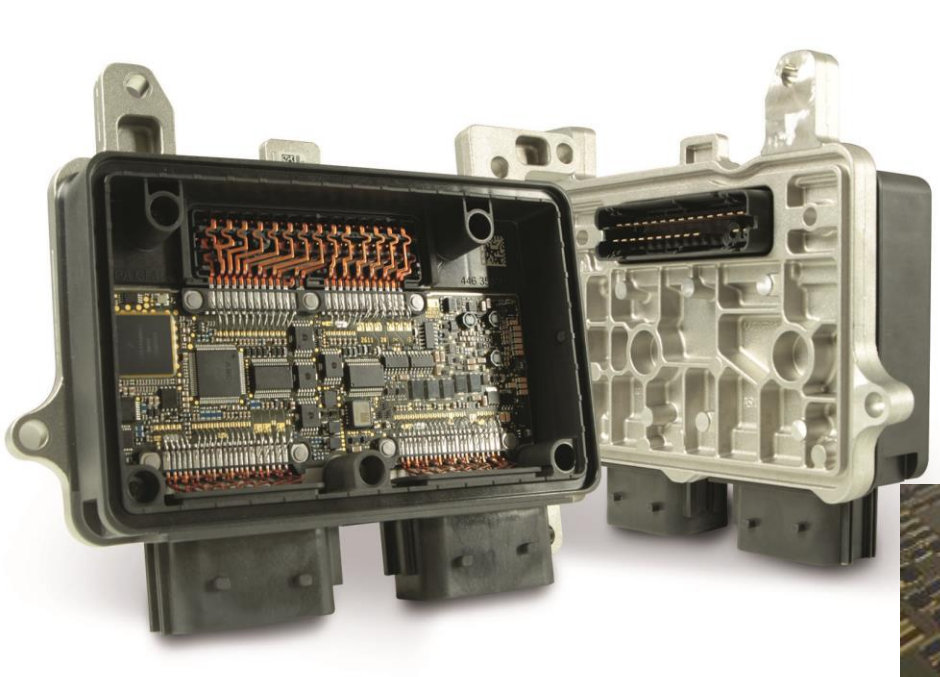
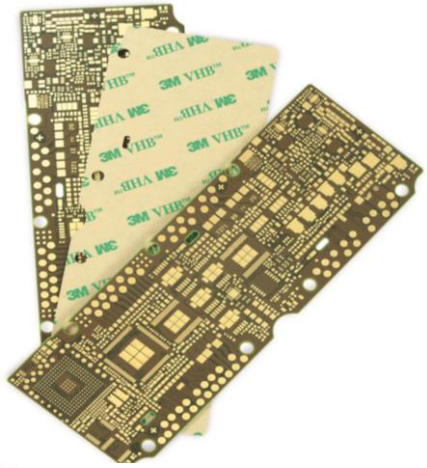
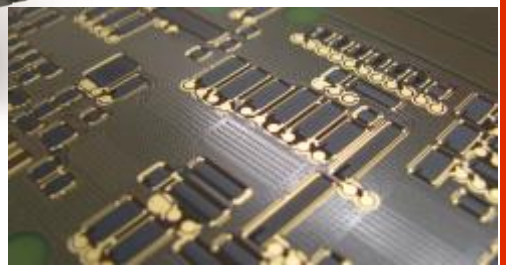
Webinar
High Performance PCB System







Miniaturisation – HDI – Thermal Management – Printed Polymer

Highly reliable printed circuit boards and devices in automotive electronics

based on an example of a High Performance PCB System

1. Miniaturisation

- HDI Technology
- Reliability – IST

2. EmbR – printed embedded resistors

- Performance - Tolerances
- Reliability

3. Thermal Management

- Thermal vias
- Heat Sink
- Thermal Simulation

4. Costs

- FR4 instead of Ceramic

Stefan Keller
Product Manager

High Performance PCB System

Market Requirements

Customer‘s objectives:

- PCB size and respectively the size of the unit needs to be reduced to one 1/4 in comparison to the currently running previous version
- Usage of complex and „small“ components
- High operating temperature (- 40 bis +140° C ambient temperature)
- Unchanged high long-term reliability, at least 10 years, 20.000 h (commercial vehicle application)
- Harsh environmental requirements e.g. vibration, mechanical shocks
- Cost effective - competitive

Requirements for PCB manufacturer:

- Competent team: technology, process development, quality management
- Project management
- Test equipment
- Investment confidence

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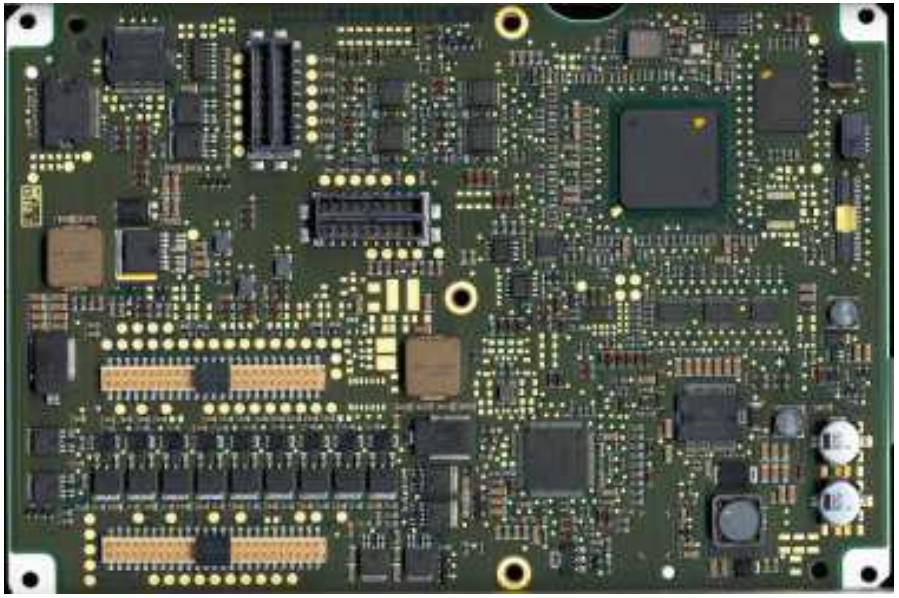
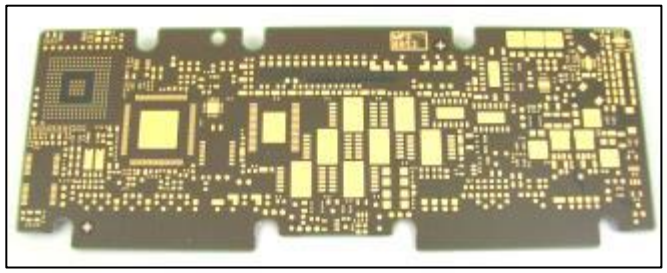
Miniaturisation



New PCB size: 1/4

1. Approach (temporary): LTCC – ceramic solution
   > works, but target only partially achieved – relatively expensive



50 x 140 mm

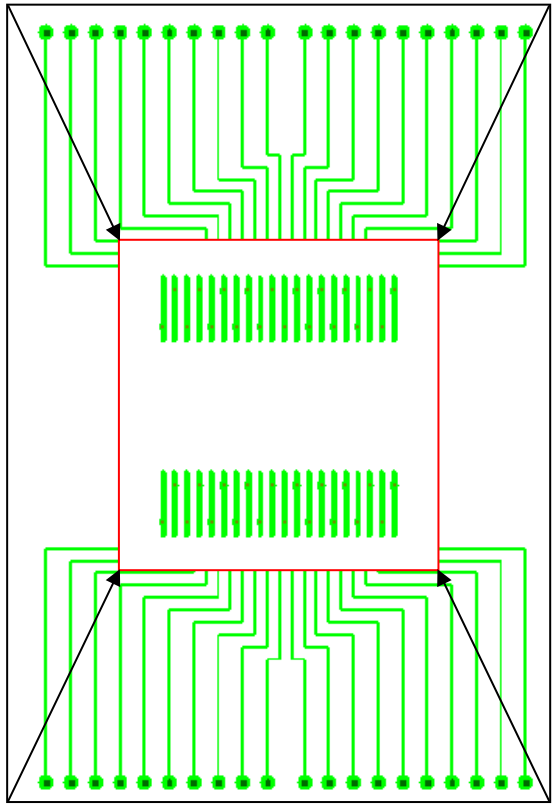
2. Approach: High Performance organic (FR4) - PCB System

Combination of HDI- and Printed Polymer Technology in connection with optimized thermal management

> Target achieved, production start at the beginning of 2015

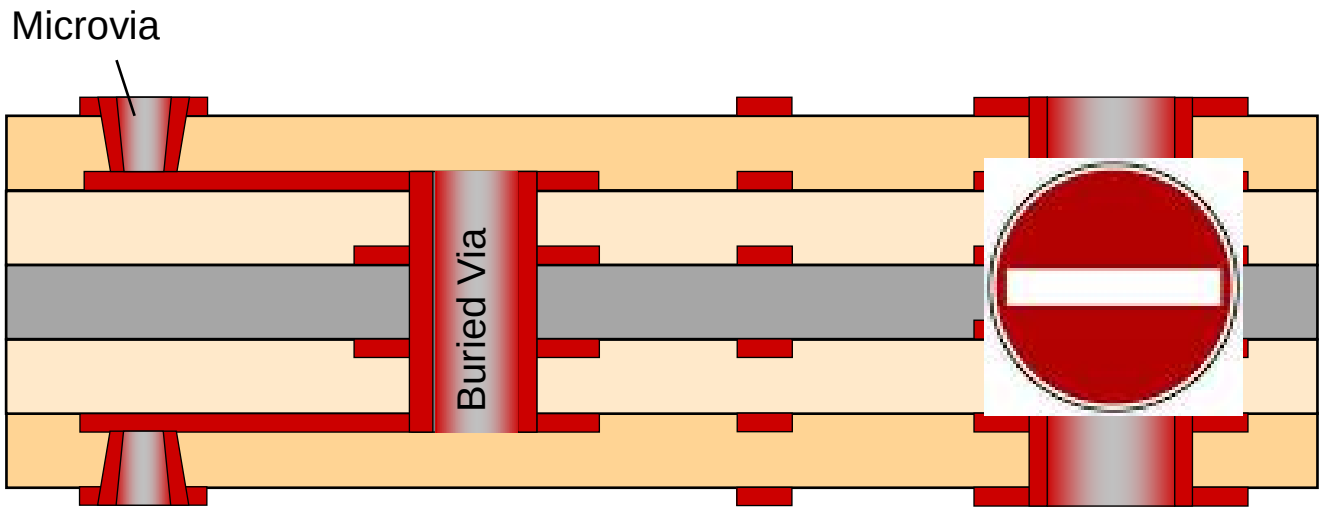
High Performance PCB System
Miniaturisation using HDI Technology

PCB size / unit size ***> Could be essential for the success of a product!***



Long-standing recommendation of WE HDI Product Management:

- **Reduction of the rooting area by using microvias + buried vias instead of plated through hole vias**
- **> perfectly implemented in the applicaton shown !**



Avoiding PTH Vias

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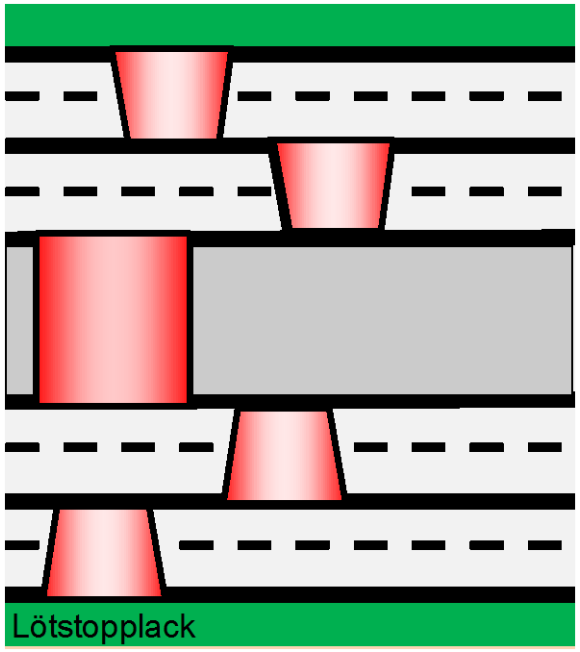
Miniaturisation by HDI Technologie

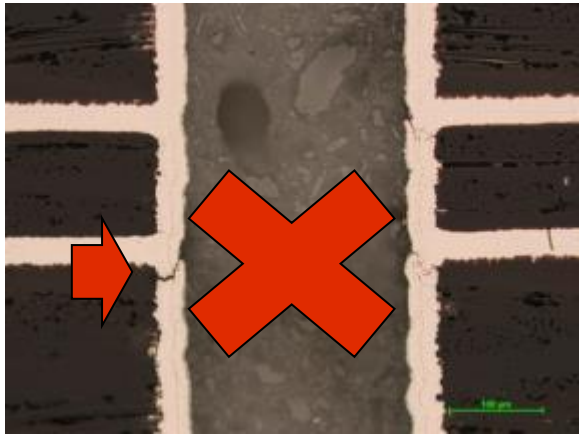


Layer stack-up HDI06_2+2b+2

- High packaging density by using Microvias + buried vias, without plated through (PTH) Vias
- 2nd Microvia layer

- Highest reliability caused by low PCB thickness < 1.0 mm (= low Z-axis expansion)
- Base material Low CTE TG 170°, filled, halogen free

PTH vias are normally the weak points of a PCB concerning thermal cycle stability.



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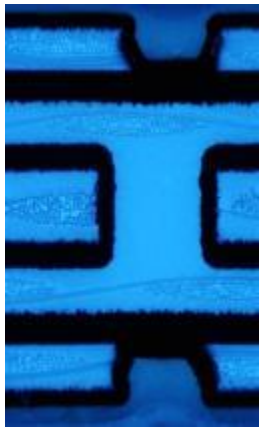
Reliability - PCB



Results of investigations:

- **Thermal cycle tests -40° / +155° C**
  (PCB + test coupons)
- **IST**

➢ **Results: each 1000 cycles passed without any problems**

Further tests were carried out on the complete system.

Investigations by customer on the unit as well.

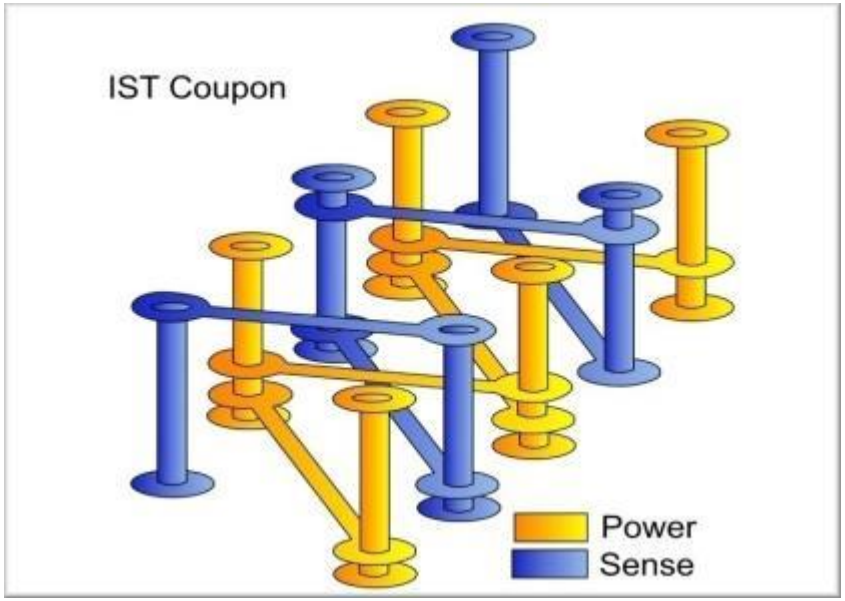
High Performance PCB System
Reliability - PCB

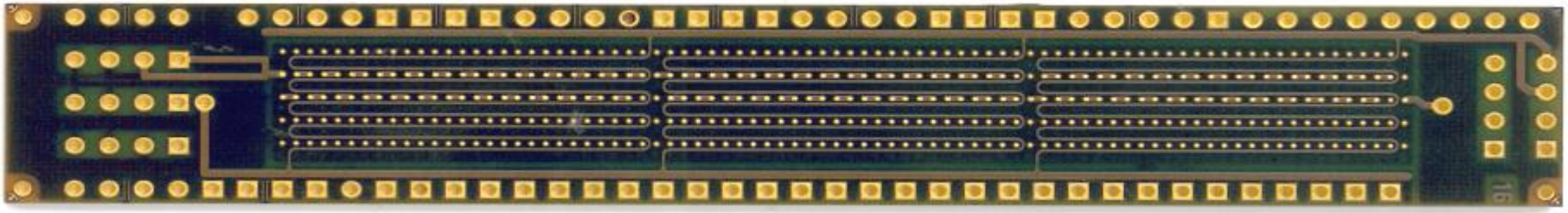
Interconnect Stress Test - IST

The IST offers some decisive advantages to the conventional thermal cycle tests:

- **1000 Temperature - cycles in 4 days**
- **Online measurement of the measuring circuit**
- **IST = very meaningful test**

- **Special test coupon**
  matched to the PCB design





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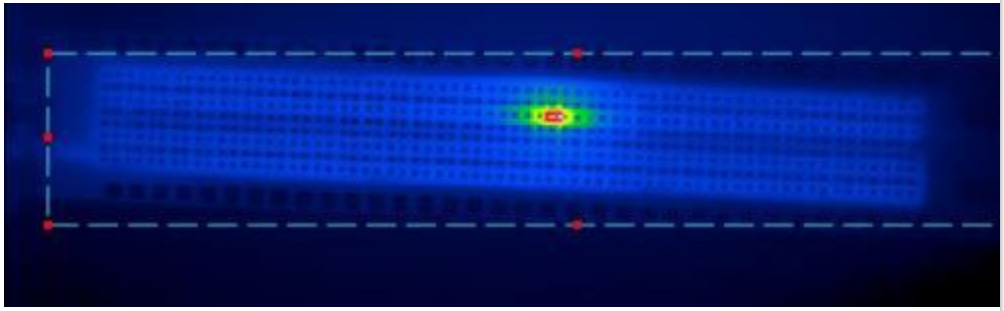
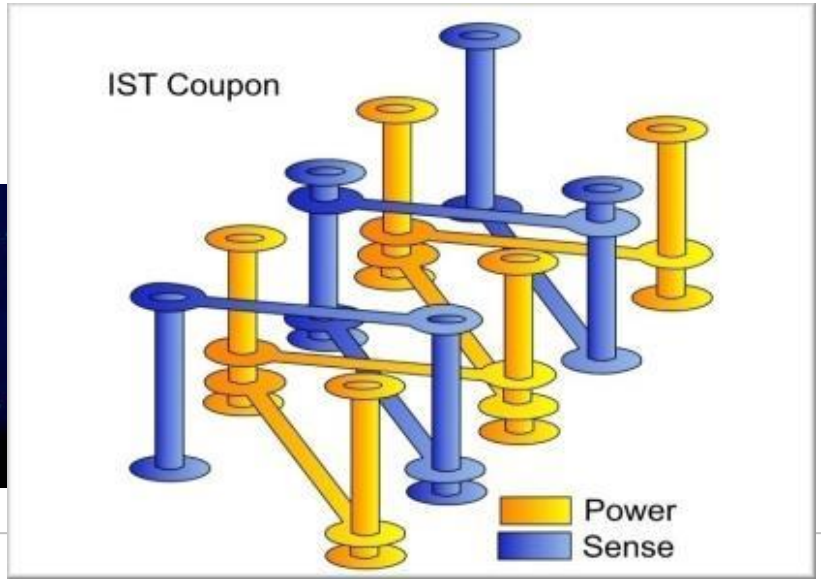
Reliability - IST

- Preparation: 6 x Reflow 245° C
  or 2 x 260° C Reflow-Simulation in IST
  or in accordance to customer specification
- **Electrical heating of coupons through power-circuit to 150°C within 3 minutes, cooling to room temperature within 2 minutes**
- **Online measurement of temperature and resistance** (+ 10 % max. resistance change permitted)





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Reliability - IST

- **Measurement results HDI build-up (without PTH vias)**

TEST RESULTS

Coupon ID	Pwr Cy-cles	Pwr %	SenseA Cycles	SnsA %	SenseB Cycles	SnsB %	Results
5209_10	**1000**	0	**1000**	0.1	**1000**	0.2	Accept
5209_11	**1000**	-0.3	**1000**	-0.2	**1000**	-0.1	Accept
5209_14	**1000**	0.6	**1000**	0.6	**1000**	0.5	Accept
5209_2	**1000**	-0.1	**1000**	-0.1	**1000**	0.1	Accept
5209_5	**1000**	-0.2	**1000**	-0.2	**1000**	-0.3	Accept
5209_8	**1000**	-0.5	**1000**	-0.5	**1000**	-0.4	Accept
5209_9	**1000**	-0.3	**1000**	-0.2	**1000**	-0.3	Accept
							CusSpec
Mean							**N/A**
Std Dev							
Min							**N/A**
Max							
Range							
Coef Var							**N/A**

TEST PROTOCOL: 334

----------PASS----------

Reliable produced Microvias have a high thermal cycle stability of significantly more than 1000 IST cycles

(≙ 3000 conventional thermal cycles)

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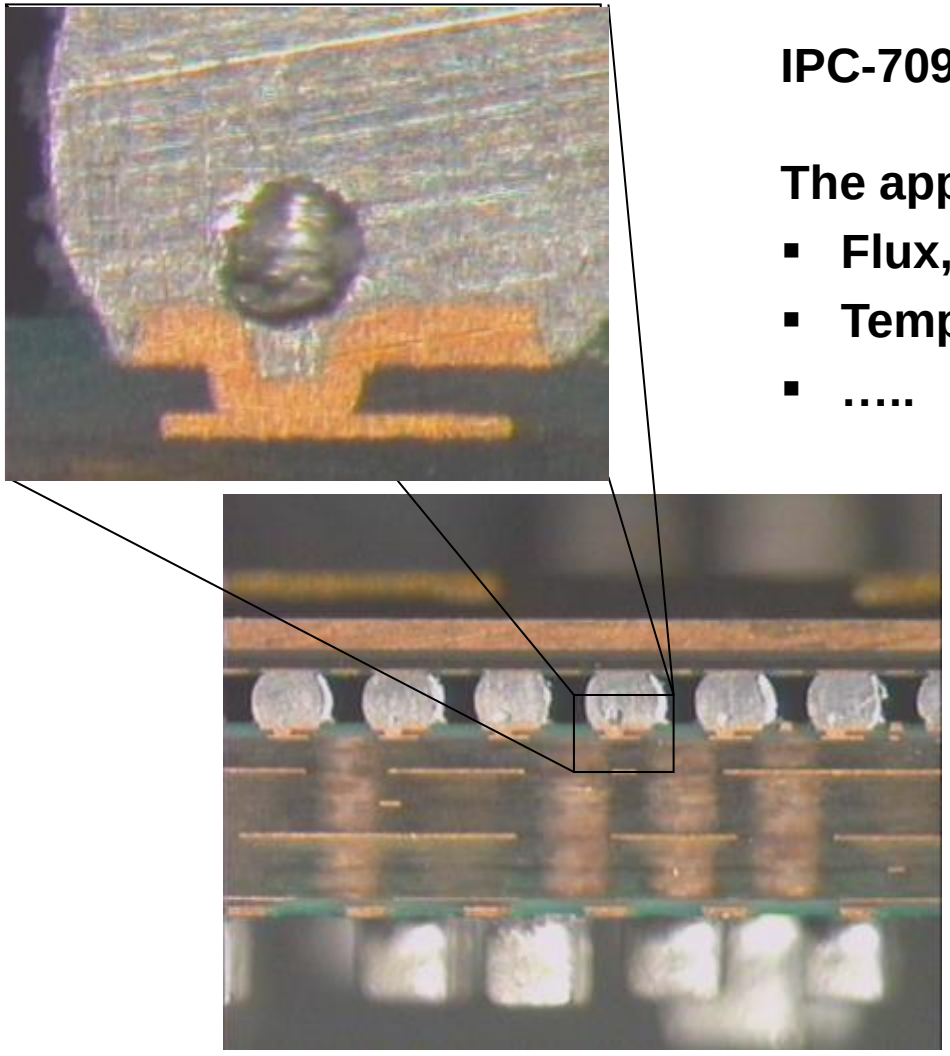
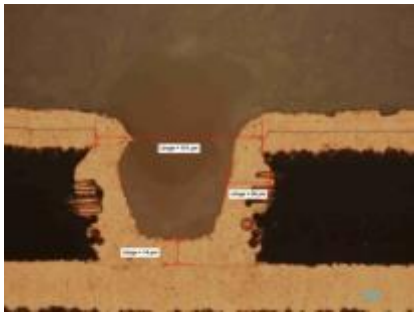
Reliability – Solder Process



IPC-7095C: „max. 22% of the image diameter“

The appearance of voids depends on:

- **Flux, solder paste**
- **Temperature profil**
- **…..**



•µViP technology is being used by WABCO in HDI products for over 10 years with 0 ppm

WABCO

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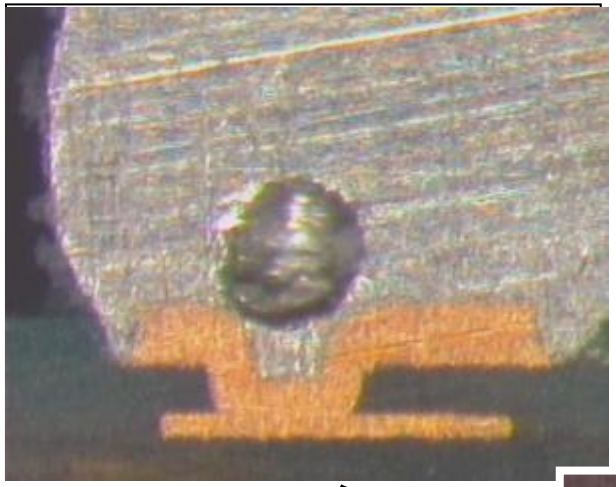
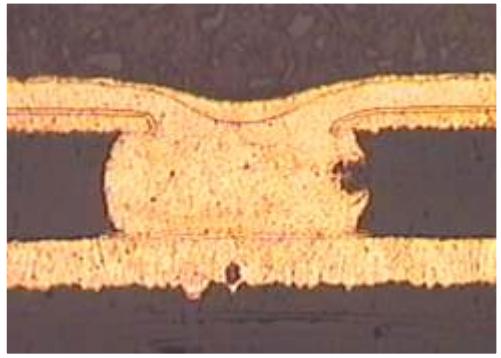
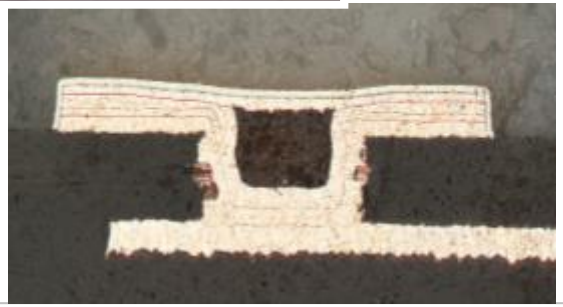
Reliability – Solder Process / Microvia Filling





Copper - Filling

Filling = extra charge!!



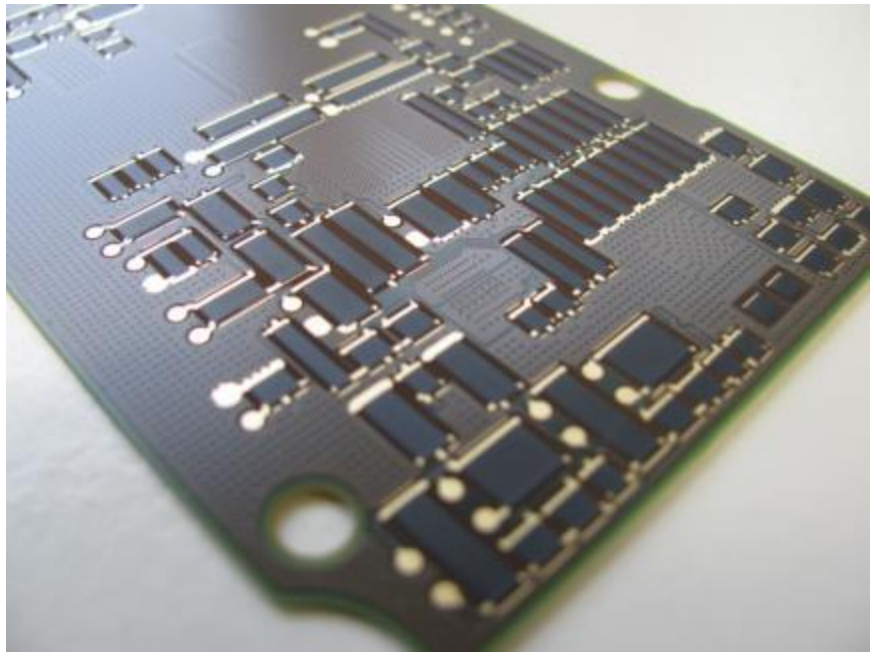
Filled & capped

As both variants, filled and unfilled Microvias, have advantages and disadvantiges, WE does not give an recommendation.

Everyone has to make their own decision!

High Performance PCB System

Printed Resistors – Printed Polymer in general



Applications:

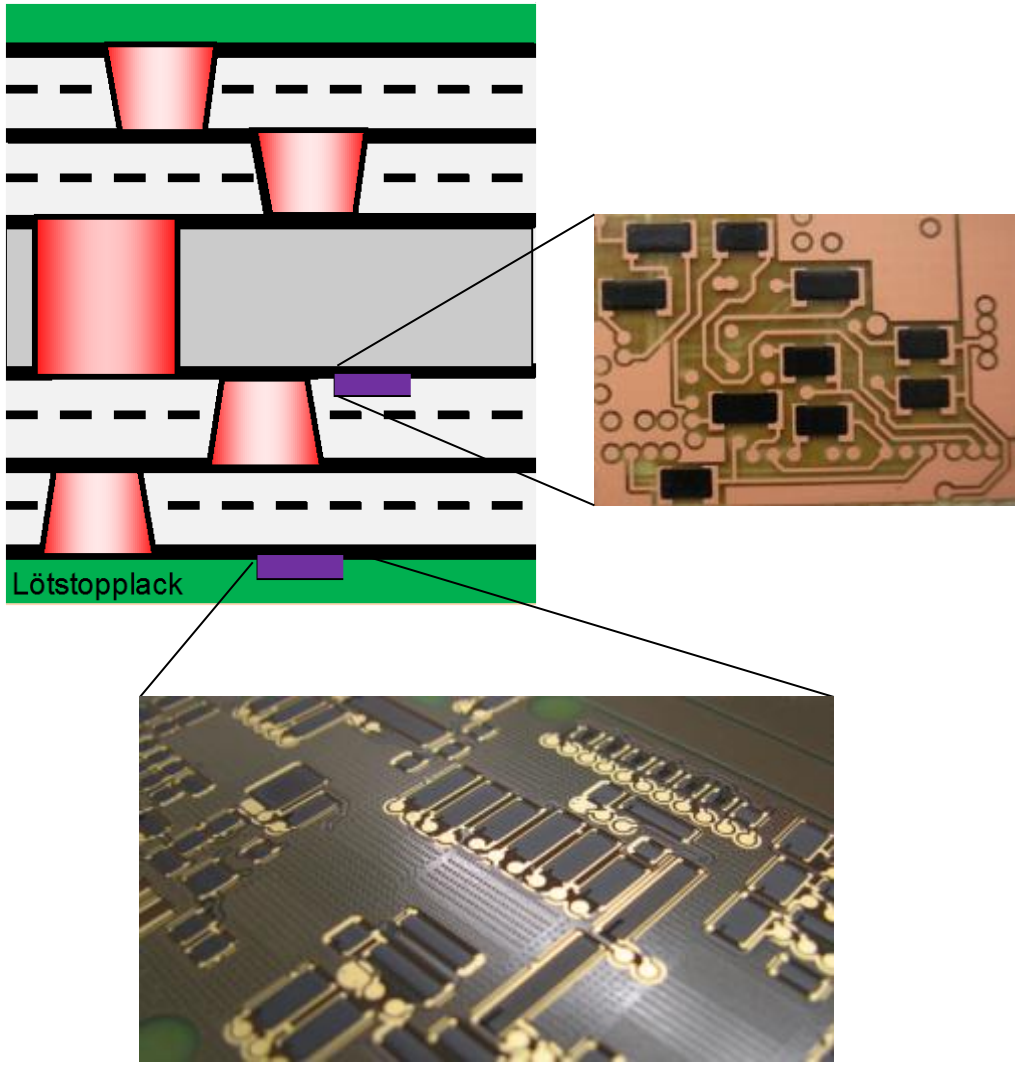
- Pull-up and Pull-down resistors
- Voltage dividers
- General circuit resistors
- High reliability requirements

Facts:

- Pastes with different resistance values
- Tolerance printing process R +/- 30 % (standard)
- Tolerance after laser trimming +/- 5 % for the entire product lifetime
- Resistor values from 50Ω to 1 MΩ (standard)
- Low temperature coefficient (≙ resistance change) +/- 300 ppm/K
- Standard size min. 1,75 mm × 1,25 mm
- Thickness of printed resistors approx. 20 µm
- Design Rules available

High Performance PCB System

Printed Resistors – Printed Polymer



WE: 10 years experience with printed resistors and with polymer pastes (carbon)

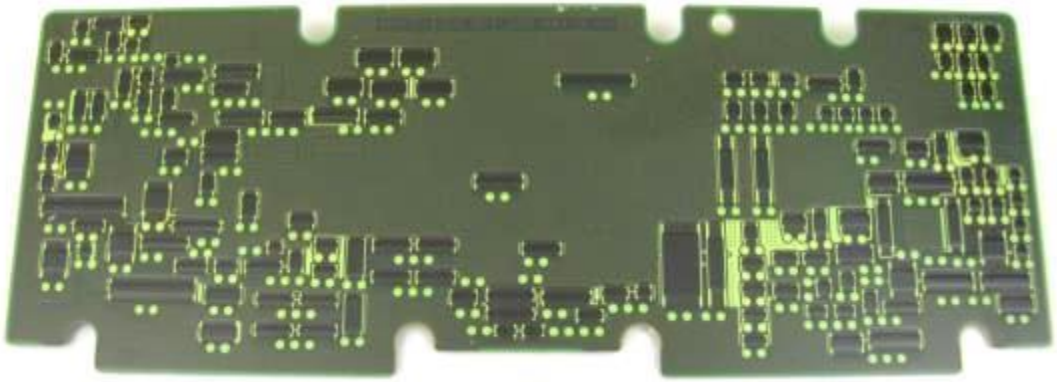
- **Miniaturisation using embedded resistors EmbR**
- **Reliability advantages**

$$R = \frac{p}{0{,}02} \times \frac{\text{Lenth}}{\text{Width}}$$

p = paste resistance value

High Performance PCB Systems

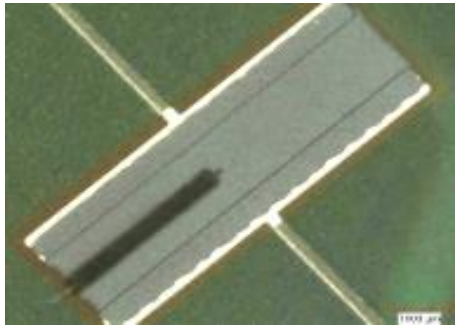
Printed Resistors – Laser Trimming

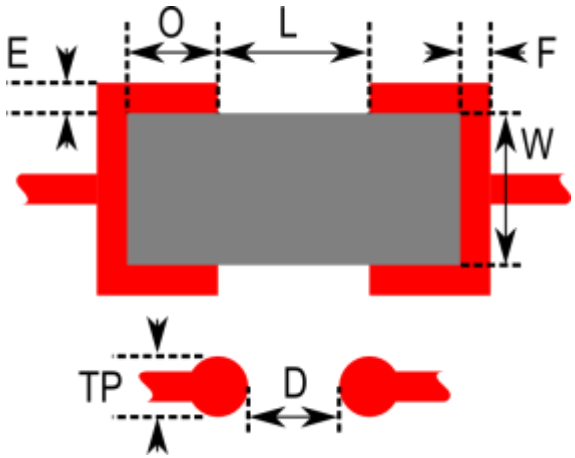


Tolerance of resistance value without laser trimming max. +/- 30%

With Laser Trimming
Process tolerance: down to +/- 1%

Entire product lifetime: +/- 5%





Traceability:
The laser trimming process can also enable perfect traceability by using binary coding on additionally designed resistors.

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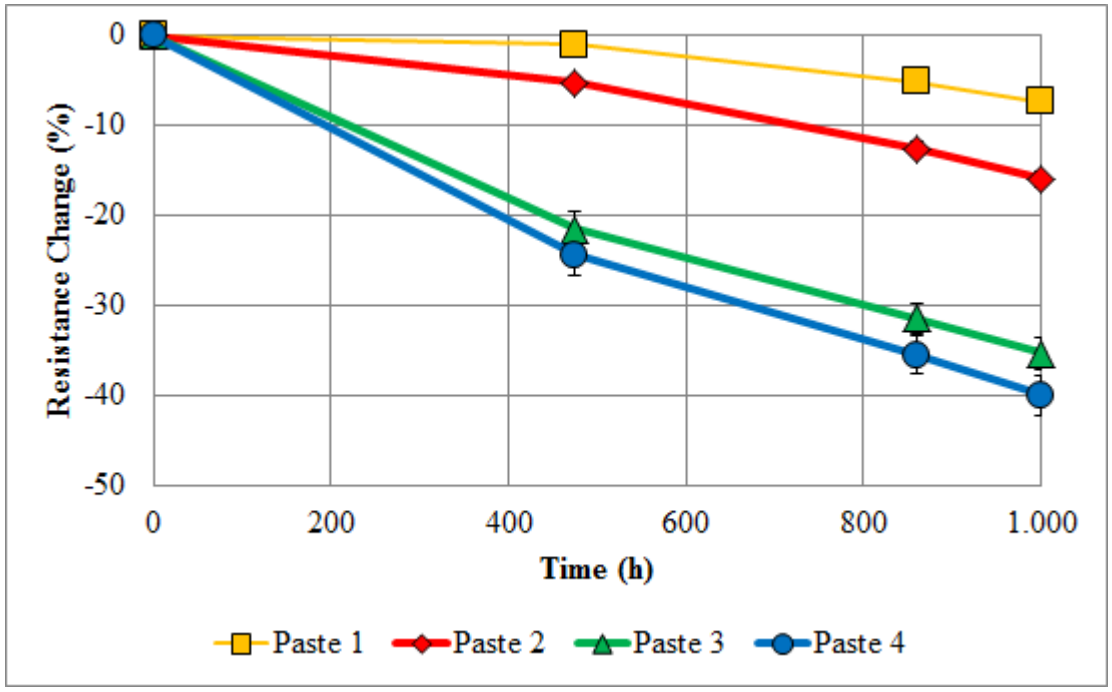
Printed Resistors – Choice of Pastes



Resistance change: 4 pastes @ 155° C operated with max. power

1. Step: extensive investigations were necessary, in order to dertermine which pasts could fulfil the demanding requirements of the complete system.

The stability of the resistance values under temperature influence was a particular challenge for many paste systems.

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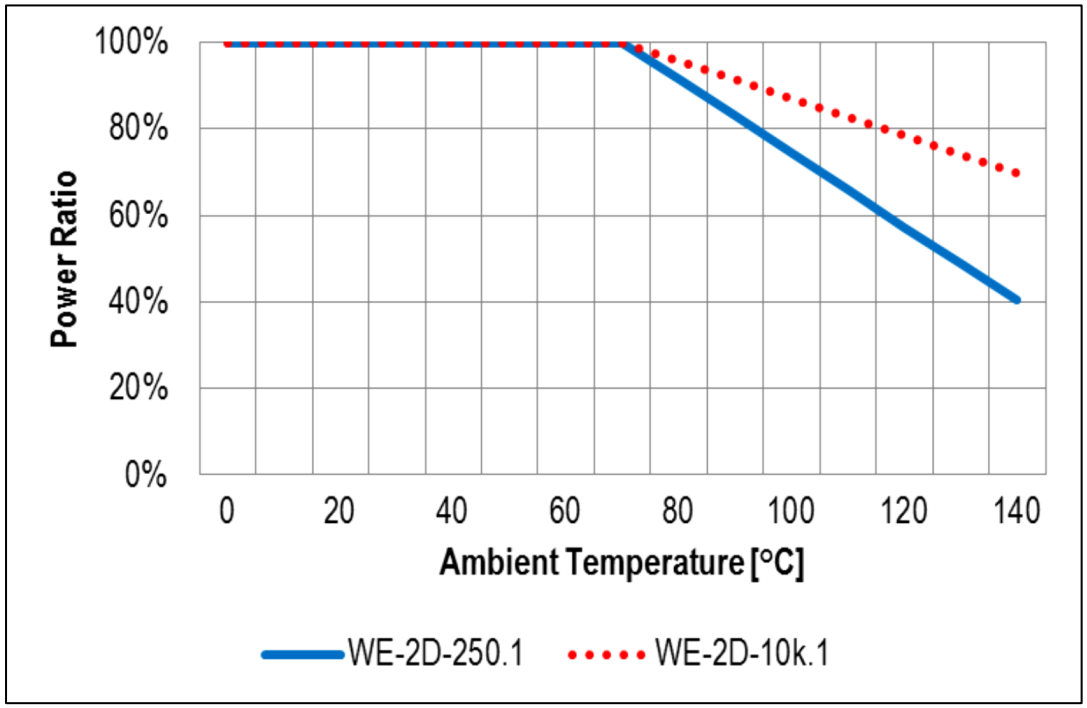
Printed Resistors – Tests

- **Power Derating**



Aim of Power–Derating tests is to
c of the
r age
the resistor. Currant is constant.

Paste	Rated Power at 70°C (mW/mm²)
WE-2D-250.1	179
WE-2D-10k.1	100

Result: even at 140° C the power dissipation is far above the disired 50 mW/mm².

The performance of the printed resistors is at least as good as comparable soldered resistors or other embedded technologies.

- **Thermal Cycle Test (conventional)**

-40° C / + 155° C, **1000 cycles**, transfer time max. 20 s, dwell time 15 Min., resistance change max. 2 %

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Printed Resistors – Tests

Qualification of the System

Resistors and Voltage Dividers

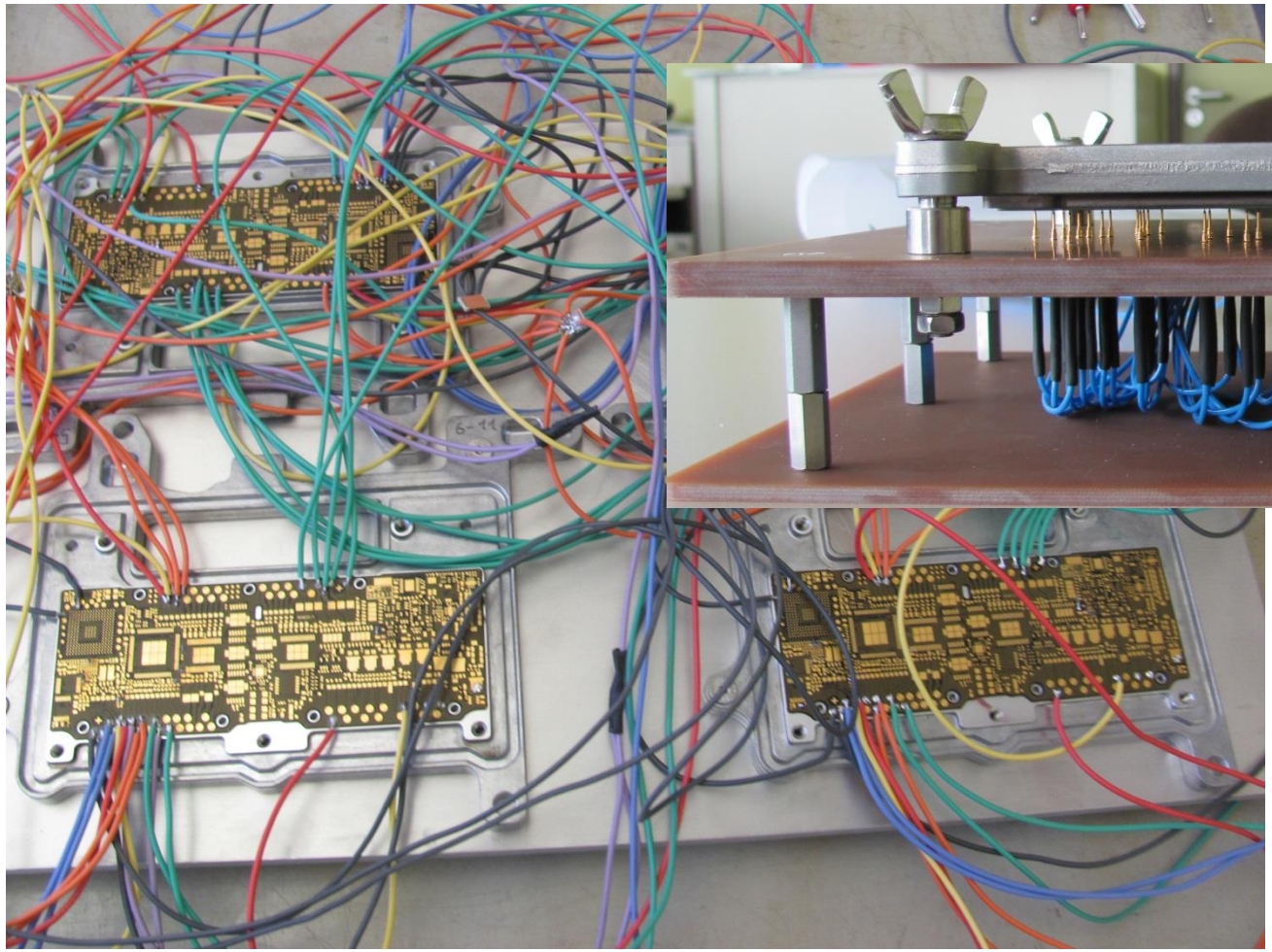
Test	Test method	Procedure	Max. Deviation Single Resistor
Temperature Coefficient of Resistance (TCR)	DIN EN 60115-1:2012-04, 4.8	+20 / -40°C ...+20°C / +140°C	- 700 …– 300 ppm/K
High Temperature Exposure (HTE)	MIL-STD-202 Method 108	**1000 h @ T_A = 150° C unpowered**	+/- 3%
Moisture Resistance	MIL-STD-202 Method 106	25°/65°, 95% rH, 3 cycles in 24h, 10 days, unpowered	+/- 2%
Biased Humidity	MIL-STD-202 Method 103	1000 h, 85°C, 85% rH, 10 % of operating power (50 mW/mm²)	+/- 3%
High Temperatur Operating Life (HTOL)	MIL-STD-202 Method 108	1000h HTE, then **1000 h HTOL @ T_A = 140° C at rated power**	+/- 20%
Resistance to Soldering Heat	IPC-TM650	5 times 260 +/- 5 ° C, 10 +/- 1 s	+/- 2 %

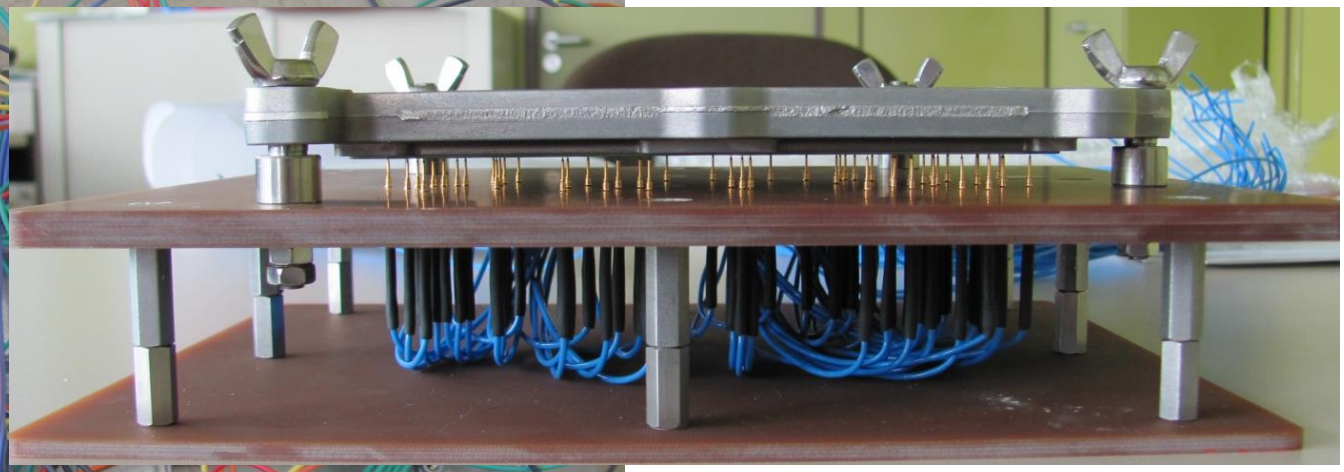
extract of the qualification programm

The same tests have been done by customer on the assembled units.

High Performance PCB System
Printed Resistors – Tests

Qualification of the System: Preparation HTOL





High Performance PCB System

Printed Resistors – Tests

Annual Re-Qualificatin of the System
Resistors and Voltage Dividers

Requalifizierung: Auswertung HTOL und TWT

Kopfdaten: Prüfdatum: 27.07.2015

Kunde: WABCO
Typ: TCNG
geprüft von: A. Reeb
Labor SH

Leiterplatte
WE- Nr.: 396638
FA-Nr.: 577887
LK-Nr.: 3013316402

Aluminiumbauteil
Teil-Nr.: 4463533134
Charge / KW: 25 / 30
LS-Nr.: 82513361

PDSS- Spezifikation: PDSS Stand: 10.03.2014

High Temperature Operational Life (HTOL)
1000h bestromt bei 140°C
Toleranz (Max. Änderung)
Einzelwiderstände: +- 20 %
Spannungsteilerverhältnis: +- 0,5 %

Thermal Shock (TWT)
1000 Zyklen bei -40°C/+155°C
Toleranz (Max. Änderung)
Einzelwiderstände: +- 2 %
Spannungsteilerverhältnis: +- 0,5 %

Prüfergebnis HTOL

Getestete Baugruppen: 5
(Panel-ID/PCB-ID)
11 / 9
5 / 17
9 / 10
14 / 5
3 / 13

Fehlerliste:
Widerstände außerhalb der Toleranz

	GUT	FEHLER
Einzelwiderstände:	855	0
Spannungsteiler:	80	0

Resultat:

Einzelwiderstände	Spannungsteiler
i.O.	i.O.

Prüfergebnis TWT

Getestete Baugruppen: 5
(Panel-ID/PCB-ID)
10 / 12
8 / 18
10 / 6
12 / 9
9 / 7

Fehlerliste:
Widerstände außerhalb der Toleranz

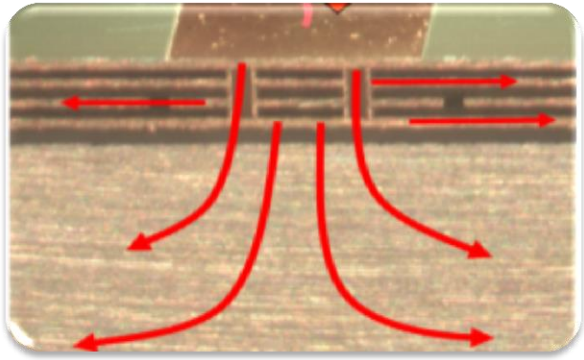
	GUT	FEHLER
Einzelwiderstände:	855	0
Spannungsteiler:	80	0

Resultat:

Einzelwiderstände	Spannungsteiler
i.O.	i.O.

High Performance PCB System

Thermal Management – in general



Options on PCB basis:

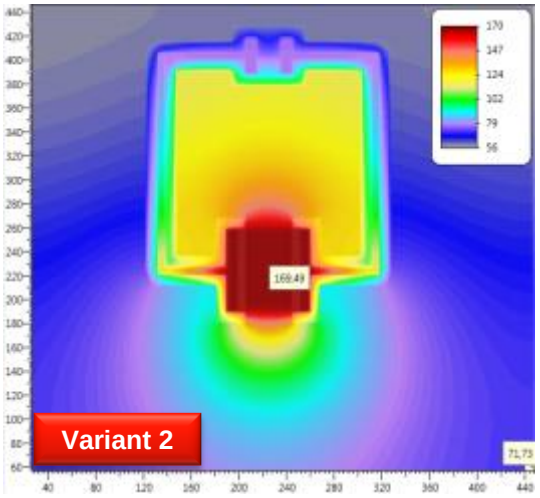
- **Heat dissipation using vias**
- **Heat spreading using planes and heatsinks glued onto the PCBs**

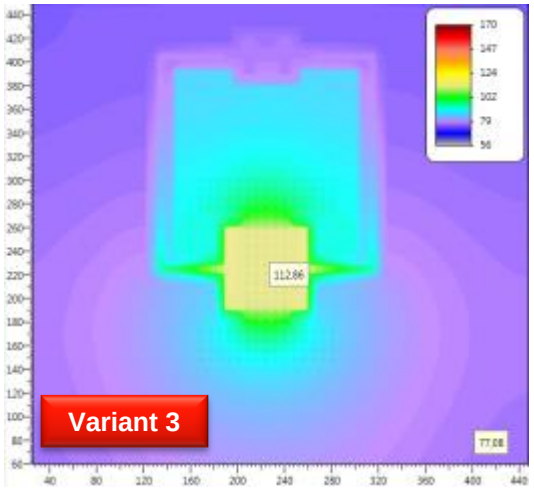
Target:

- **Lowering of temperature at the component**
- **Avoiding critical temperatures inside of the component and unit**
- **Extention of lifetime and ensure of long term reliability of the unit**

At threshold a thermal simulation in preliminary stages is recommended

Thermal Simulation



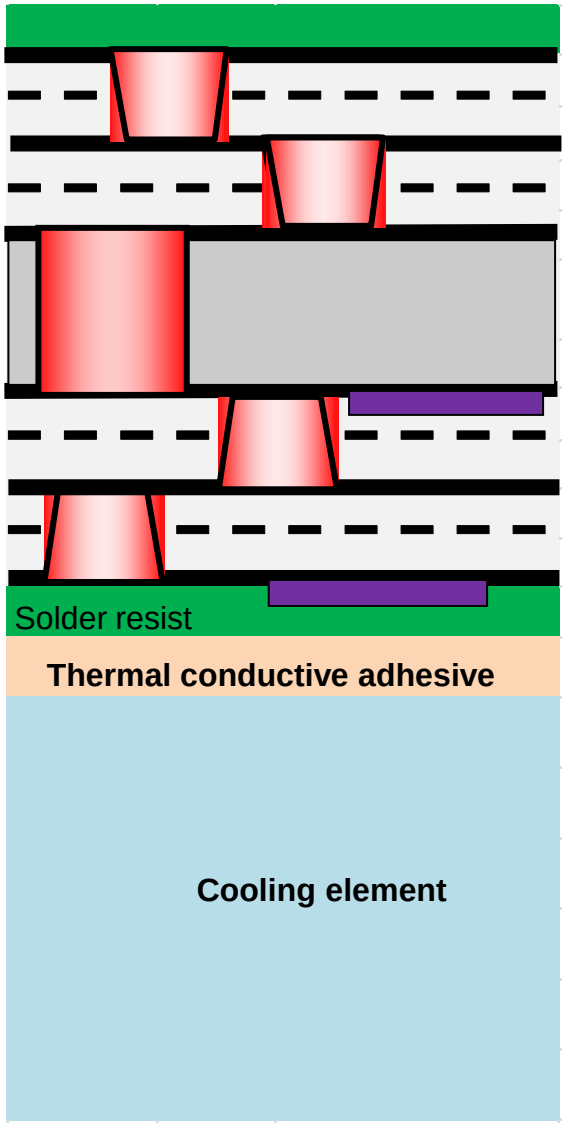


High Performance PCB System

Thermal Management – PCB System

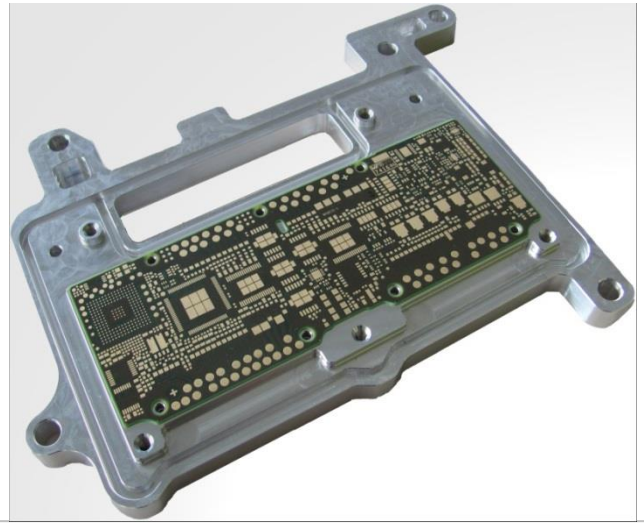
Requirements on the system:

- Operating temperature 140° C, for short time 150°C
- ALU cooling element with high surface finish quality
  - Thick wire bondable
  - Sufficient adhesive strength in connection with thermal conductive adhesive
- New logistical challenge for the PCB manufacturer



Optimized Thermal Management

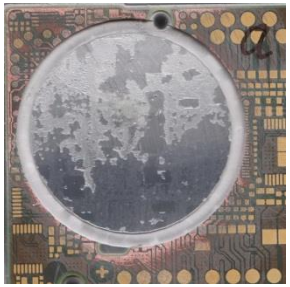
- High number of Microvias (direcly in solder pads) and buried vias
  - Large cross section
  - Low thermal resistance
- Thin thermal conductive adhesive 50 µm
- EmbR very close to heat sink (cooling element)

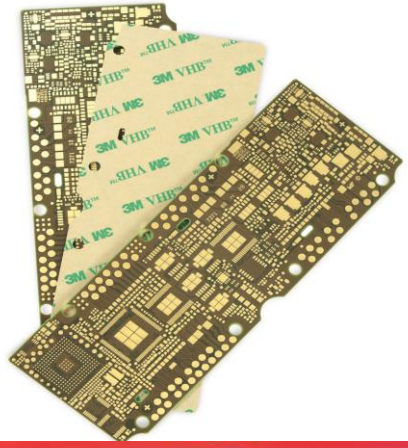


High Performance PCB System

Thermal Management – Adhesive strength

Verification of ahesive strength of PCB on cooling element

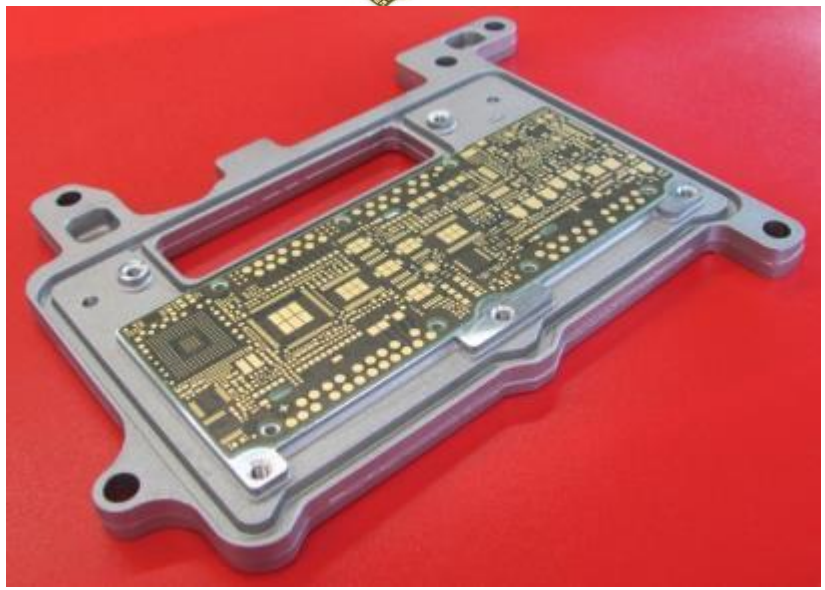




Target: approx. 0.60 N/mm²

Pretreatment

- ***Thermal cycles (-40°C / +155°C) 1000 cycles***
- ***Climate chamber 1000 h (85°C / 85% air humidity)***
- ***Hich temperature exposure (HTE Test) 1000 h in oven / 155°C***



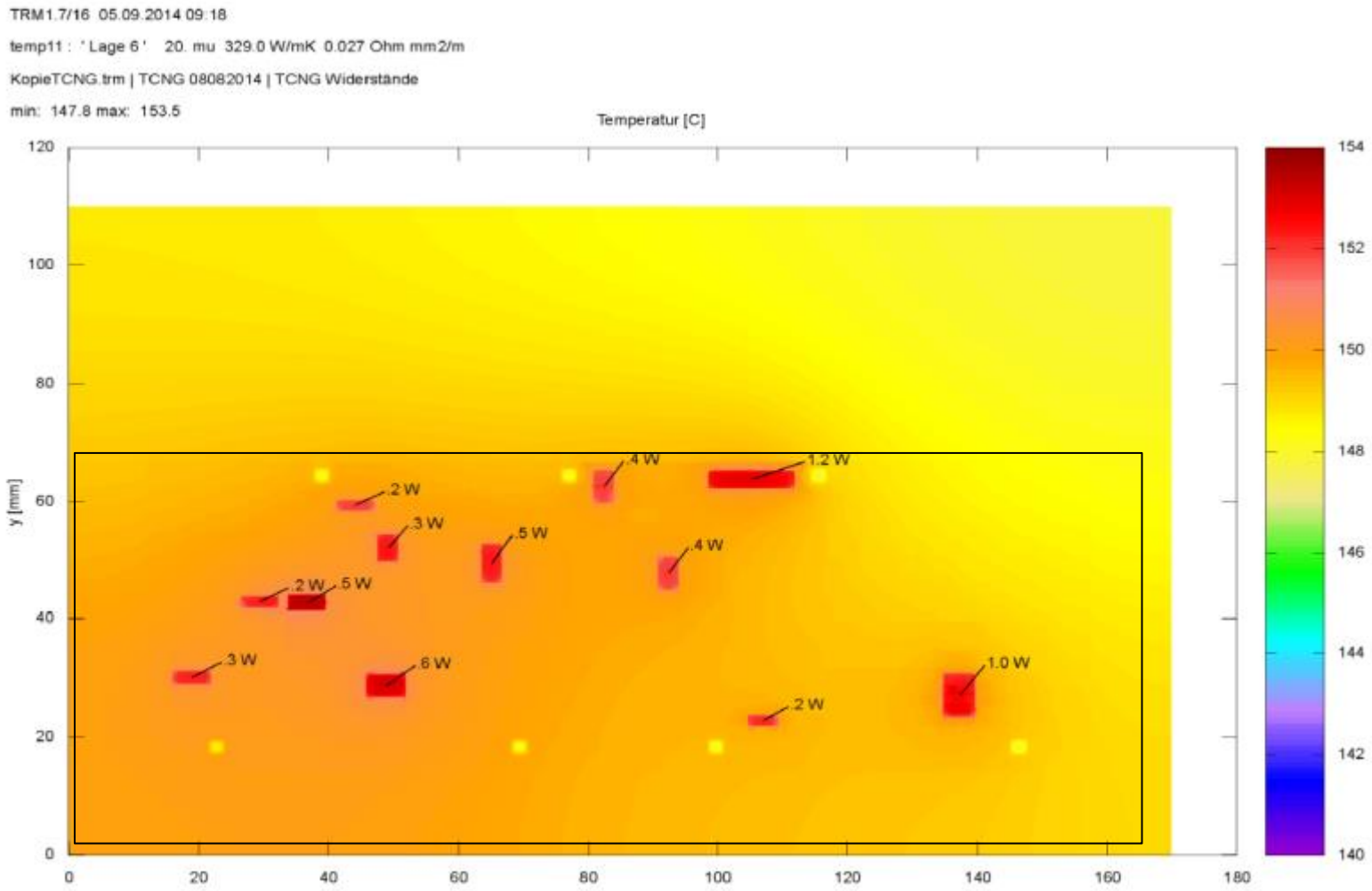
Result:

Necessary to ensure required adhesion strength:

- **Lamination considering defined pressure, temperature and time parameters**
- **Surface tension ALU min. 38 mN/m**

High Performance PCB System

Thermal Management – Simulation PCB bottom side



Ambient temperature: 140°C

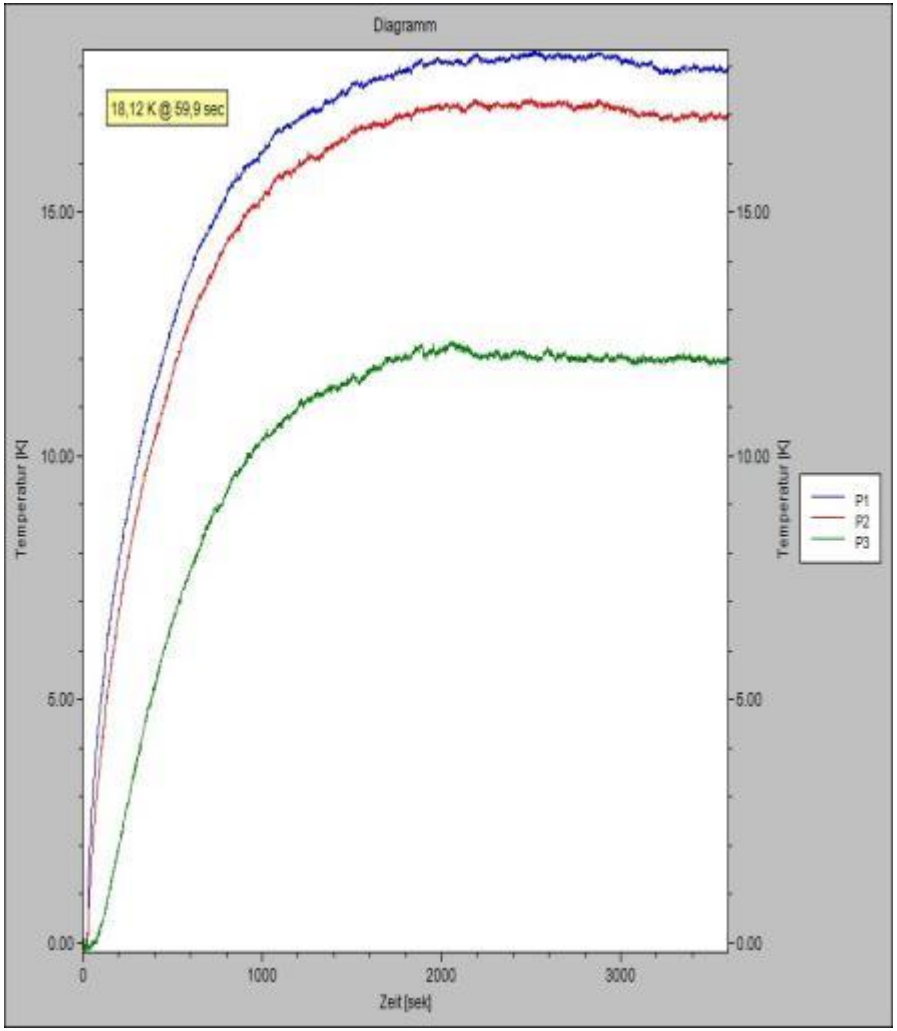
Max. temperature at resistor: 153.5 °C

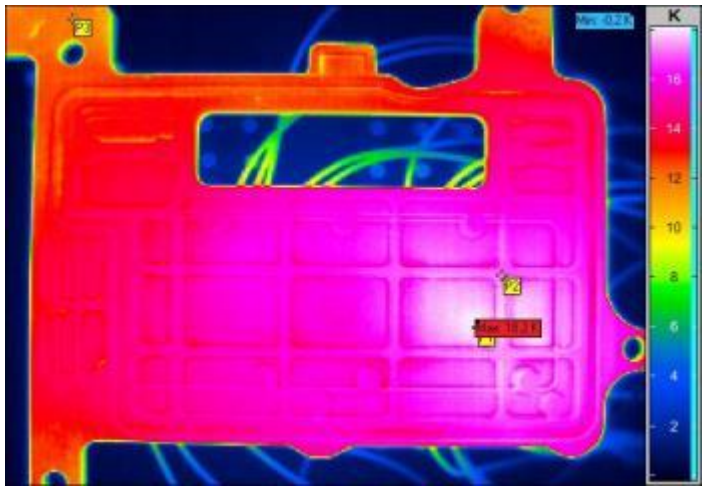
Power in accordance with customer specifikation

Thermal Simulation - Würth Elektronik CBT Product Management

High Performance PCB System
Thermal Management – Thermography Measurement

PCB bottom side



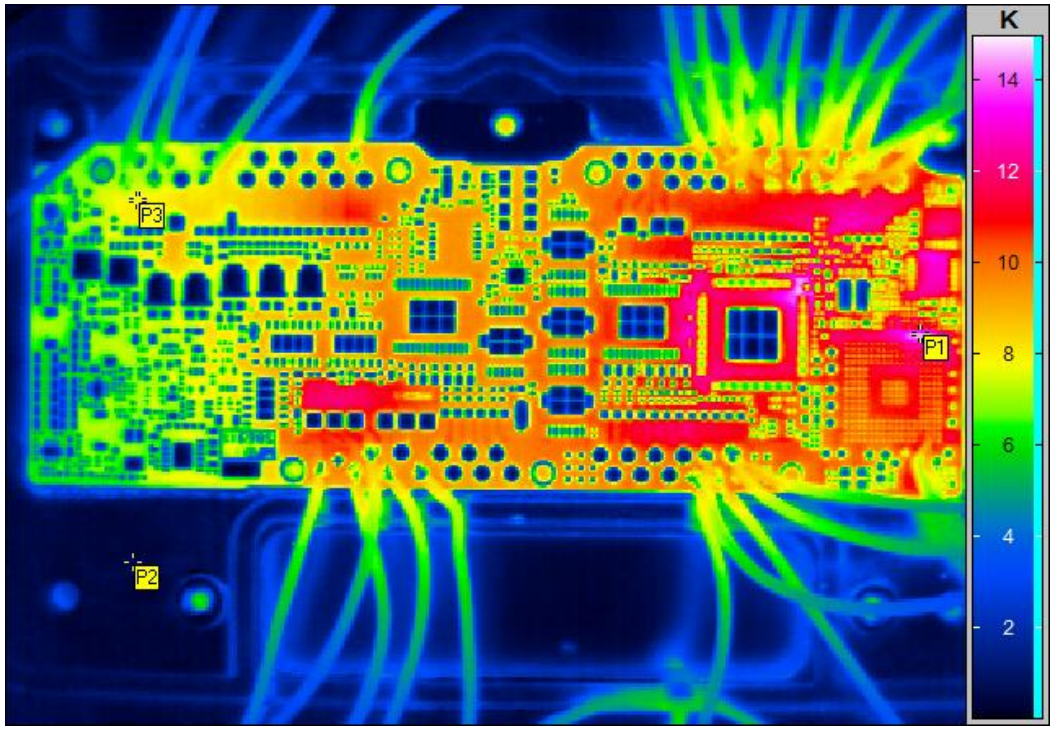


The thermography measurements essentially confirm the results of the simulation.

As these measurements are very complex, only a limited number of resistors could be investigated.

Ambient temperature 140° C
Resistors powered with 5-30 V (HTOL Test)
Measurement after 60 minutes

High Performance PCB System
Thermal Management – Thermography Measurement



PCB Top side

The thermography measurements show that critical hot spots, caused by powered resistors, are avoided, also on the PCB Top side.

Ambient temperature 140° C
Resistors powered with 5-30 V (HTOL Test)
Measurement after 60 minutes

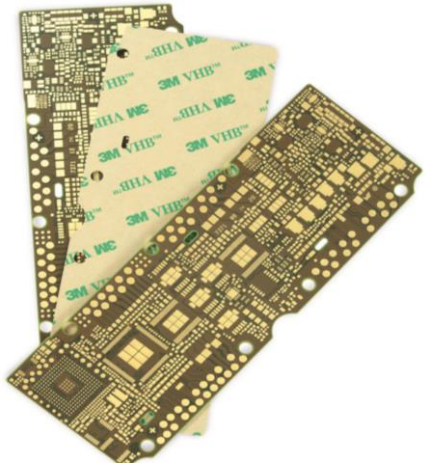
High Performance PCB System Costs

Ceramic

- High temperature resistance

FR4

- **High funktionality**
- **Highest packaging density**
- **Cost-efficient**



High Performance PCB System

Costs – PCB in general

- **Main advantage FR4 PCB: manufactured in „large“ production panels**

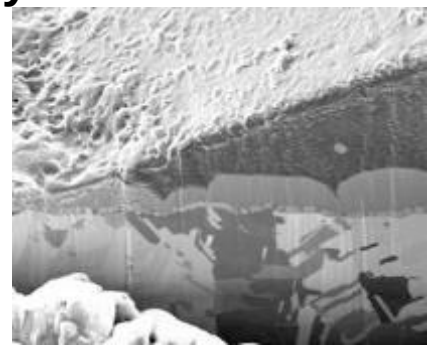
PCB Cost drivers

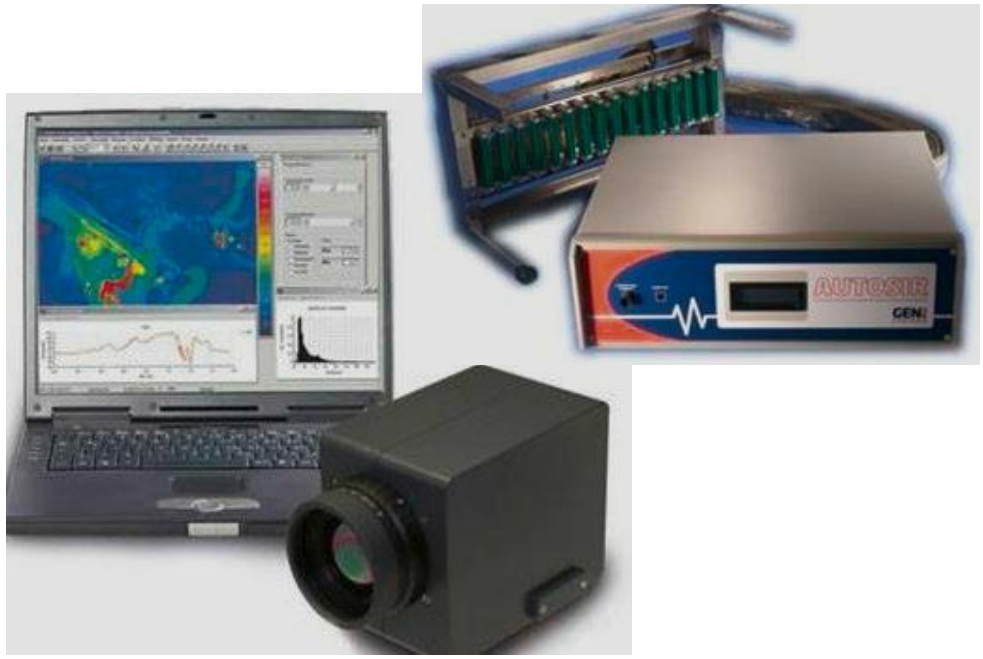
		Presented System
PCB size	+	Relatively small size
Unfavourable delivery panel / X-Out	++	Single PCB
Complex build-up	≈	Two lamination processes
Material costs	++	Only one core, four pre-pregs, TG170
Mech. drilled vias	++	Only buried vias in a thin core
Number of plating steps	≈	Only three „simple“ plating processes
Complex contour machining	+	Simple milling contour

High Performance PCB System
Requirements on PCB Manufacturer

- Metallurgic analysis
- Inspection according to IPC-6012 Class 3
- Stereo/optical microscopy (VIS/UV)
- IR camera
- Ionograph
- CAF Measurement equipment
- Climate test chamber
- Thermal Cycle Test
- IST
- High Current Impulse Test
- Pressure Cooker Test
- X-Ray fluorescense spectroscopy
- Thermal simulation
- Testequipment for
  - HTOL
  - Power Derating

Labview - controlled





- **Collaboration with institus**
  - REM/EDX (Uni Basel, EMPA Zürich)
  - FIB (Uni Basel, EMPA Zürich)
  - XPS (IGB Stuttgart)
  - Wetting tests (ISIT Itzehoe)
  - Ultrasonic microscopy (ISIT Itzehoe)

High Performance PCB System

Summary

- **Miniaturisation by** **- HDI Technology**
  - Printed resistors (Printed Polymer)

- **Highest reliability using a thin HDI build-up without PTH vias**

- **A technology combination of**
  - **HDI**
  - **Printed resistors**
  - **Optimized Thermal Management**

  can enable a cost effective substitution of a ceramis solution by a FR4 - PCB

- **A competent and broadly based PCB manufacturer can realize such a task. System solutions will be an essential part of collaboration in the future.**

Knowing the relationships - is a secret of success!

We are looking forward to good cooperation!

Stefan Keller
Product Manager

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