 – 20 %</td>
<td>110 – 330</td>
<td>±15 %</td>
</tr>
<tr>
<td>X5R</td>
<td>0402</td>
<td>1 – 1000 nF</td>
<td>2.5 – 50</td>
<td>10 – 20 %</td>
<td>110 – 330</td>
<td>±15 %</td>
</tr>
<tr>
<td>X7R</td>
<td>0201</td>
<td>0.1 – 10 nF</td>
<td>2.5 – 25</td>
<td>10 %</td>
<td>150 – 330</td>
<td>±15 %</td>
</tr>
<tr>
<td>X7R</td>
<td>0402</td>
<td>1 – 10 nF</td>
<td>6.3 – 25</td>
<td>10 %</td>
<td>150 – 330</td>
<td>±15 %</td>
</tr>
</tbody>
</table>
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
Spacecraft Interface Module (SIM)

- Board was manufactured “first time right”
- Initial electrical tests, FPGA tests and functional tests passed
- Performance is on par with the standard SIM-FUMO board, despite non-optimized layout
FUNCTIONAL DEMONSTRATOR

Embedded component area gain
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
EVALUATION TEST PLAN

Chart I: INCOMING INSPECTION

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

ESCC 3009
ESCC 4001

FOUR-LAYER TEST BOARD

AT&S
QinetiQ Space
imec

© IMEC 2016
CFPDS 2016 – 21-22/11/2016, ESTEC, NOORDWIJK, NL- M. CAUWE, G. SCHMID, S. DE CUYPER

© IMEC 2016
CFPDS 2016 – 21-22/11/2016, ESTEC, NOORDWIJK, NL- M. CAUWE, G. SCHMID, S. DE CUYPER
EVALUATION TEST PLAN

Chart II: STRESS TESTING

**INTERCONNECT LEVEL**
- BTI1-2: Vibration, Continuity, Interconnection resistance, El. meas. at room temperature
- BTI3-4: Mechanical shock, Continuity, Interconnection resistance, El. meas. at room temperature
- BTI5-6: Bending, Continuity, Interconnection resistance, El. meas. at room temperature
- BTI7-8: Thermal cycling, Continuity, Interconnection resistance, El. meas. at room temperature

**COMPONENT LEVEL**
- BTI9-11: Resistor, Insulation resistance
- BTI12-14: Capacitor, Insulation resistance

**BOARD LEVEL**
- BTI15-16: Thermal stress, Dielectric withstanding voltage, Continuity, Interconnection resistance
- BTI17-18: Damp heat, Dielectric withstanding voltage, Continuity, Interconnection resistance
- COUPON: IST, Continuity

**STRESS TESTING**
- El. meas. at room temperature

**Standards**
- ESCC 3009
- ESCC 4001

**ECCS-Q-ST-70-38C**
**AEC-Q200-005**

**ECCS-Q-ST-70-10C**
EVALUATION TEST PLAN

Chart III: COMPONENT LEVEL

Resistor

- BTI9
  - Power step-stress testing

- BTI10-11
  - Operational life (1000 h)
    - El. meas. at room temperature
      - Operational life (1000 h)
        - El. meas. at room temperature

Capacitor

- BTI12
  - Voltage step-stress testing

- BTI13-14
  - Operational life (1000 h)
    - El. meas. at room temperature
## TEST RESULTS

<table>
<thead>
<tr>
<th>Test</th>
<th>Type</th>
<th>Resistor</th>
<th>Capacitor</th>
<th>0-ohm resistor</th>
<th>Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component values</td>
<td>Embedded</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Surface-mount</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Overload</td>
<td>Embedded</td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Surface-mount</td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Board insulation resistance</td>
<td>Embedded</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Board dielectric withstanding voltage</td>
<td>Embedded</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Vibration</td>
<td>Embedded</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Surface-mount</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Mechanical shock</td>
<td>Embedded</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Surface-mount</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Bending (AEC-Q200)</td>
<td>Embedded</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Thermal cycling</td>
<td>Embedded</td>
<td></td>
<td></td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Thermal stress</td>
<td>Embedded</td>
<td></td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Damp heat</td>
<td>Embedded</td>
<td></td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>IST</td>
<td>Embedded</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
<td>n.a.</td>
</tr>
<tr>
<td>Operating life</td>
<td>Embedded</td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Surface-mount</td>
<td></td>
<td></td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
TEST RESULTS

Component performance

▸ After embedding, resistance is outside spec for resistors with a 1% tolerance

▸ All electrical parameters of capacitors remain within spec after embedding

▸ **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/)
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
WHAT’S NEXT?

Passive component embedding is in volume production for commercial applications
▸ Market size still small
▸ Automotive qualification is ongoing

PCESA project demonstrated potential for space applications and identified remaining challenges
▸ Component availability
▸ Design rules for embedding
▸ Qualification and procurement
OUTLOOK

Next steps

▸ Establish a European supply chain with an extension of the possible voltage, power and temperature ratings

▸ Implement an ESA qualified production scheme
  - Cooperation between AT&S and ESA qualified PCB supplier
  - Test methodology for PCBs with embedded components

▸ Define technology demonstrator with embedded passive components (GSTP IOD)
  - Verify design and procurement flow
  - Validate product reliability and performance

▸ Embedding active components
  - Diodes, MOSFETs
  - Small modules (PM, RF)
  - Power components (GAN)
  - More complex SIP modules
ASPIRE
INVENT
ACHIEVE