HIGH PERFORMANCE PCB SYSTEM

Miniaturisation: HDI & Thermal Management & Printed Polymer

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

HIGHLY RELIABLE PRINTED CIRCUIT BOARDS AND DEVICES IN AUTOMOTIVE ELECTRONICS

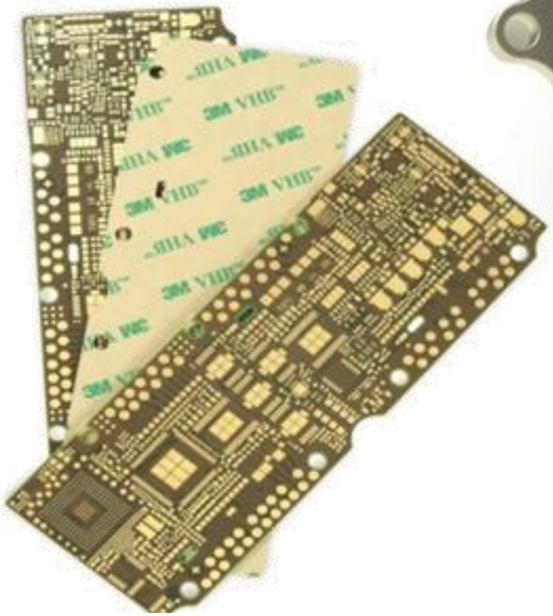
Based on an Example of a High Performance PCB System

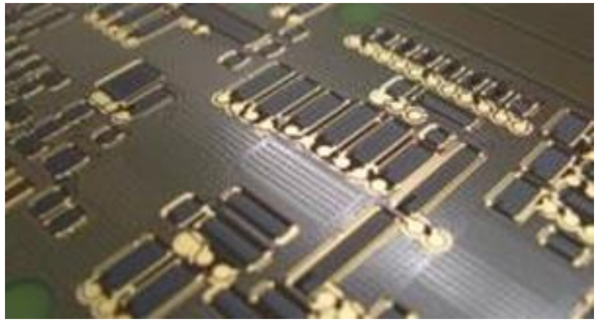
1. Miniaturisation
   - HDI Technology
   - Reliability and Verification by IST

2. EmbR – printed embedded resistors
   - Performance – Tolerances
   - Reliability

3. Thermal Management
   - Thermal vias
   - Heat Sink
   - Thermal Simulation

4. Costs
   - PCB replaces Ceramics





HIGH PERFORMANCE PCB SYSTEM

Market Requirements

Customer's Objectives

- PCB size and the **size of the unit** needs to be **reduced by 75 % (to ¼)** in comparison to the currently running previous version
- Usage of complex and „small" components
- **High operating temperature** (- 40 °C to +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 – **Cost competitive**

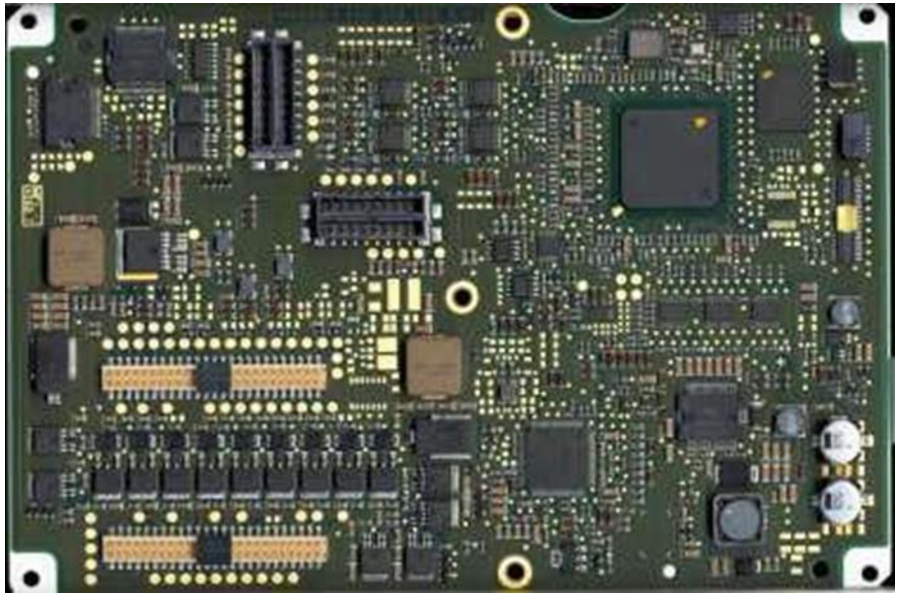
Requirements for PCB Manufacturer

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

MINIATURISATION

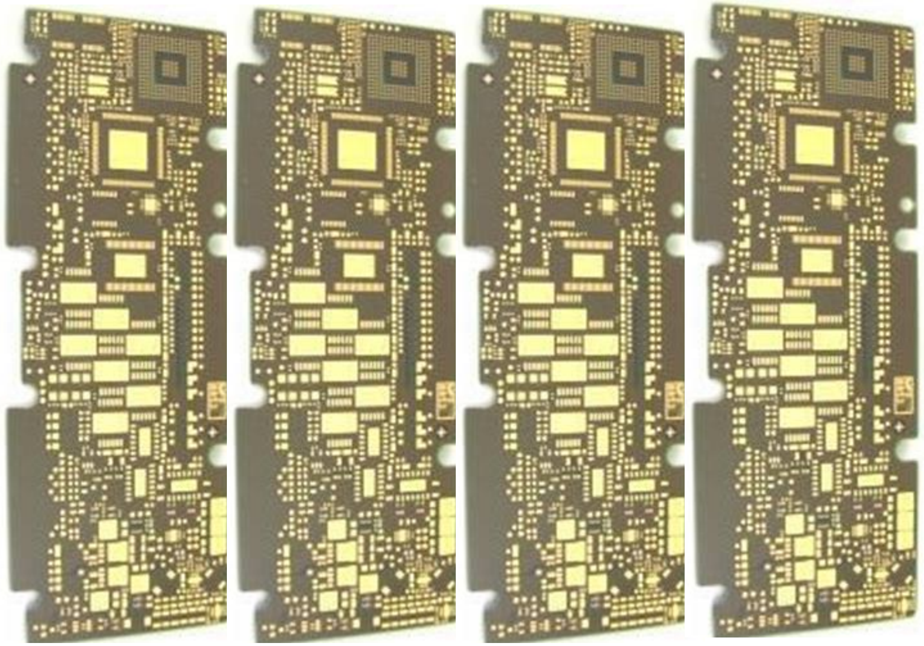
Reduction PCB Size

- Initial situation



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

- 2. Approach: High Performance FR4 - PCB System
  - Combination of HDI- and Printed Polymer Technology with optimized thermal management
  - -> Target achieved, production start in Q1/2015

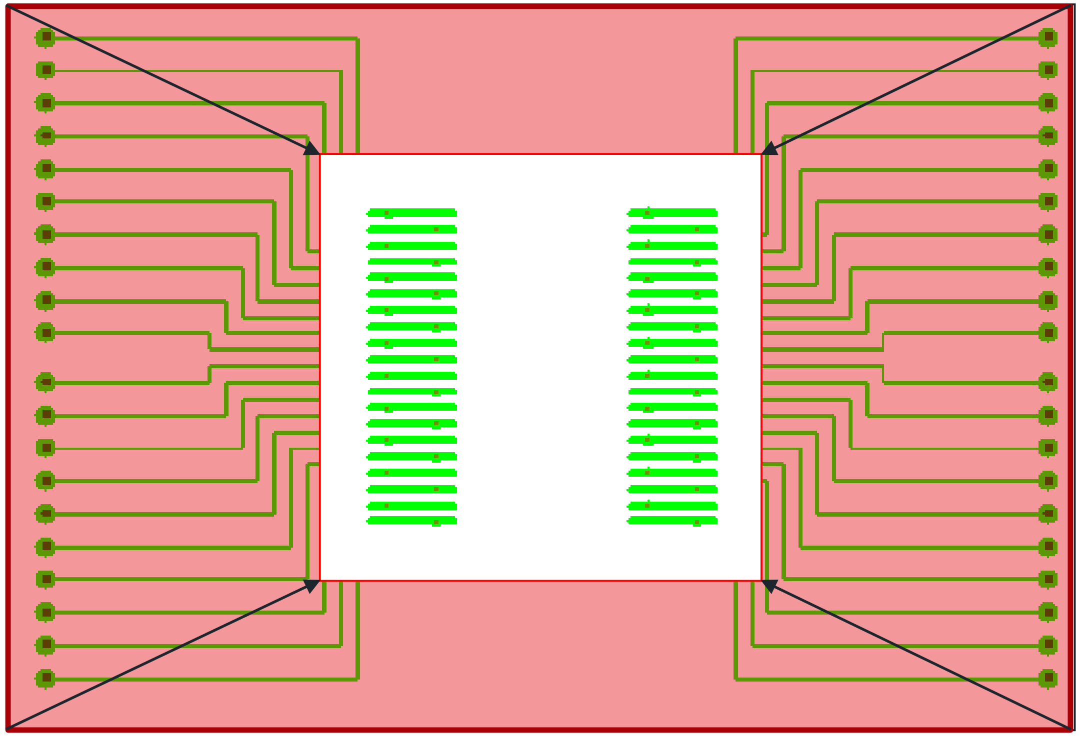


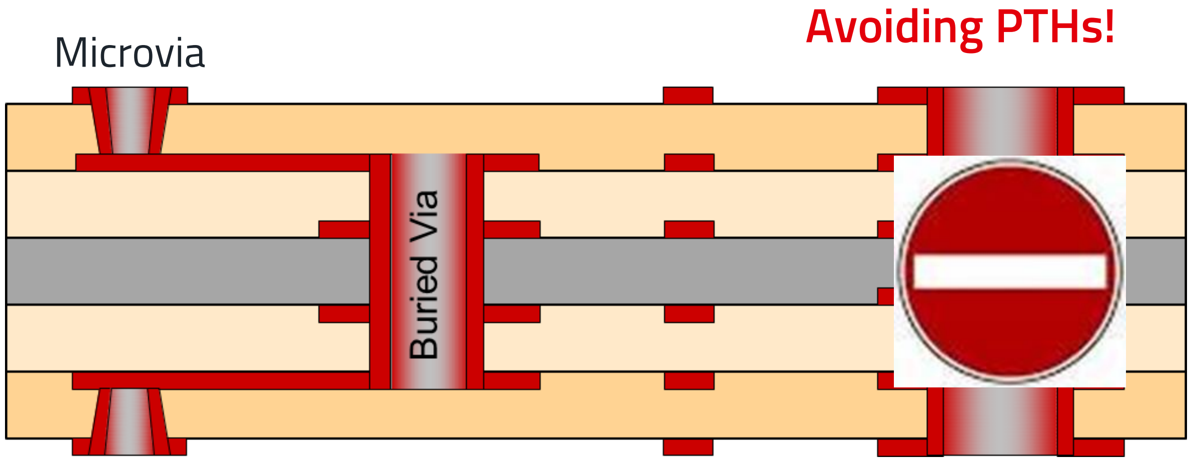
50 mm x 140 mm

MINIATURISATION

Miniaturisation Using HDI Technology

- PCB size / unit size → **Could be essential for the success of a product!**
- Perfectly implemented in the application shown!





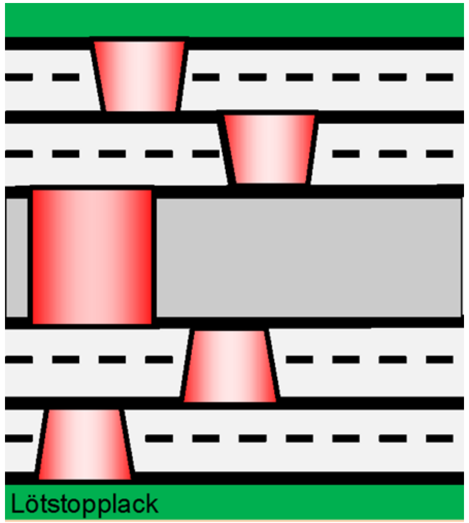
Basic Recommendation for Miniaturisation
Reduction of the rooting area by using microvias + buried vias instead of Plated Through Holes

MINIATURISATION

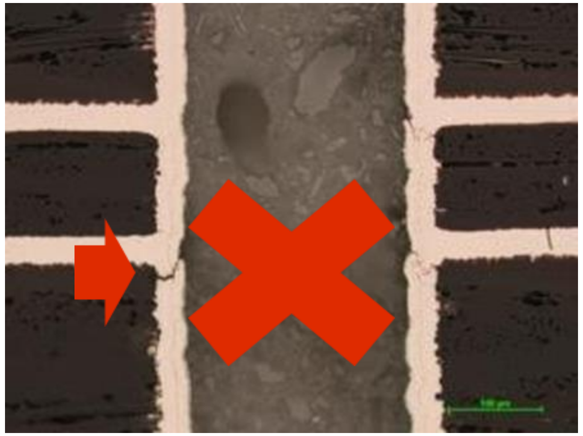
Miniaturisation Using HDI Technology

- Stackup HDI06_2+2b+2
- High packaging density
  - By using Microvias + buried vias
  - Without plated through Vias (PTH)
  - 2nd Microvia layer
- Highest reliability
  - Caused by low PCB thickness < 1.0 mm (= low Z-axis expansion)
  - Base material Low CTE Tg 170 °C, filled, halogen free

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



Stackup HDI06_2+2b+2



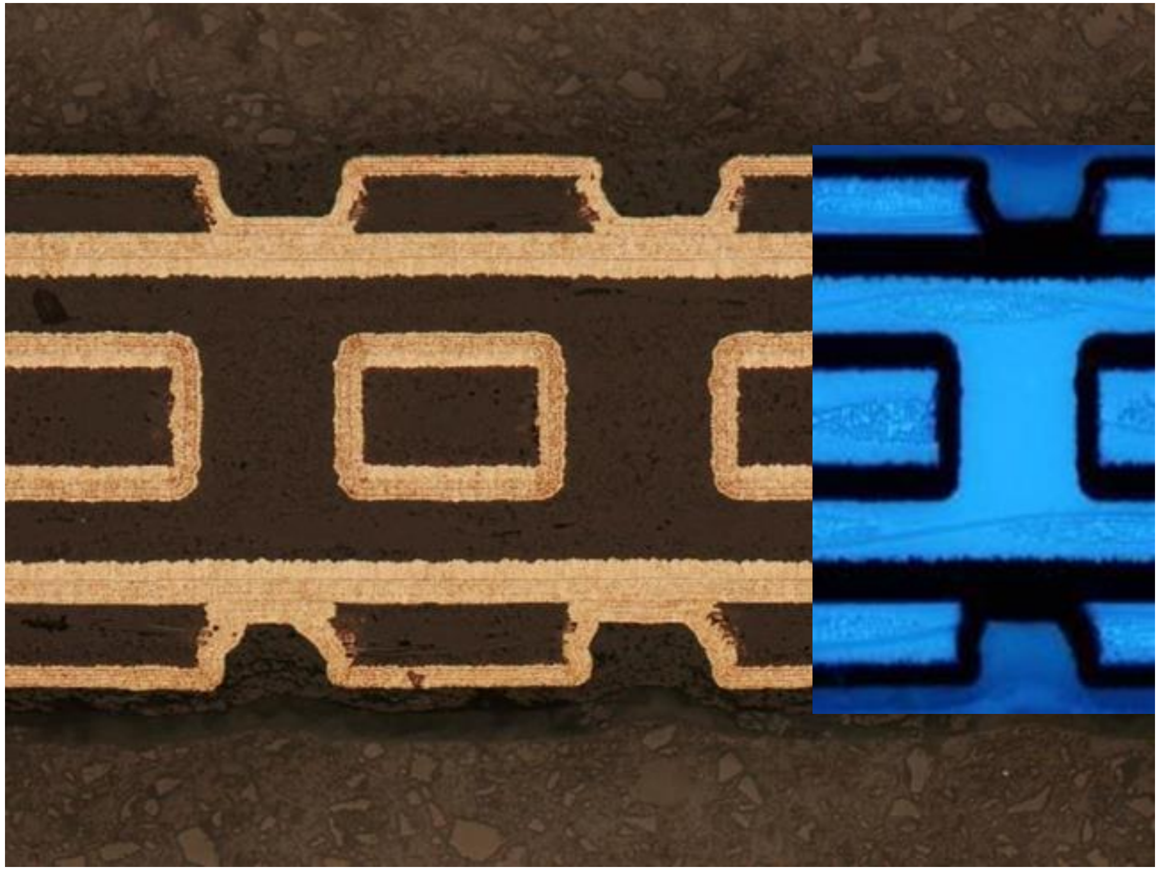
RELIABILITY OF THE PRINTED CIRCUIT BOARD

Executed Tests

- Thermal cycle tests (TCT)
  - -40 °C / +155 °C
  - PCB + Test coupons
- Interconnect Stress Test (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.

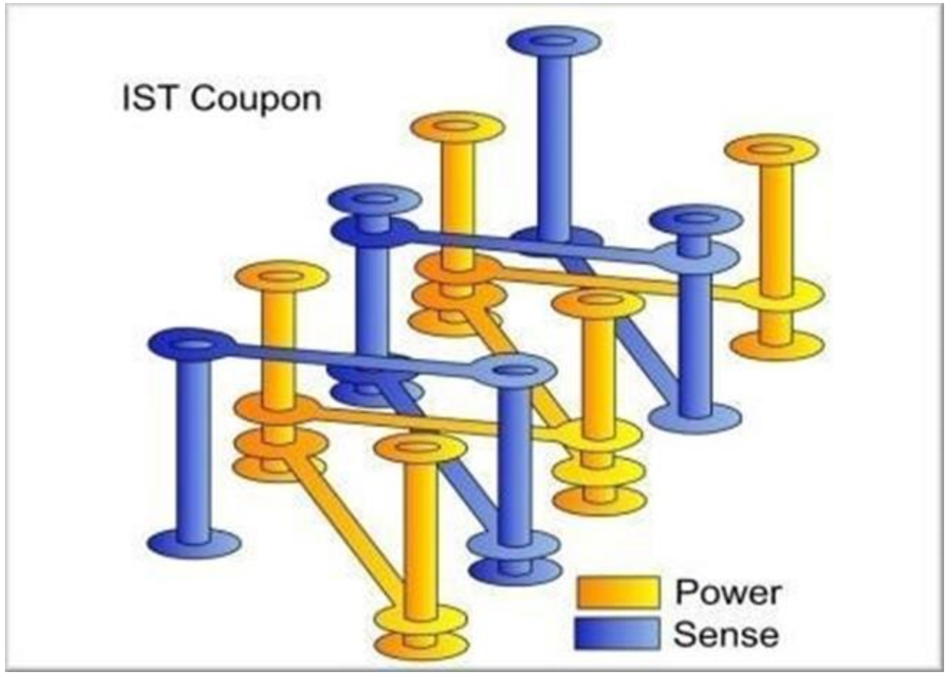


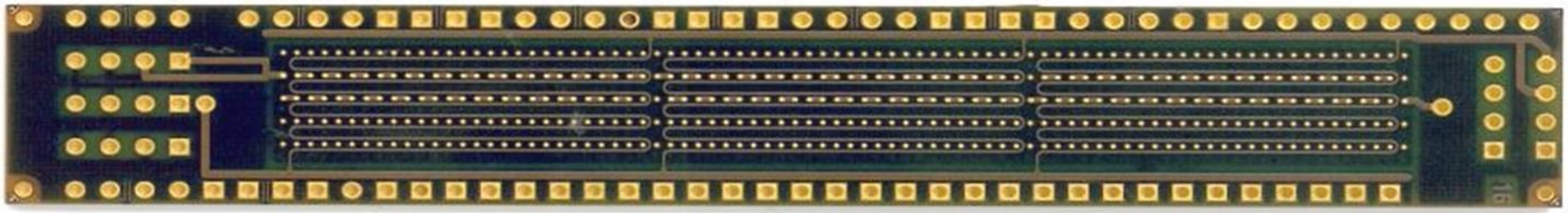
PROOF OF RELIABILITY

Interconnect Stress Test – IST

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

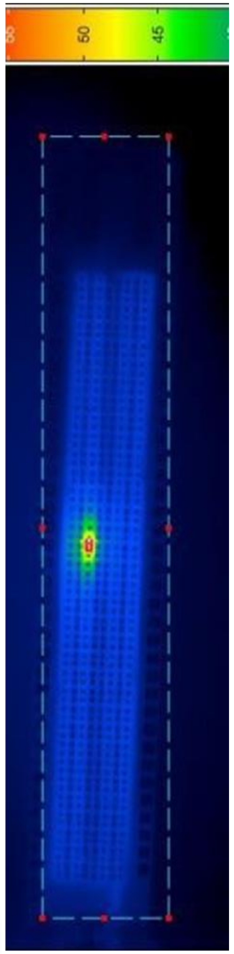
- 1.000 Temperature cycles in 4 days
- Online measurement of the measuring circuits
- IST = very meaningful test
- Special test coupon matched to the PCB design



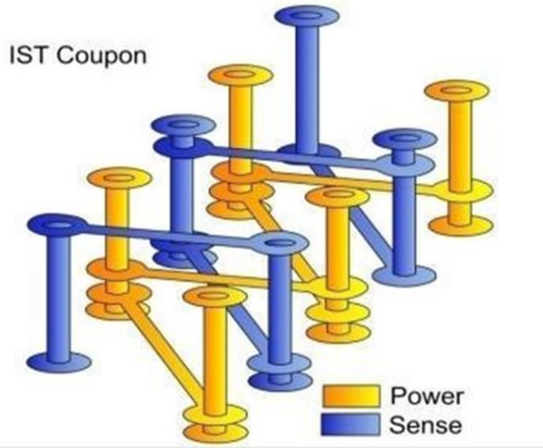


PROOF OF RELIABILITY

Interconnect Stress Test – IST



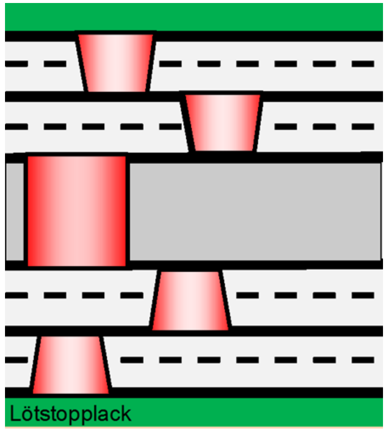
- Pre conditioning
  - 6 x Reflow 245°C or
  - 2 x 260°C Reflow-Simulation by IST or
  - In accordance to customer specification
- Electrical heating of coupons through power-circuit to 150 °C within 3 minutes
- Cooling to room temperature within 2 minutes
- Online measurement of
  - Temperature
  - Resistance
- Error detection



PROOF OF RELIABILITY BY IST

Measurement Results HDI Build-up

- Design without PTH vias
- Reliable produced Microvias have a high thermal cycle stability of significantly more than 1000 IST cycles (≙ 3000 conventional thermal cycles)



TEST RESULTS

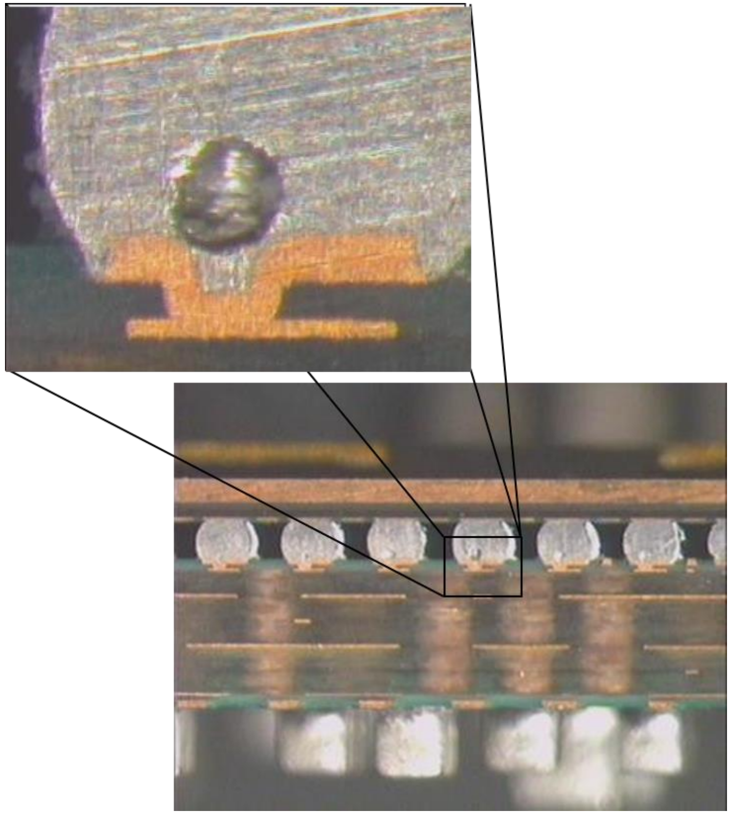
Coupon ID	Pwr Cy-cles	Pwr %	SenseA Cycles	SnsA %	SenseB Cycles	SnsB %	Results
5209_10	**1000**	0	**1000**	0.1	**1000**	0.2	Accept
5209_11	**1000**	-0.3	**1000**	-0.2	**1000**	-0.1	Accept
5209_14	**1000**	0.6	**1000**	0.6	**1000**	0.5	Accept
5209_2	**1000**	-0.1	**1000**	-0.1	**1000**	0.1	Accept
5209_5	**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-----------------------------------

RELIABILITY OF THE PRINTED CIRCUIT BOARD

Solder Process

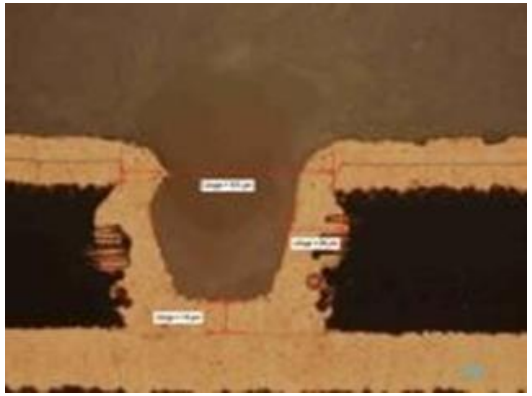


IPC-7095C:
„max. 22 % of the image diameter“

The formation of voids is also dependent on:

- Flux/ solder pastes
- Solder temperature, solder profile
- The uniform or non-uniform heating of the printed circuit board (layout, stackup)

- Confirmation by user

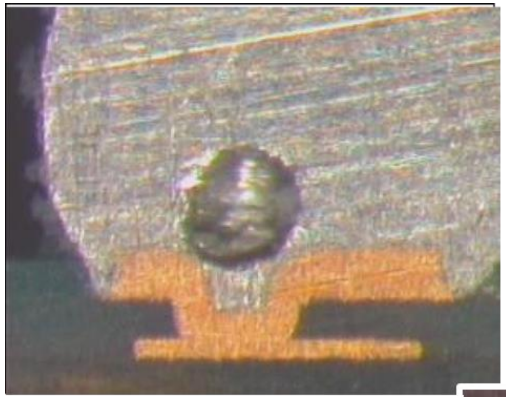


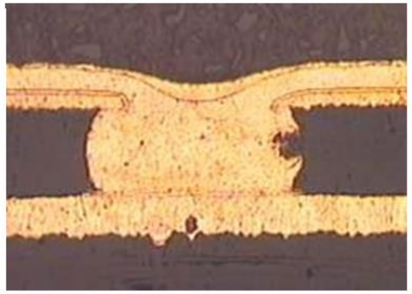
„Microvia-in-Pad-Technology (µViP) is being used by WABCO in HDI products for over 10 years with 0 ppm.“

WABCO

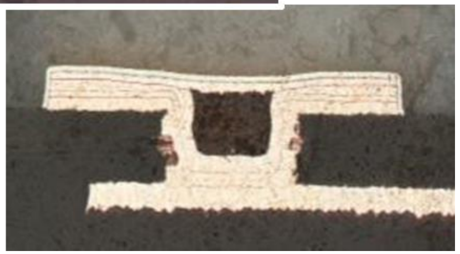
RELIABILITY OF THE PRINTED CIRCUIT BOARD

Solder Process / Microvia Filling





Copper-Filling



Filled & capped

- Two variants
  - Filled microvias (extra charge)
  - Unfilled microvias (void risk)

- So both have
  - Advantages
  - Disadvantages

- User must decide for himself
- WE does not give any recommendation

PRINTED RESISTORS

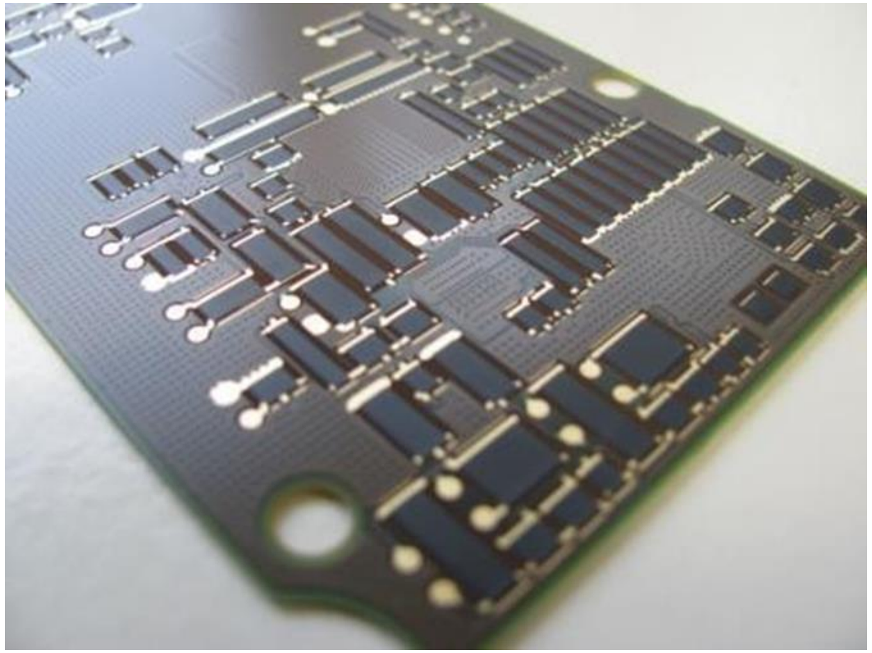
Printed Polymer in General

Applications:

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

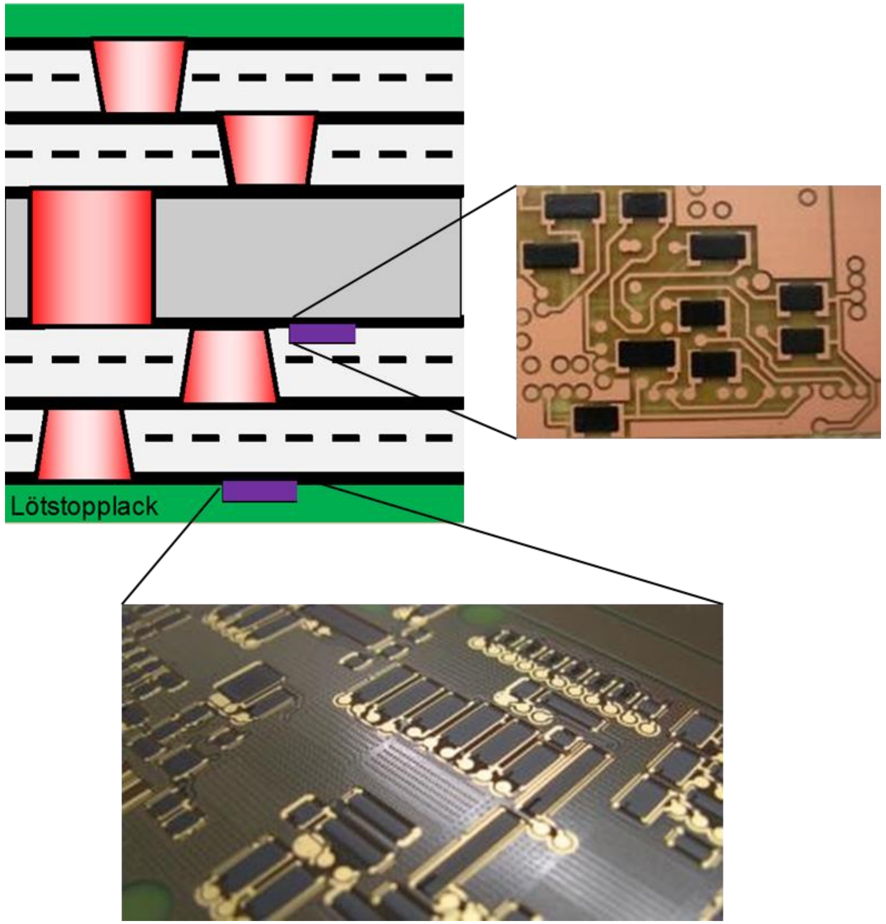
Facts:

- Pastes with different resistance values
- Tolerance printing process R ± 30 % (standard)
- Tolerance after laser trimming ± 5 % for the entire product lifetime
- Resistor values from 50 Ω 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 Guide available



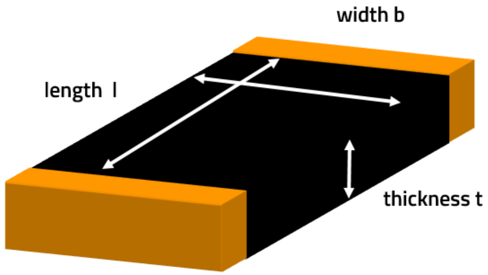
PRINTED RESISTORS

Printed Polymer in General



- Würth Elektronik has many years of experience with printed resistors using polymer pastes (also known casually as "carbon").
- EmbR: Miniaturization potential through embedded resistors
- Reliability advantages
- Dimensioning of the resistors

$$R = \frac{\text{length } l}{\text{width } b} \text{ x ink resistance } \rho$$



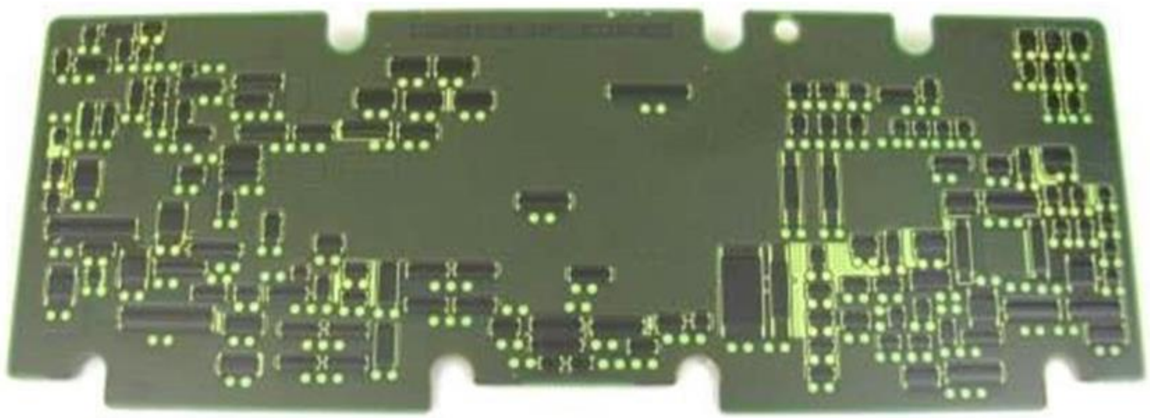
The ink resistance ρ takes into account the square value of the paste and the resistance thickness

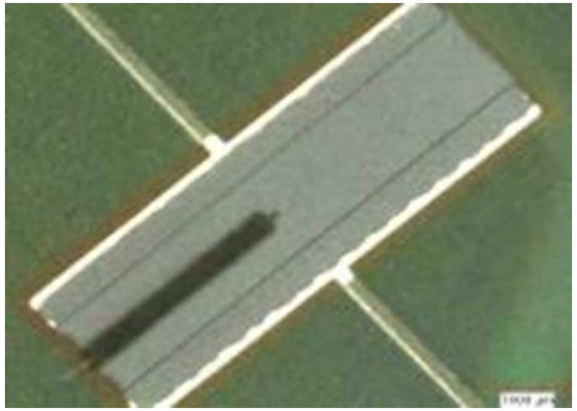
PRINTED RESISTORS

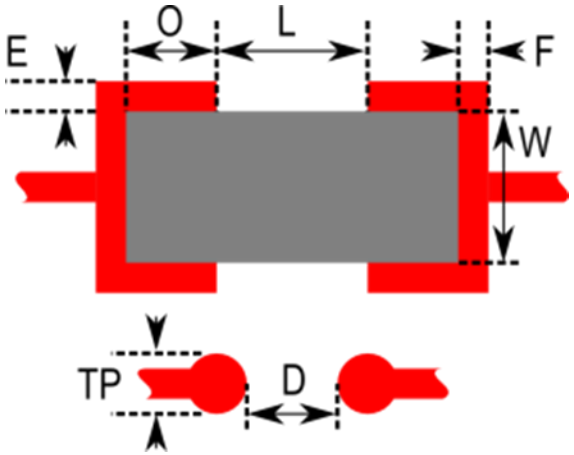
Laser Trimming

Tolerance of resistance value

- Without Laser Trimming maximum ± 30 %
- With Laser Trimming :
  - Up to a maximum of ± 1 % after print
  - Over the entire product lifetime: ± 5 %







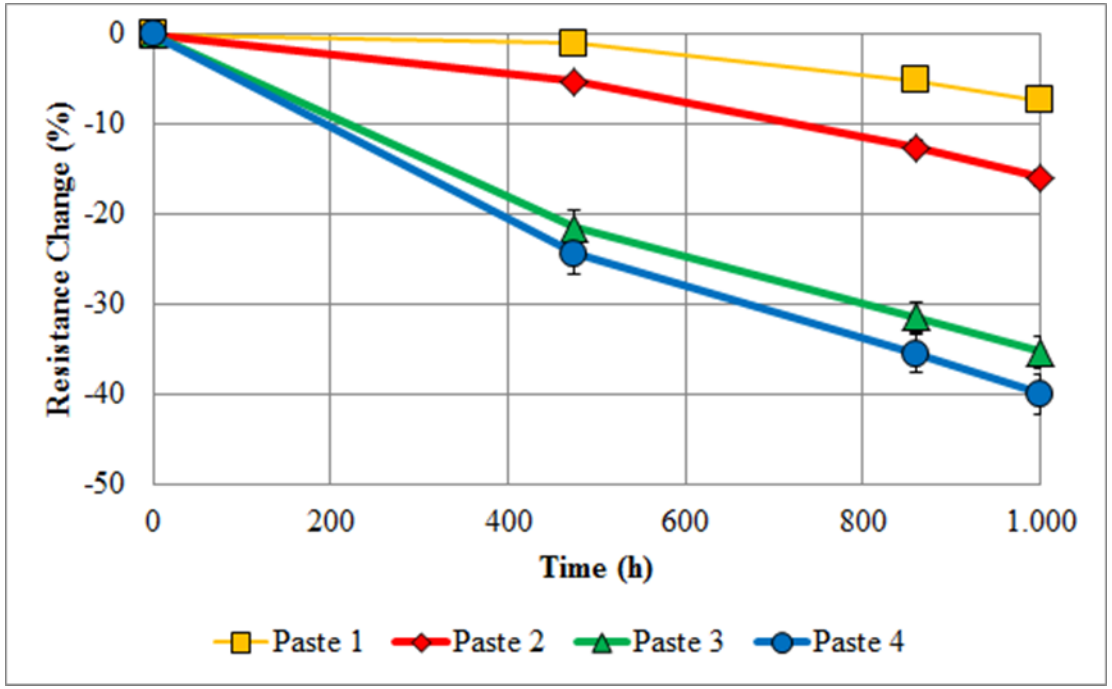
Traceability

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

PRINTED RESISTORS

Choice of Pastes

- Resistance change of 4 pastes @ 155 °C operated with maximum power:



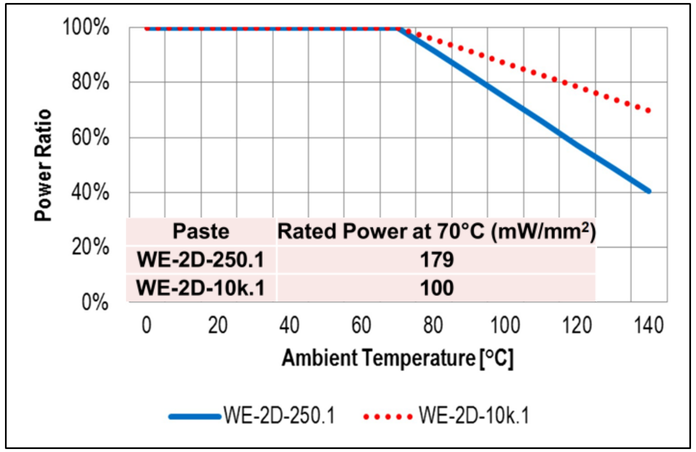
1. Step: Extensive investigations were necessary, in order to determine which pastes could fulfil the demanding requirements of the complete system.

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

PRINTED RESISTORS

Tests

- Power Derating
  Aim of tests is to determine the maximum electrical load of the resistor, without irreversibly damage the resistor. Currant is constant.



- Result: Even at 140 °C the power dissipation is far above the desired 50 mW/mm²

- TCT Thermal Cycle Test (conventional)
  - -40 °C / +155 °C, 1.000 Cycles
  - Transfer time max. 20 s, dwell time 15 Minuten
  - Resistance change max. 2 %

Results

- Passed 4000 cycles at +125 °C without failure.
  - Thermal expansion is comparable to the base material.

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

PRINTED RESISTORS

Qualification of the System Resistors and Voltage Dividers

- Extract of the qualification program

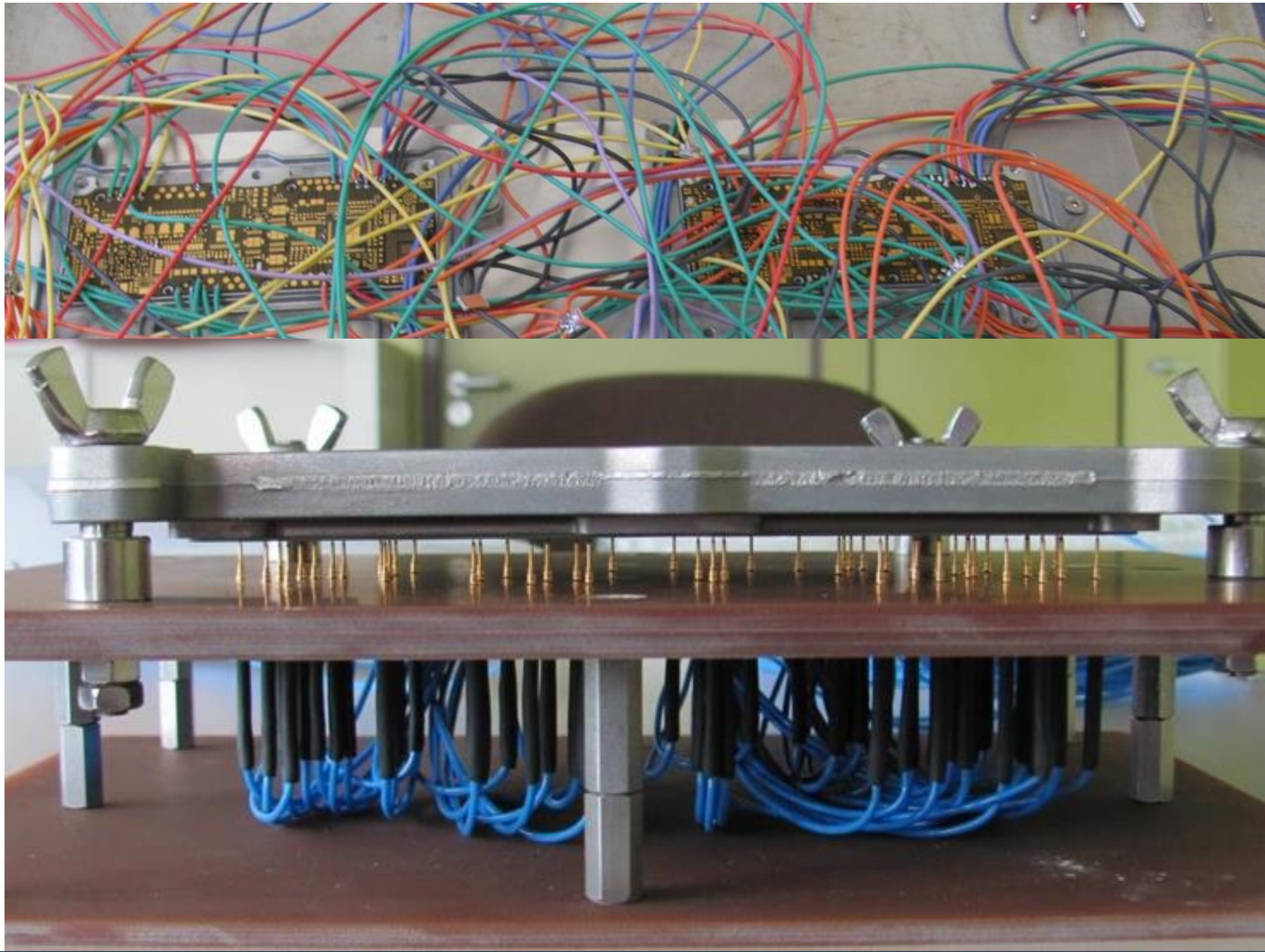
Test	Test method	Procedure	Max. Deviation Single Resistor
Temperature Coefficient of Resistance (TCR)	DIN EN 60115-1:2012-04, 4.8	+20 / -40°C ...+20°C / +140°C	- 700 …– 300 ppm/K
High Temperature Exposure (HTE)	MIL-STD-202 Method 108	**1000 h @ T_A = 150° C unpowered**	+/- 3%
Moisture Resistance	MIL-STD-202 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 %

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

PRINTED RESISTORS

Qualification of the System

- Preparation, measurement setup
  High Temperature Operating Live Test (HTOL)



PRINTED RESISTORS

Annual Re-Qualification of the System Resistors and Voltage Dividers

Requalifizierung: Auswertung HTOL und TWT

WÜRTH ELEKTRONIK

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:

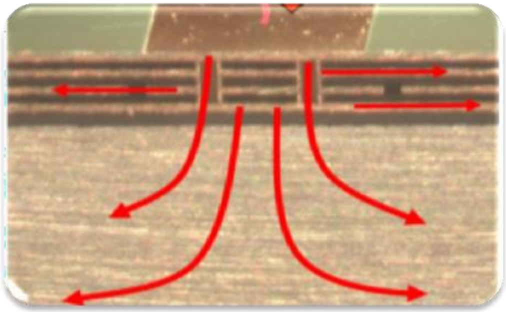
Einzelwiderstände	Spannungsteiler
i.O.	i.O.

THERMAL MANAGEMENT

General Introduction

Options on PCB basis

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

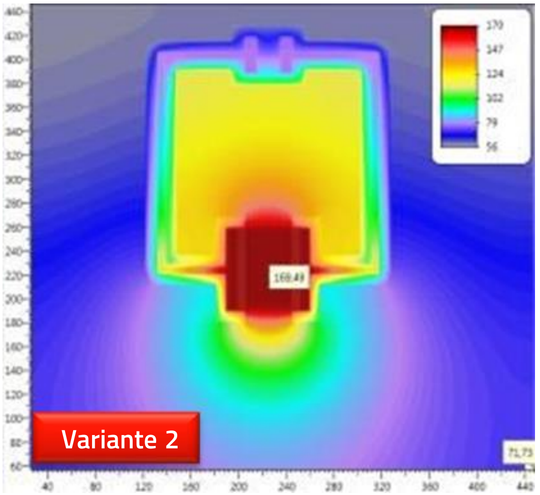


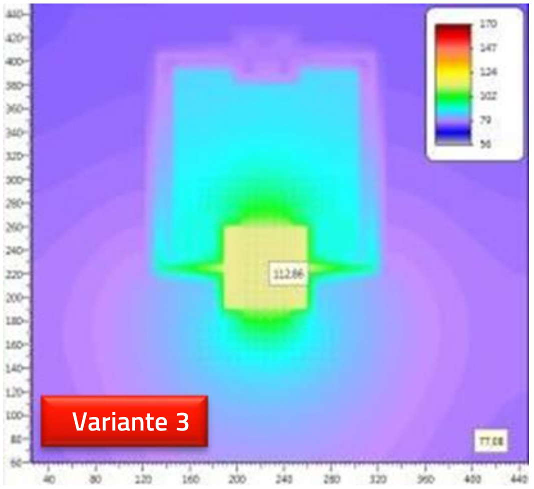
Targets

- 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

- Thermal Simulation

At threshold a thermal simulation in preliminary stages is recommended.



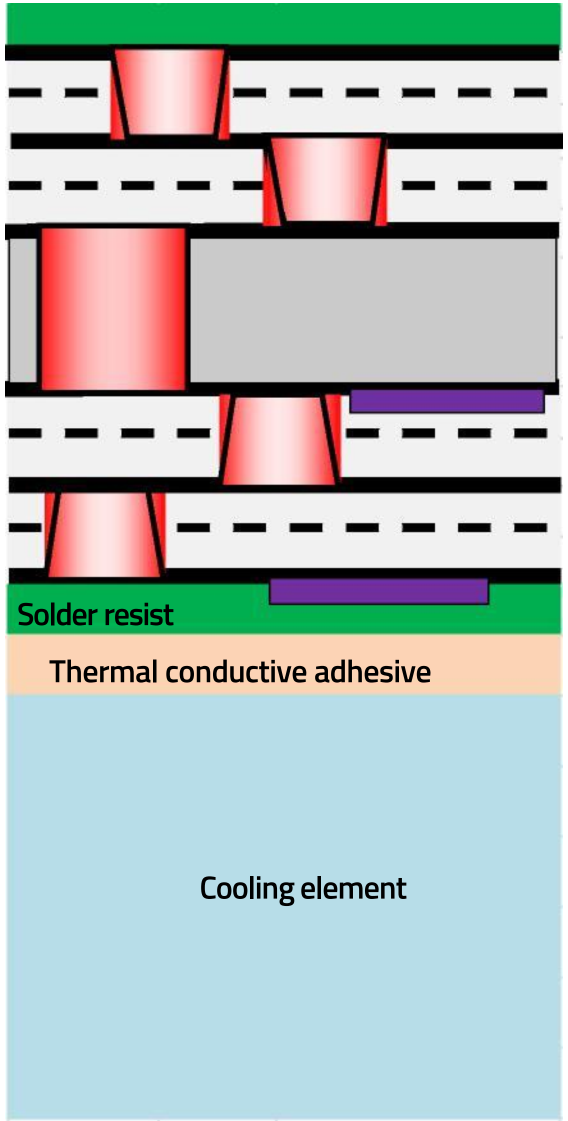


THERMAL MANAGEMENT

PCB System

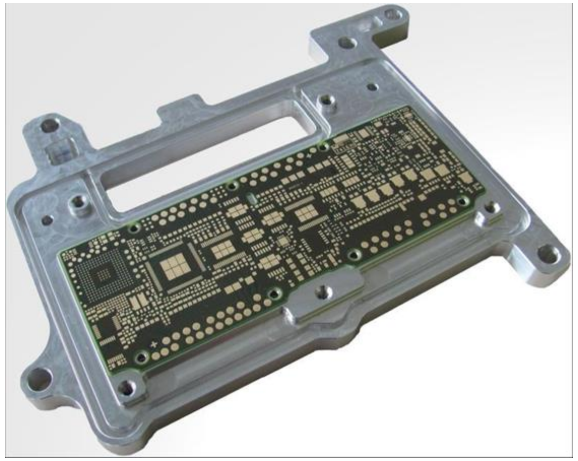
Requirements to the system

- 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 (directly 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)



THERMAL MANAGEMENT

Adhesive Bond Strength

Proof of Adhesion of PCB to ALU heat sink

Target: approx. 0.60 N/mm²

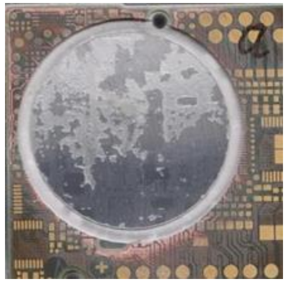
Pretreatment

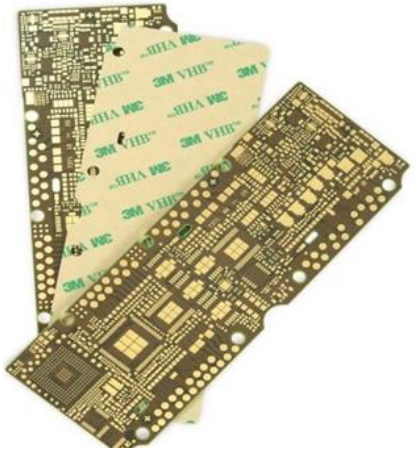
- TCT (-40 °C/ +155 °C) 1.000 Cykles
- Climate chamber 1000 h (85 °C / 85 % humidity)
- High Temperature Exposure (HTE Test) 1000 h in oven / 155 °C

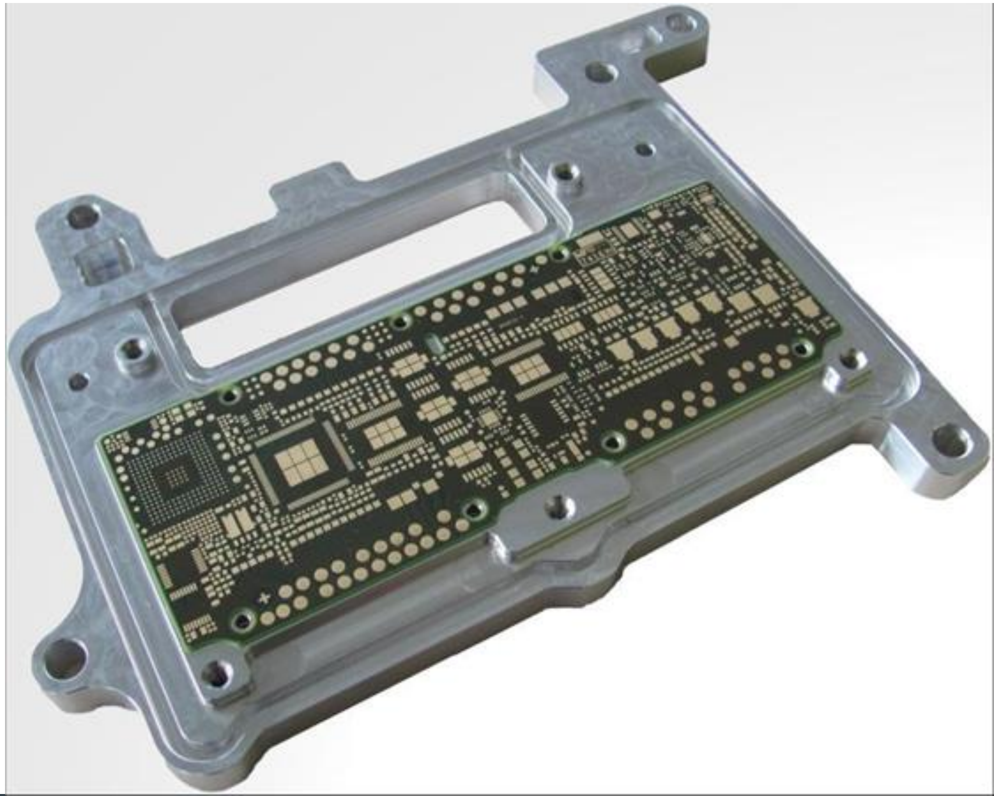
Result

For a good adhesive bond are required:

- Bonding under consideration of defined pressure, temperature and time parameters
- Surface tension ALU min. 38 mN/m

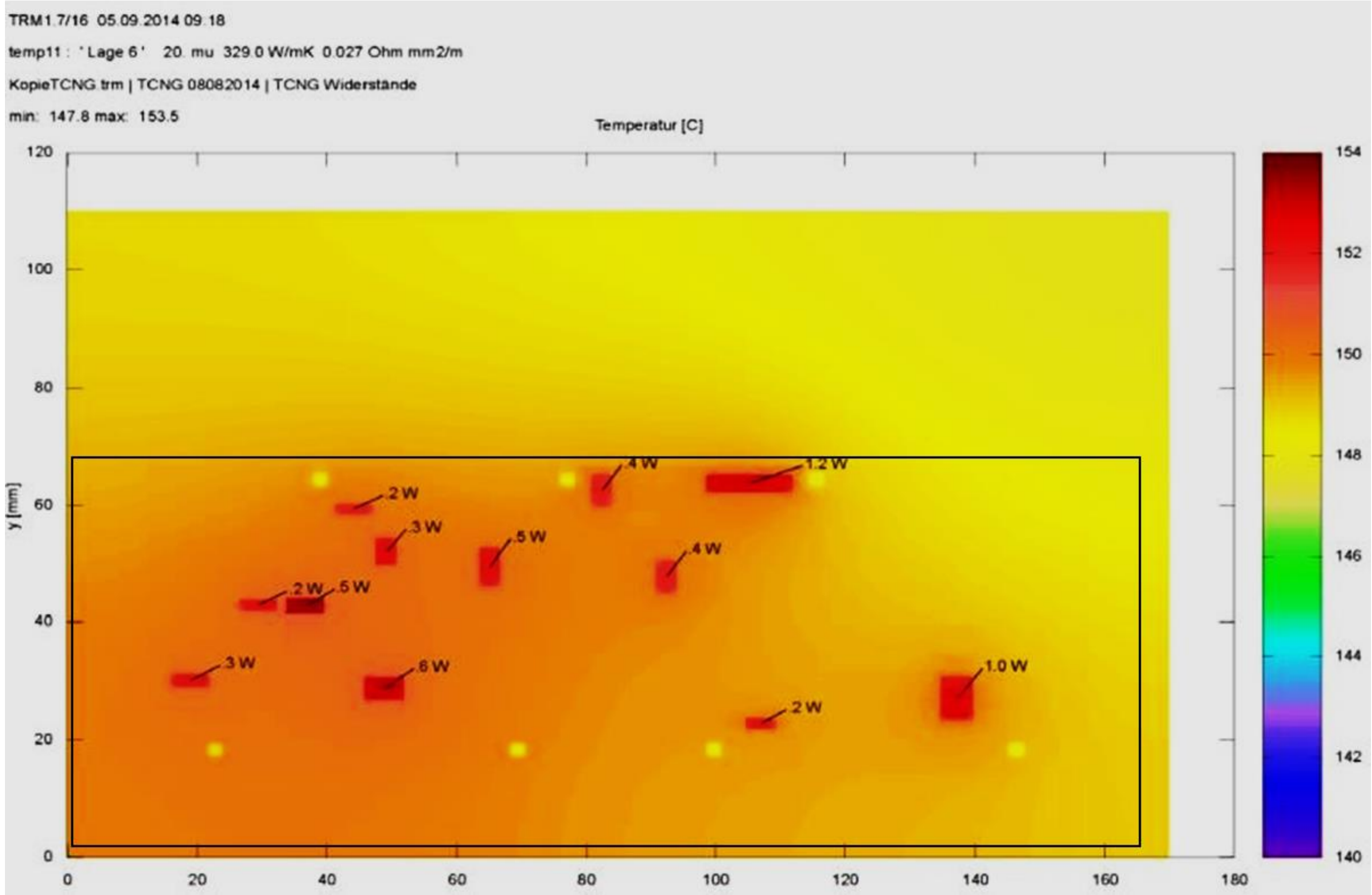






THERMAL MANAGEMENT

Simulation PCB Bottom Side



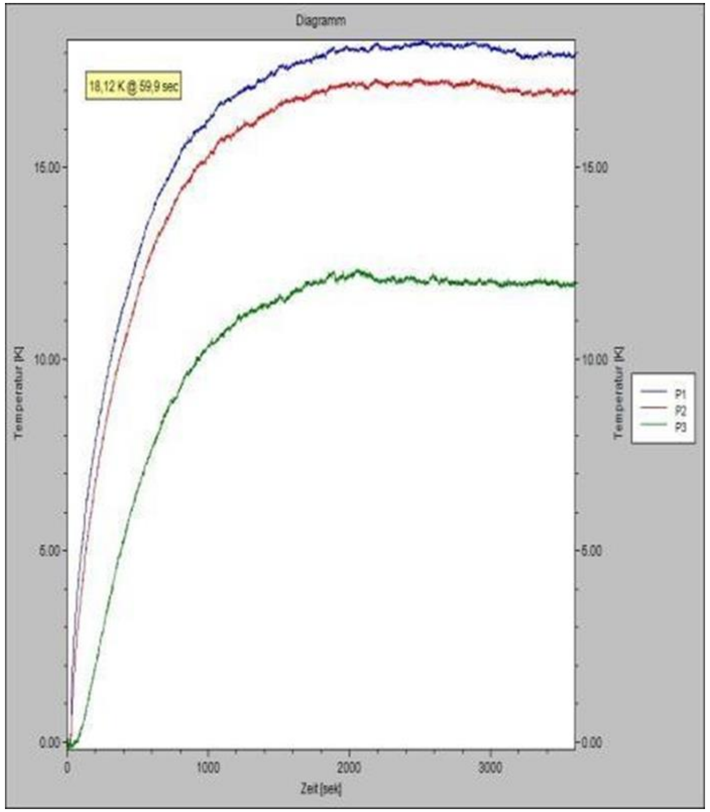
Thermal Simulation - Würth Elektronik CBT Product Management

- Ambient temperature: 140°C
- Maximum Temperature at resistor: 153,5°C
- Power in accordance with customer specification

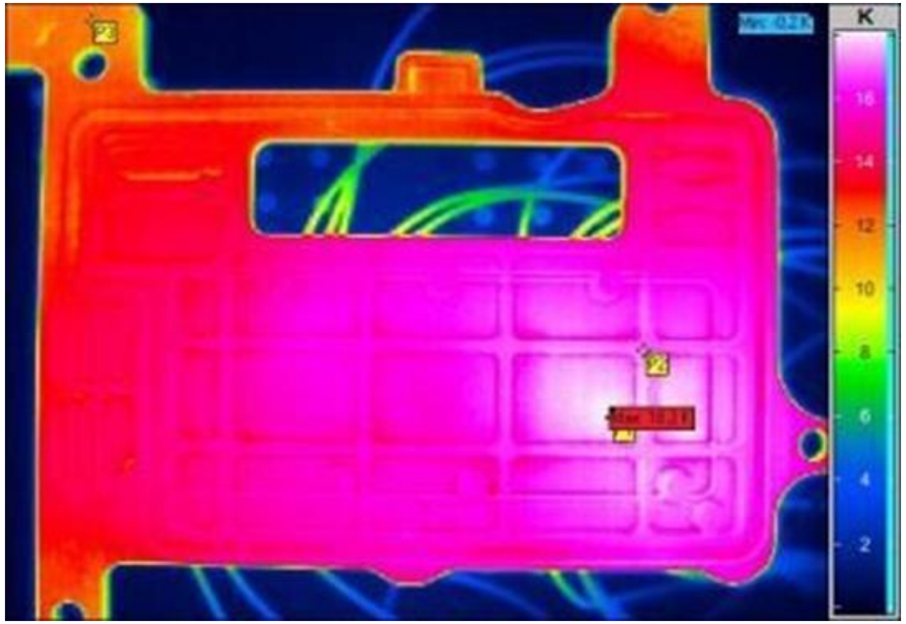
THERMAL MANAGEMENT

Thermography Measurement Bottom Side

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



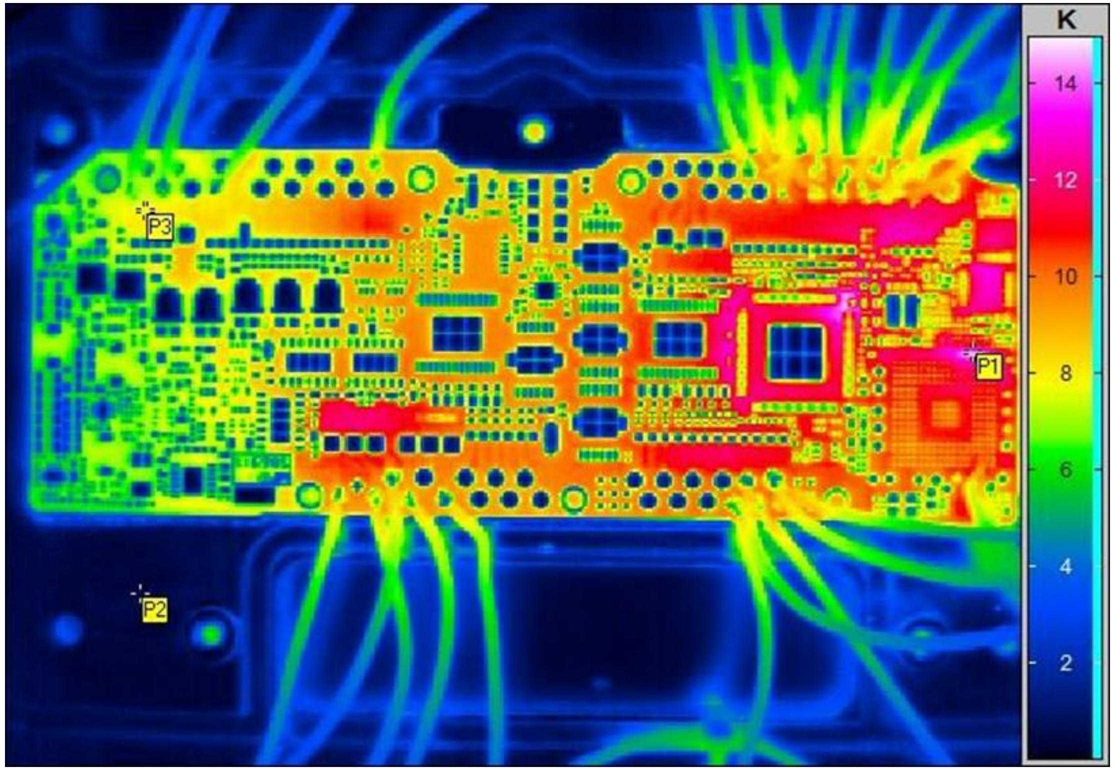
- The thermography measurements essentially confirm the results of the simulation.
- As these measurements are very complex, only a limited number of resistors could be investigated.



THERMAL MANAGEMENT

Thermography Measurement Top Side

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



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

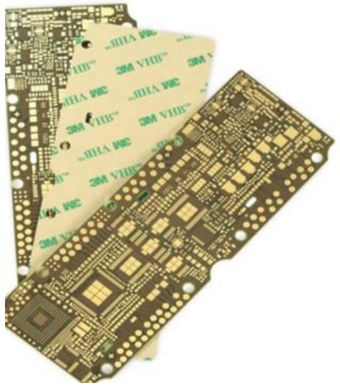
COST COMPARISON

Highly Reliable Printed Circuit Boards and Devices in Automotive Electronics

Ceramics

- High temperature resistance

FR4



- High functionality
- Highest packaging density
- Cost-efficient

COSTS - CIRCUIT BOARD GENERAL

Highly Reliable Printed Circuit Boards and Devices in Automotive Electronics

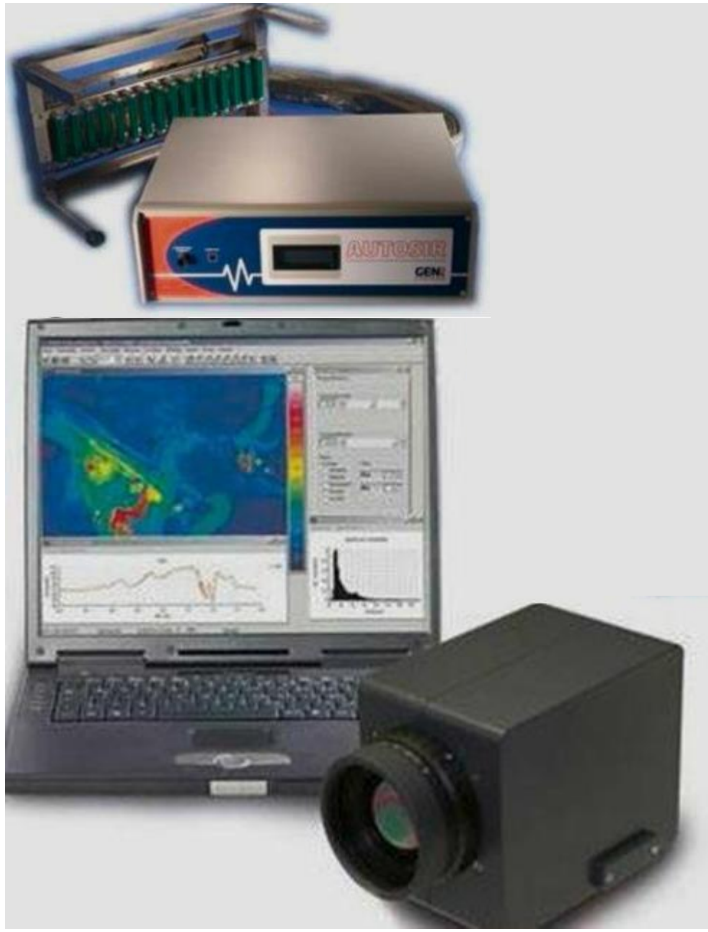
- Main advantage FR4 PCB: Production in the "large" production panel

PCB Cost drivers		FR4 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 prepregs Tg 170°C
Mechanical drilled Vias	++	Only buried vias in a thin core
Number of plating steps	≈	Only three „simple“ plating processes
Complex contour machining	+	Simple milling contour

REQUIREMENTS TO PCB MANUFACTURER

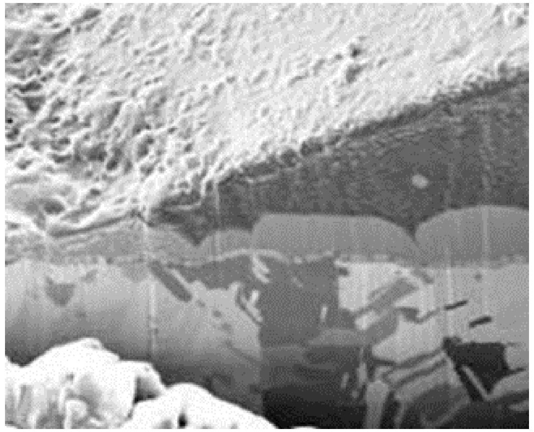
Highly Reliable Printed Circuit Boards and Devices in Automotive Electronics

- Metallurgic analysis
- Inspection acc. 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**



Collaboration with instituts

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



SUMMARY

Highly Reliable Printed Circuit Boards and Devices in Automotive Electronics

- Miniaturisation through
  - HDI Technology
  - Printed resistors (Printed Polymer)
- Highest reliability using a thin HDI build-up without PTH vias
- A technology combination of
  - HDI,
  - Printed resistors and
  - Optimized Thermal Management

  can enable a cost effective substitution of a ceramic 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 / range of services in the future.

THANKS FOR YOUR ATTENTION

High Performance PCB System

Miniaturisation: HDI & Thermal Management & Printed Polymer