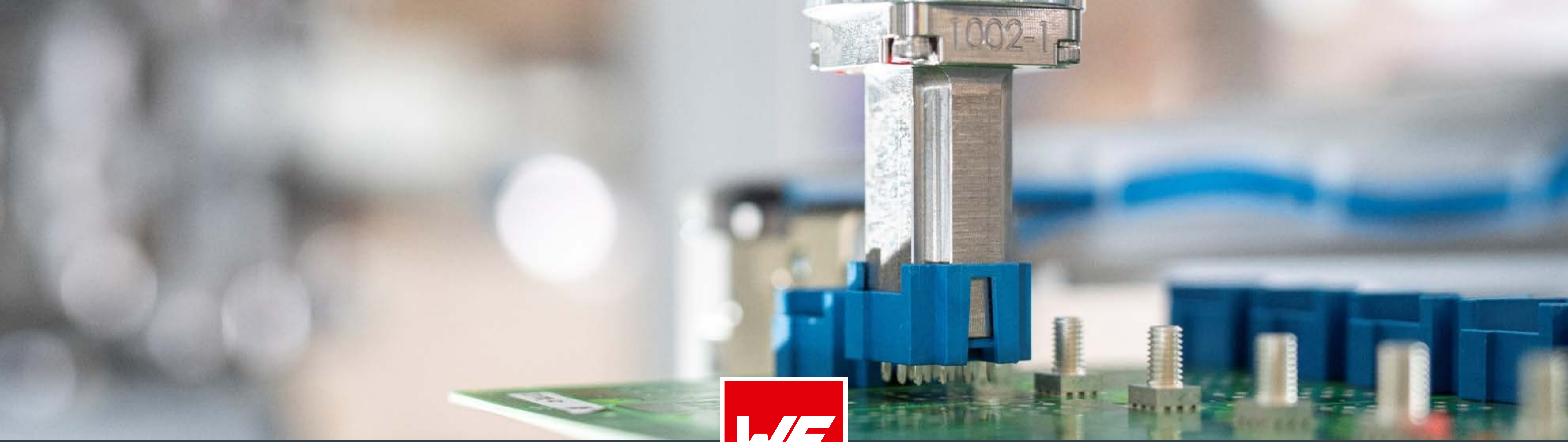


PRESS-FIT TECHNOLOGY IN (HV) APPLICATIONS

For Robust and Durable PCB Connections

POWER ELECTRONICS

ENERGY STORAGE

Power Electronics & Energy Storage event

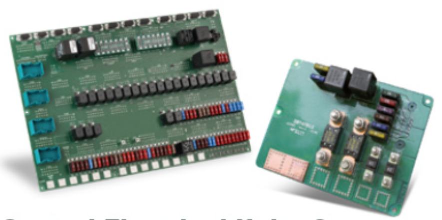
27 juni 2023 | 1931 Congrescentrum 's-Hertogenbosch

CONTENT

1. Introduction to Würth Elektronik ICS
2. Basics of Press-Fit
3. Connecting Solutions
4. Press-Fit Components
5. Press-Fit Technology in (HV) Applications
6. Handouts Reference Material – for reading afterwards

Würth Elektronik ICS

Intelligent Power & Control Systems



Central Electrical Units & Powerboards

Power Boxes

Controllers

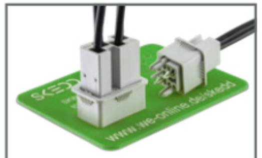
HIGH-PERFORMANCE COMPONENTS FOR A WIDE APPLICATION SPECTRUM

SYSTEMS FOR MOBILE MACHINES AND COMMERCIAL VEHICLES

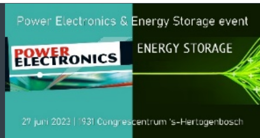
HMI Solutions

HV Solutions

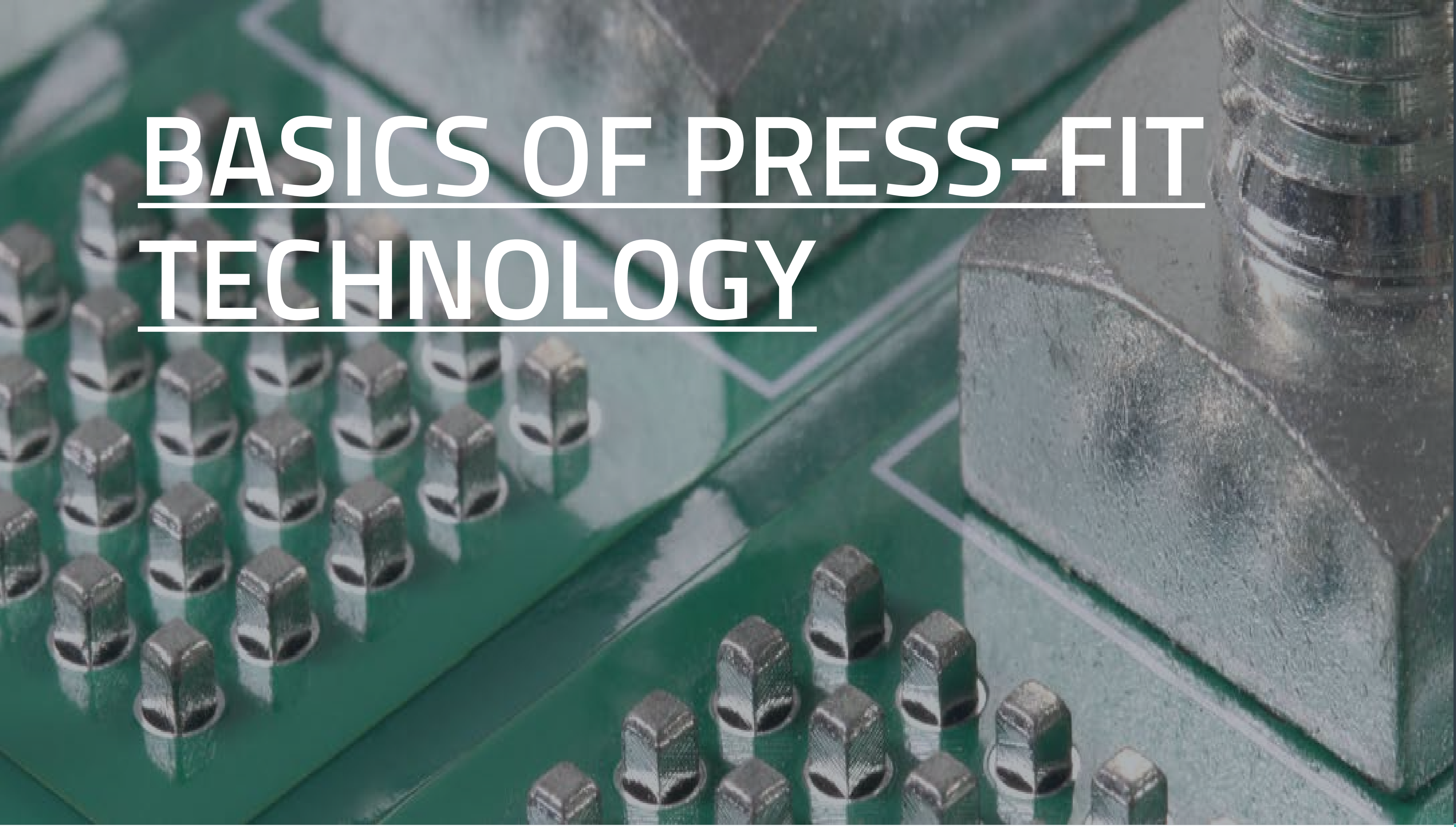
Powerelements



Plug Connection Technology



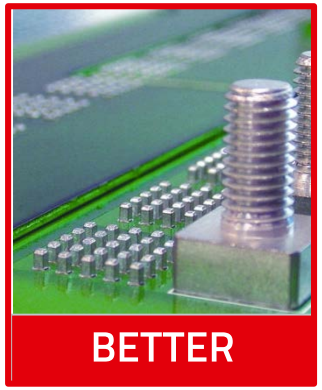
BASICS OF PRESS-FIT TECHNOLOGY

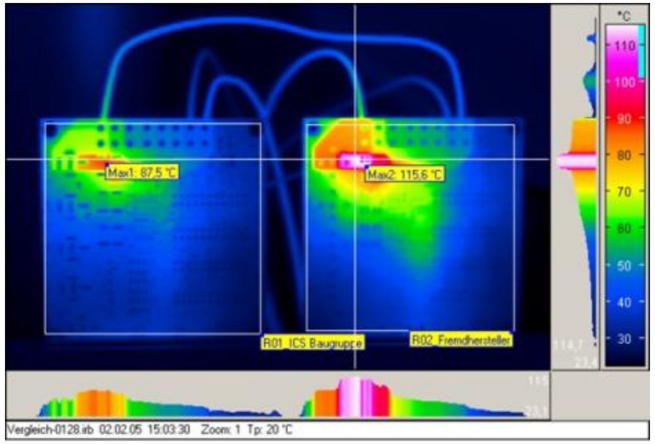


PRESS-FIT TECHNOLOGY VS. SOLDERING TECHNOLOGY

Stable solution without thermal load

- Elimination of soldering defects (e.g. solder bridges, cold solder joints, etc.)
- Avoidance of flux residues, which can lead to contact faults
- Higher holding force
- No size restrictions for assemblies to be processed due to soldering system specifications
- Long connectors remain clean and can be used for transfer on the rear side
- Lower contact resistance due to homogeneous material transition
- Very high current carrying capacity
- Higher environmental friendliness





Comparison of the thermographic image of an assembly with soldered connection and press-fit technology

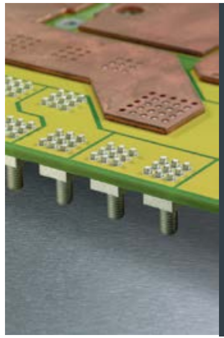
left: Press-fit technology; right: soldering technology

Basics of Press-fit Technology

CURRENT CARRYING CAPACITY

Solder connection

- Heterogeneous material transition due to applied solder leads to higher power dissipation
- Contact resistance is about twice as high as with press-fit technology and is approx. **400 µΩ**



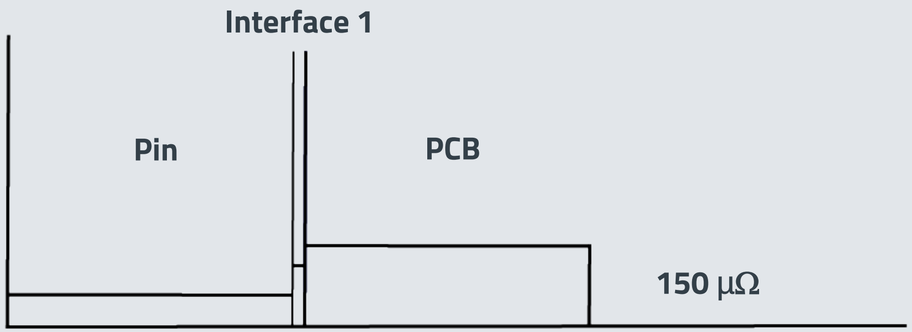
Press-fit connection

- Seamless and very homogeneous material transition between press-fit pin and PCB copper
- Contact resistance is approx. **150 µΩ**

Interface 1 **Interface 2**

Pin **Solder** **Circuit Board**

300 - 400 µΩ



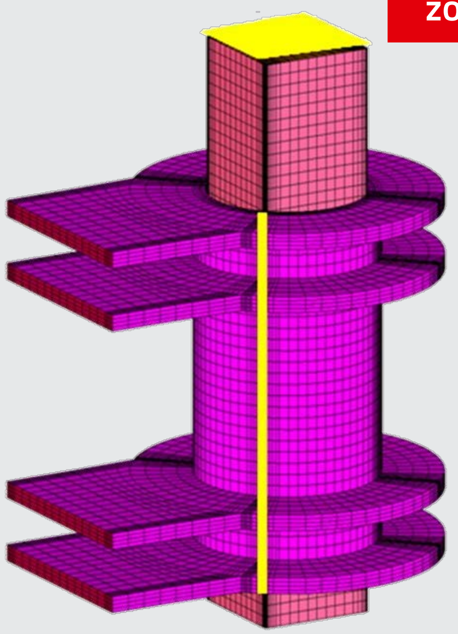
PRESS-IN ZONE

Physical consideration of the press-in zone

- In order to ensure a high current transmission, the contact resistance of the press-fit connection must be smaller than the intrinsic resistance of the pressed pin.
- This is ensured if the connection area between pin and sleeve is at least equal to the cross-sectional area of the pin.

Connection surface between pin and sleeve ≥ Cross-sectional area of the pin

Schematic illustration of a press-fit zone with solid pin in a 4-layer circuit



Basics of Press-fit Technology

PRESS-IN ZONE

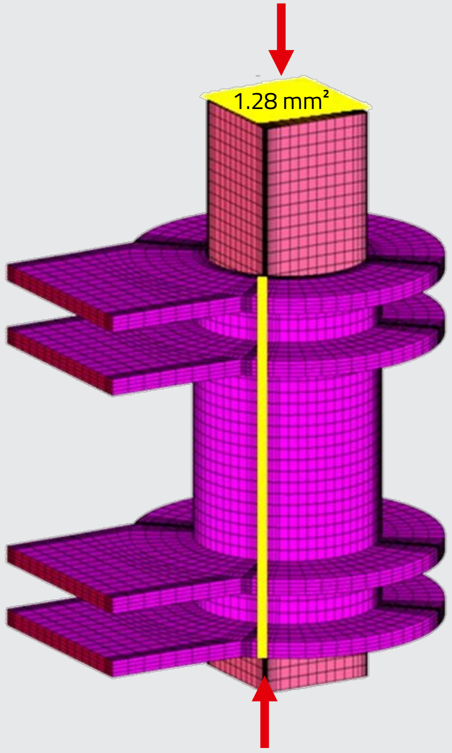
Assumption:

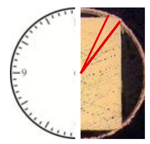
- The cross-section of a solid press-fit pin is 1.28 mm² (1.13x1.13mm)
- Diagonal is 1.60mm
- The PCB has a thickness of 2.40 mm with a copper sleeve diameter of 1.45 mm.

Connection area between pin and sleeve ≥ cross-sectional area of the pin:
$4 \times 2.40\ mm \times \varphi \times 0.725\ mm \geq 1.28\ mm^2$=
$\varphi \times 0.725\ mm \geq 1.28\ mm^2 / 4 \times 2.40\ mm$

$\varphi \geq 0.184$ or $\varphi \geq 10.6°$ in angular measure

If pin and sleeve are made of the same material (Cu) and the connection angle per connection is at least 10°, the press-fit zone does not represent an electrical or thermal bottleneck.

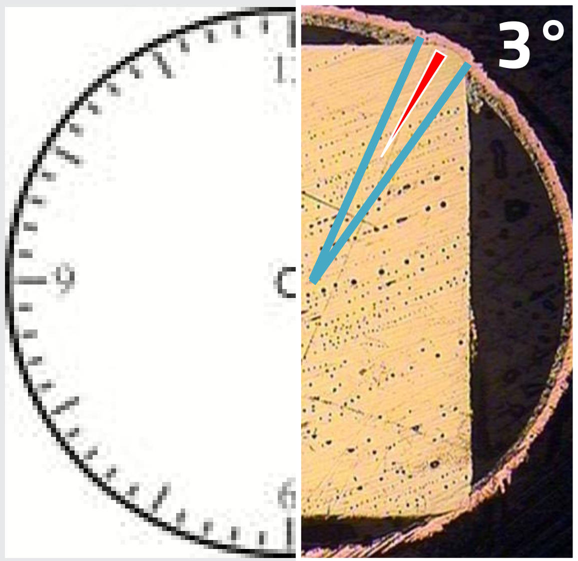




Basics of Press-fit Technology

PRESS-IN ZONE

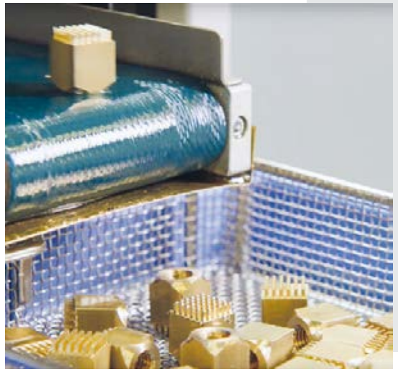
- **In practice:** Pin material of the powerelements is made of brass. This is due to material characteristics as conductivity, stiffness and milling capabilities.
- Copper has a 4x better conductivity to brass.
- That means the copper in the PCB has 4-times better electrical conductivity (57.5 MS/s), than the brass pin (14.6 MS/m).
- In theory, we could reduce the contact angle to 3°.



Minimum pin connection compared to the real press-in zone

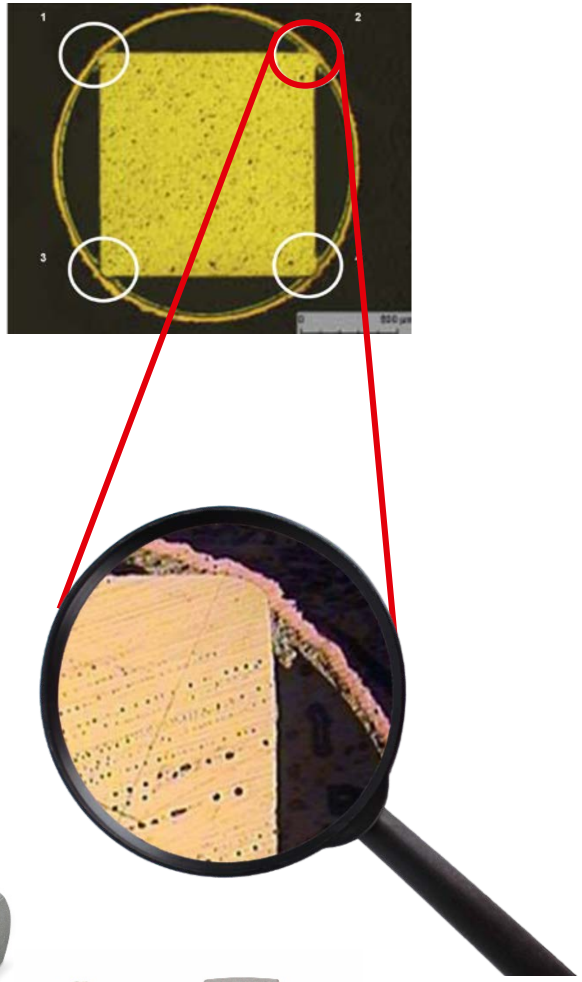
- *Minimum tie-in angle of 3°*
- *Real press-in zone, 10°-12°*

According to Ohm's law it follows:
The required connection angle is only 3°

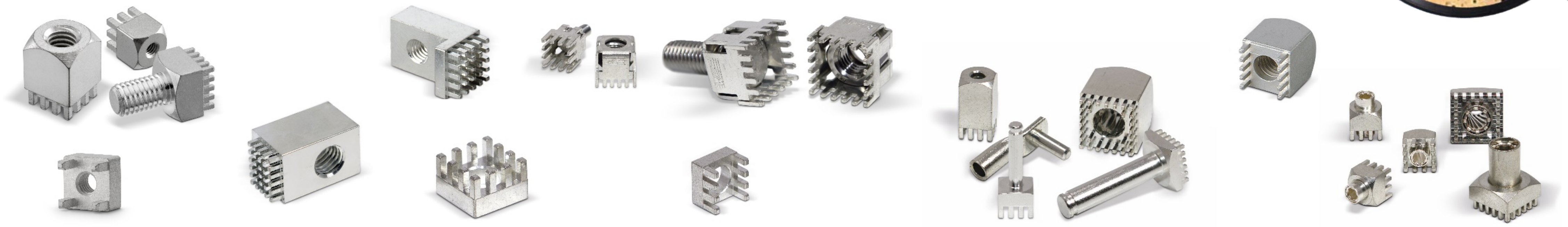


Basics of Press-fit Technology

MECHANICAL PROPERTIES



- To ensure a secure connection, the contact pin to be pressed has a **larger diagonal** than the hole in the PCB.
- Due to the oversize of the contact pin, an overpressure is generated **during press-fitting, which leads to a deformation of the contact pin or the PCB hole.**
- Very high contact forces act at the deformed points, guaranteeing **a secure and stable connection even under thermal and mechanical loads.**
- A single pin typically has a holding force of **over 20 N**, depending on the copper thickness of the sleeve used and applied press-in force.
- A surface metallization leads to an **increase of the forces by 25 – 30 %**



Basics of Press-fit Technology

CURRENT CARRYING CAPACITY

The contact resistance of the press-fit connection is smaller than the intrinsic resistance of the pressed pin.

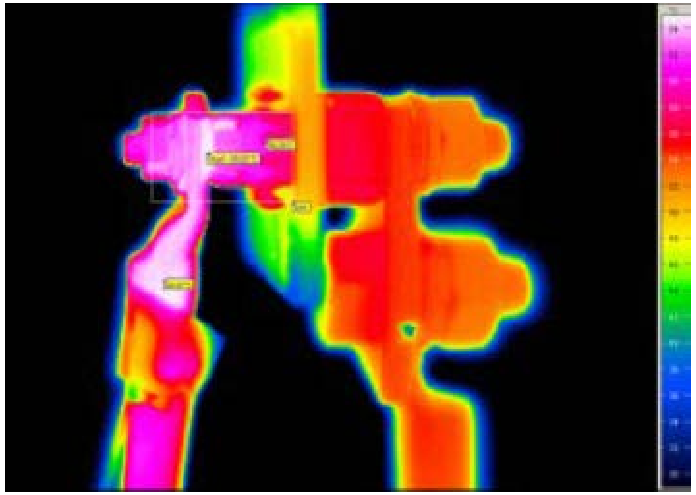
→ This results in **a very high current carrying capacity** of the press-fit connection.

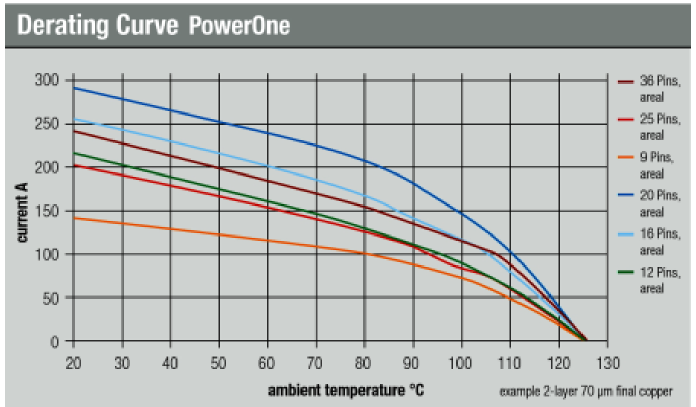
→ The press-fit connection therefore has a **low heat generation**.

→ The low power dissipation is particularly important, as any contact resistance can lead to a drop in voltage in the electrical system.

→ A too low voltage level can lead to a reset and endanger the full functionality of the system, for example CAN frame errors, analog input variations, GND issues.

Conclusion: low contact resistances are essential for maintaining a correct system operation.





CURRENT CARRYING CAPACITY – ON THE EXAMPLE OF POWERELEMENTS

THE CURRENT CARRYING CAPACITY OF THE POWERELEMENT IS INFLUENCED BY SEVERAL FACTORS:

LAYOUT OF THE PCB

- Conductor cross-sections (conductor width and copper thickness)
- Copper composition in the circuit board
- Positioning of the Powerelement
- Through-hole plating / vias

ENVIRONMENTAL CONDITIONS

- Operating temperature range
- Load currents
- Load intervals
- Thermal management / cooling (active / passive)
- Permissible temperature limit
- Dimensioning of supply lines (cables, busbars, etc.)

SELECTION OF THE POWERELEMENTS

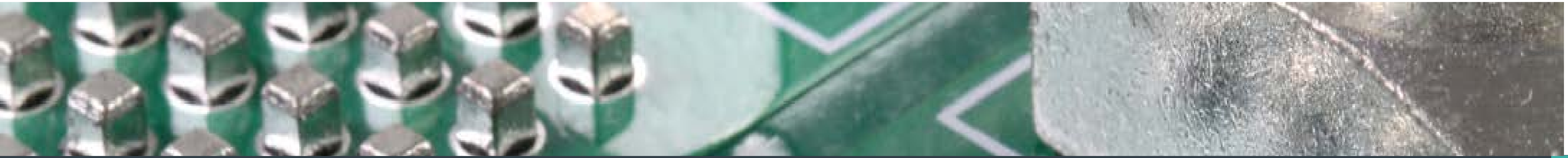
- PCB connection technology
- Material selection
- Dimension
- Number of contact points (pins)
- Dimension of soldering and screwing surfaces

The challenge in designing high-current systems lies in the optimal **interaction of all system components.**

ADVANTAGES OF PRESS-FIT TECHNOLOGY

Numerous outstanding features

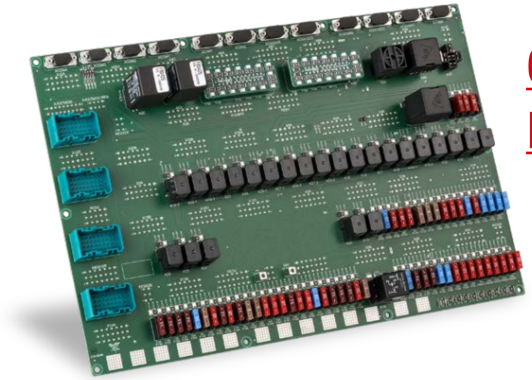
- **Seamless and homogeneous material** transition between press-fit pin and PCB copper
- **Gas-tight connection** through cold welding
- Excellent **mechanical stability** under the toughest environmental conditions
- **No thermal stress** on the printed circuit board
- Significantly **lower contact resistance** between the press-fit pin and the PCB sleeve due to cold-welded connection
- **No danger of cold solder joints**
- **High mechanical load capacity** and **vibration resistance**
- **Compact design** of the assemblies and **reduction of the required installation space** through double-sided assembly of the printed circuit board



PCB WITH PRESS-FIT TECHNOLOGY VS. WIRING HARNESSES

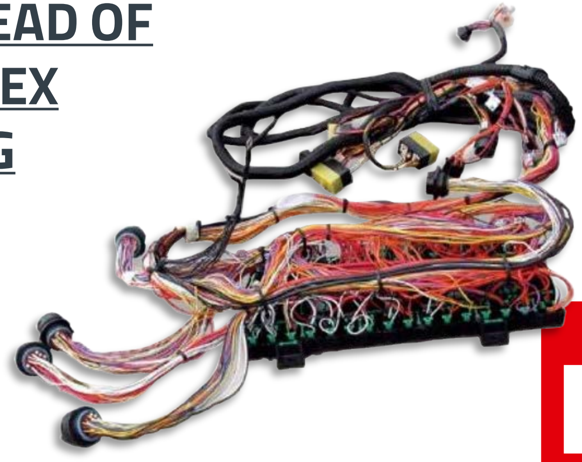
- Clear and reliable solution
- Up to 30 % wiring harness reduction
- Reduction of cable cross-section by up to 50%
- Connection of power and signal lines without complex potential separation
- No wiring errors
- Up to 80 % less assembly effort
- Reduction of interfaces
- Weight and space savings

- Real life example: Central electric PCB of a passenger bus:
- Original wire harness 986 wires.
- Reduction using a PCB system: 263 wires
- Reduction 36%

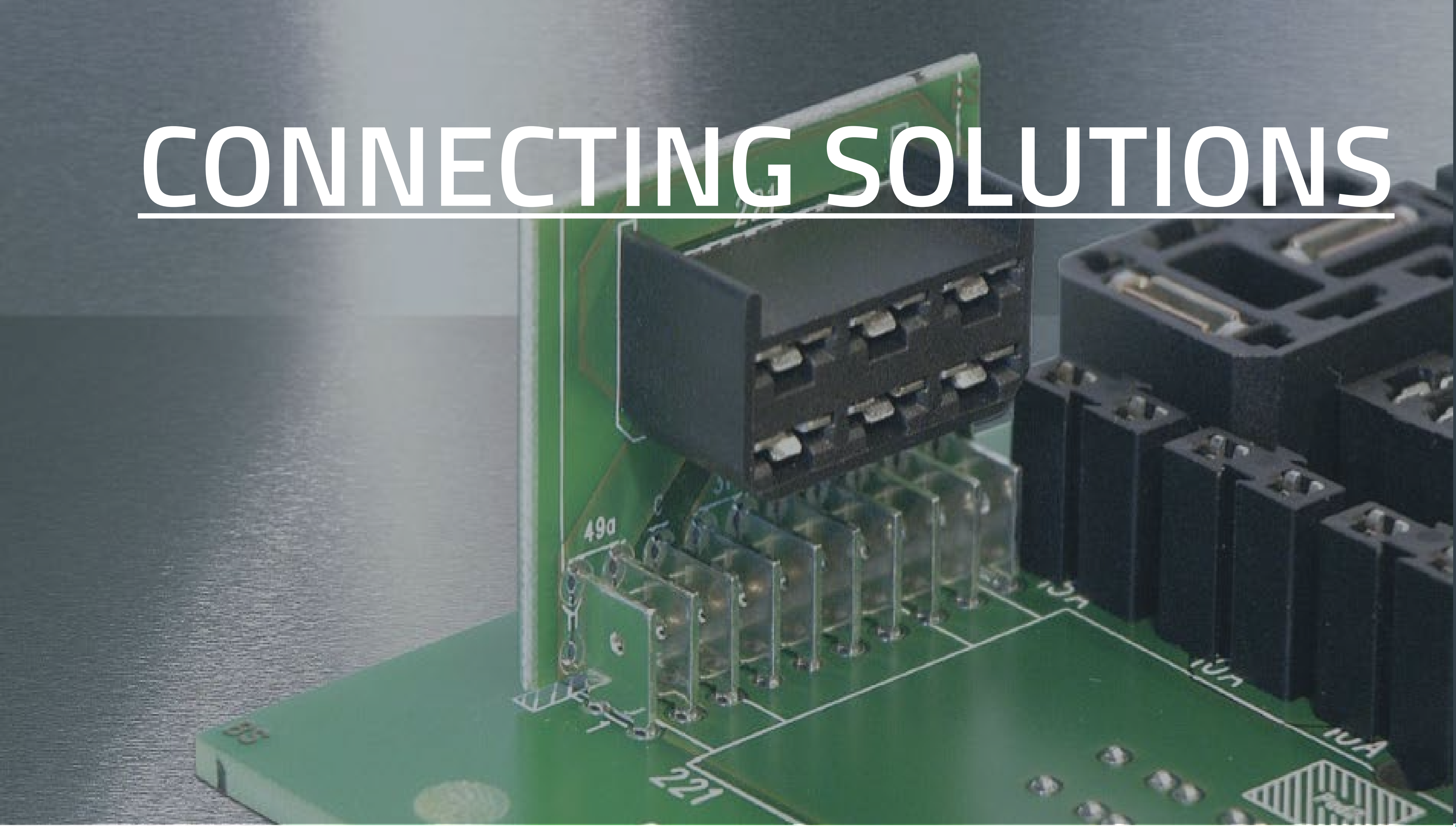


CLEVERLY PRESSED-IN…

…INSTEAD OF COMPLEX WIRING



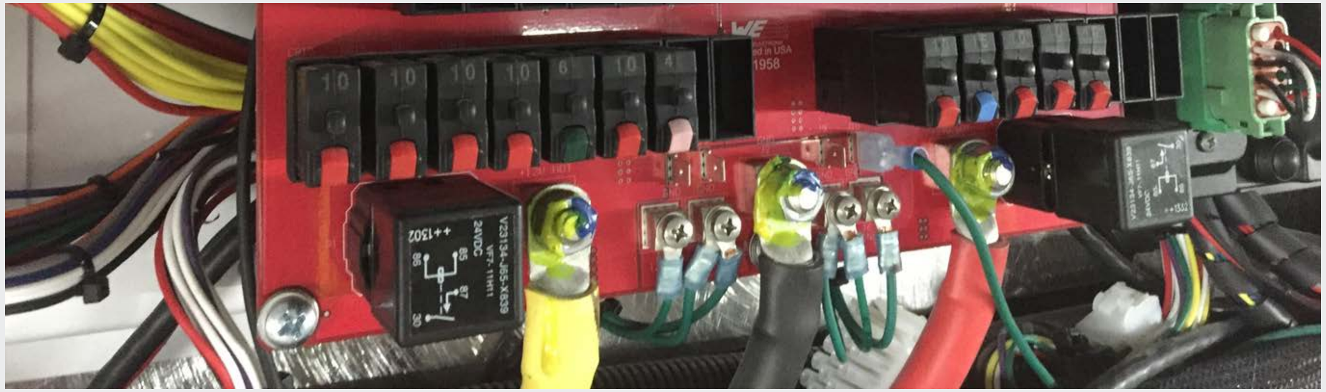
CONNECTING SOLUTIONS



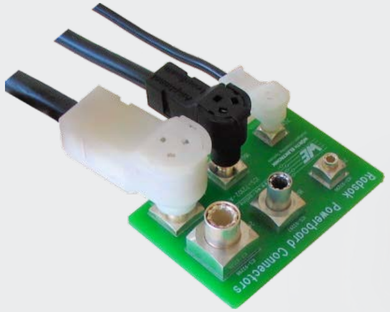
Connecting Solutions

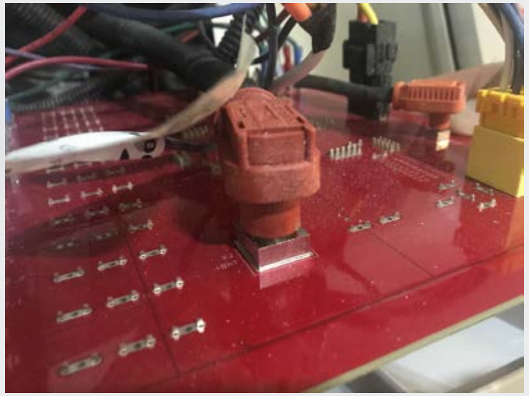
CABLE CONNECTION

CABLE LUG



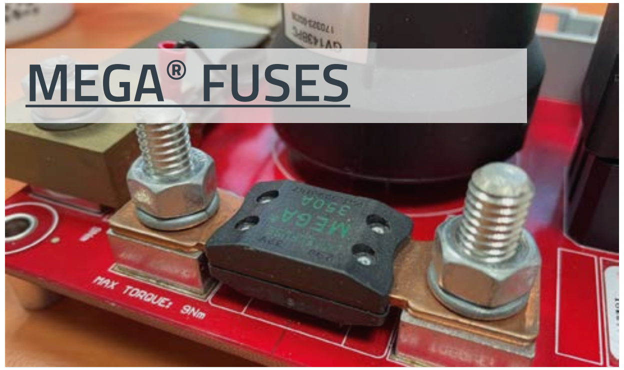
PLUG & PLAY CONNECTION



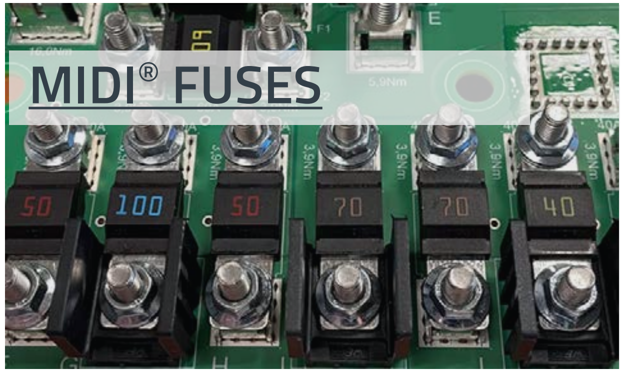


Connecting Solutions

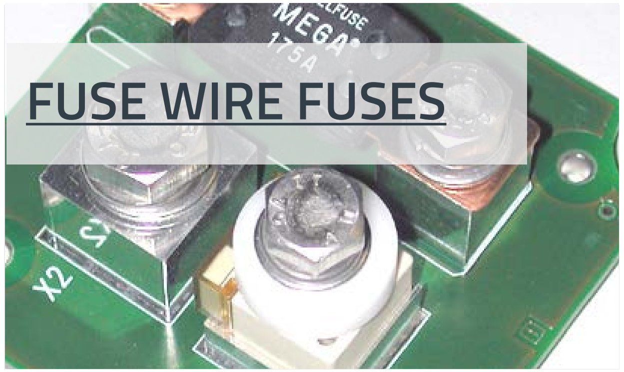
CONNECTION OF RELAYS AND FUSES



MEGA® FUSES

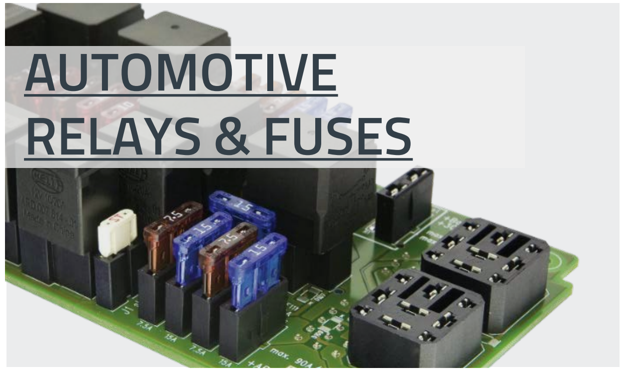


MIDI® FUSES

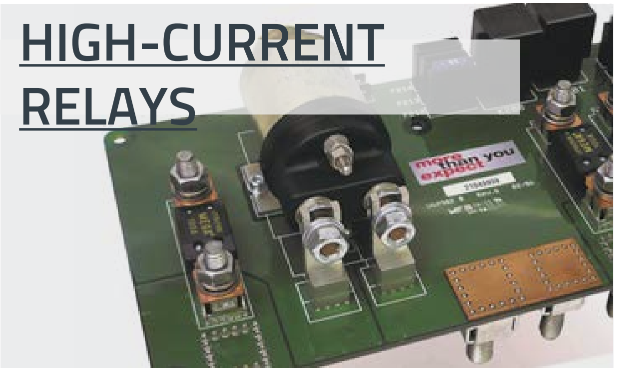


FUSE WIRE FUSES

HV FUSES & RELAYS



AUTOMOTIVE RELAYS & FUSES

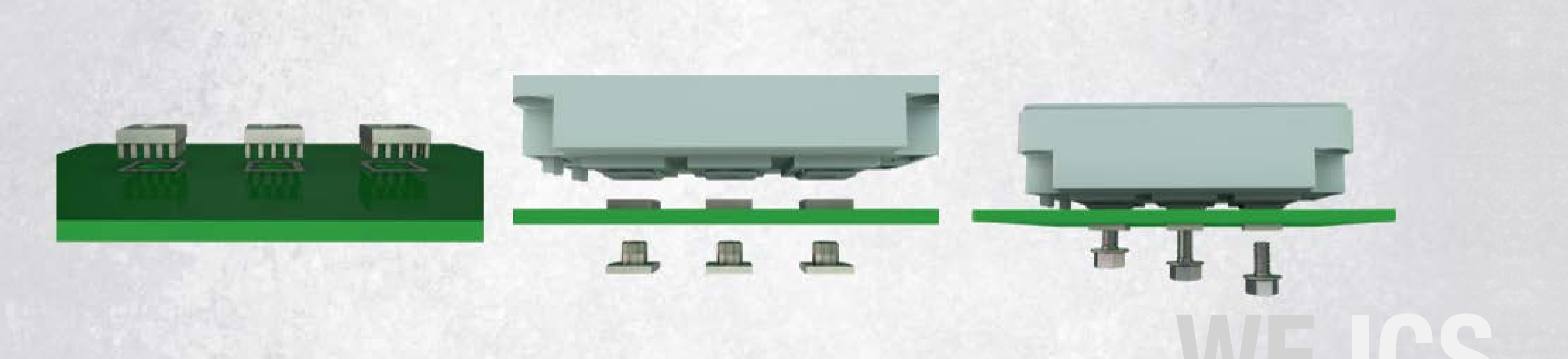


HIGH-CURRENT RELAYS

Connecting Solutions

IGBT CONNECTIONS

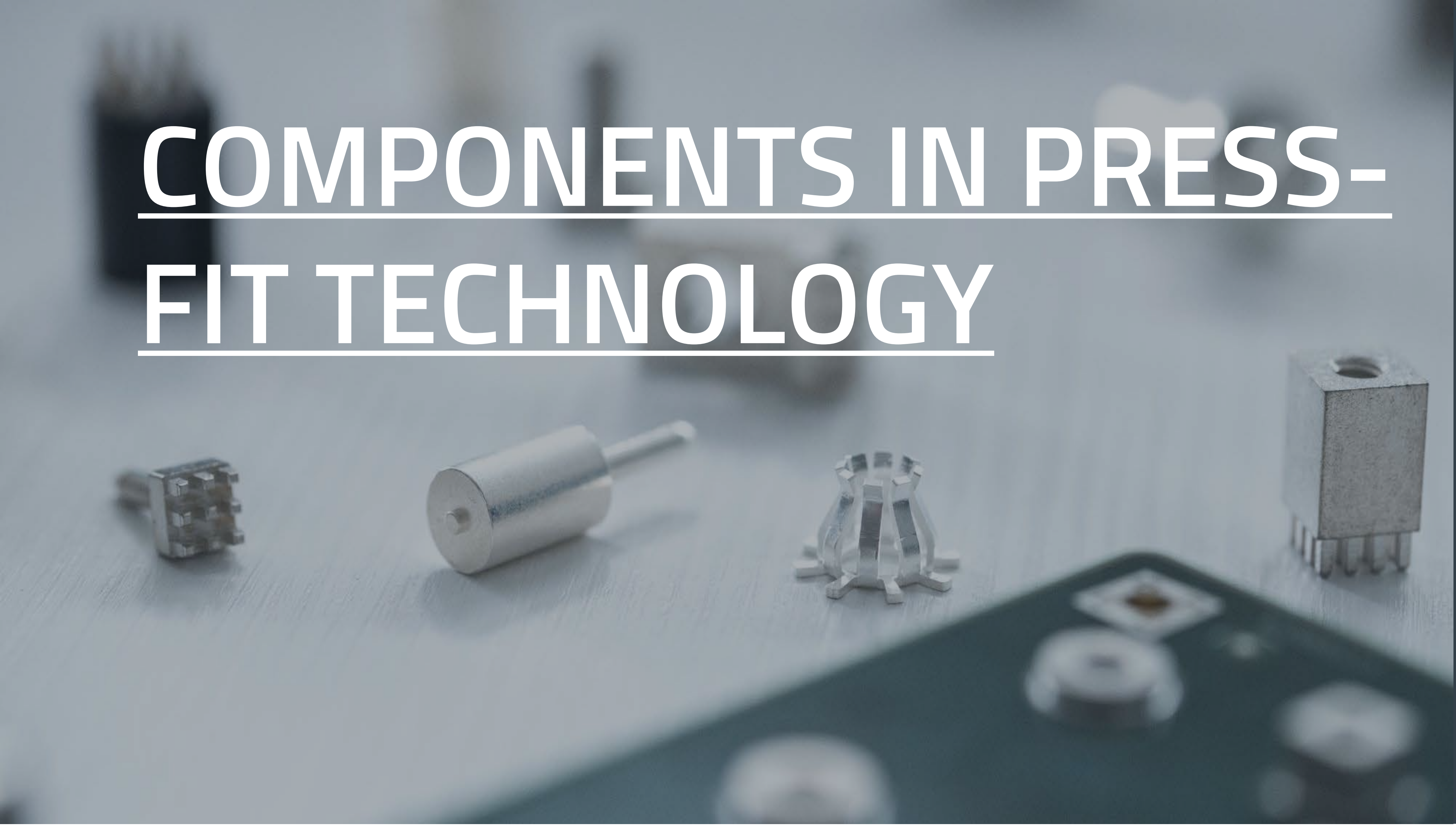
POWERTWO



Connection of an IGBT module with **PowerTwo**

Power Electronics & Energy Storage event
POWER ELECTRONICS
ENERGY STORAGE

COMPONENTS IN PRESS-FIT TECHNOLOGY



Components in Press-Fit Technology

RELAY AND FUSE BASES

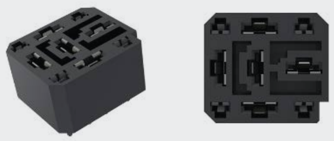
for T-shaped relays

for star-shaped relays

Gate connector, 1-pole

for high current relays, 4-pole

for mini relays



for ATO® fuses

for MINI® fuses

for one-pin fuses

for MAXI® fuses

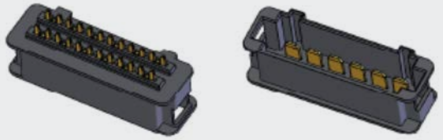
Components in Press-Fit Technology

CONNECTORS

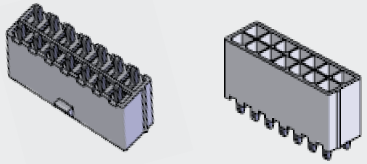
PowerCon 28-2 / JPT

PowerCon 28-3 / JPT

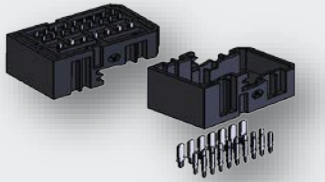
Powercon 48-2



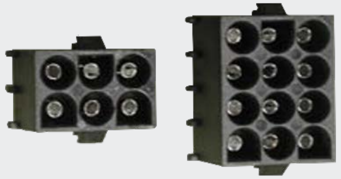
QuadCon Molex MiniFit



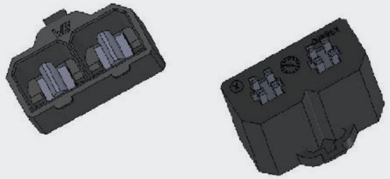
MCP Connector



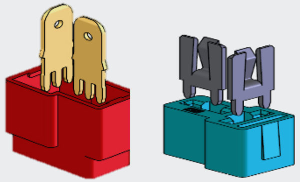
MATE-N-LOCK



Mini-Fit Senior



Fastin-Faston Male & Female



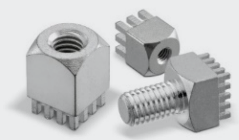
Components in Press-Fit Technology

ROHS AND LEAD-FREE POWERELEMENTS

Components in Press-Fit Technology

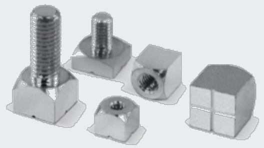
ROHS AND LEAD-FREE POWERELEMENTS

PowerOne



PowerTwo

PowerOne SMD



LF PowerPlus

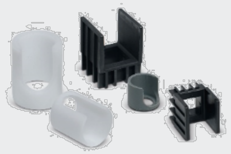
PowerLamella

LF PowerBasket

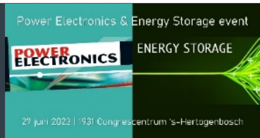
PowerRadSok

PowerFlex

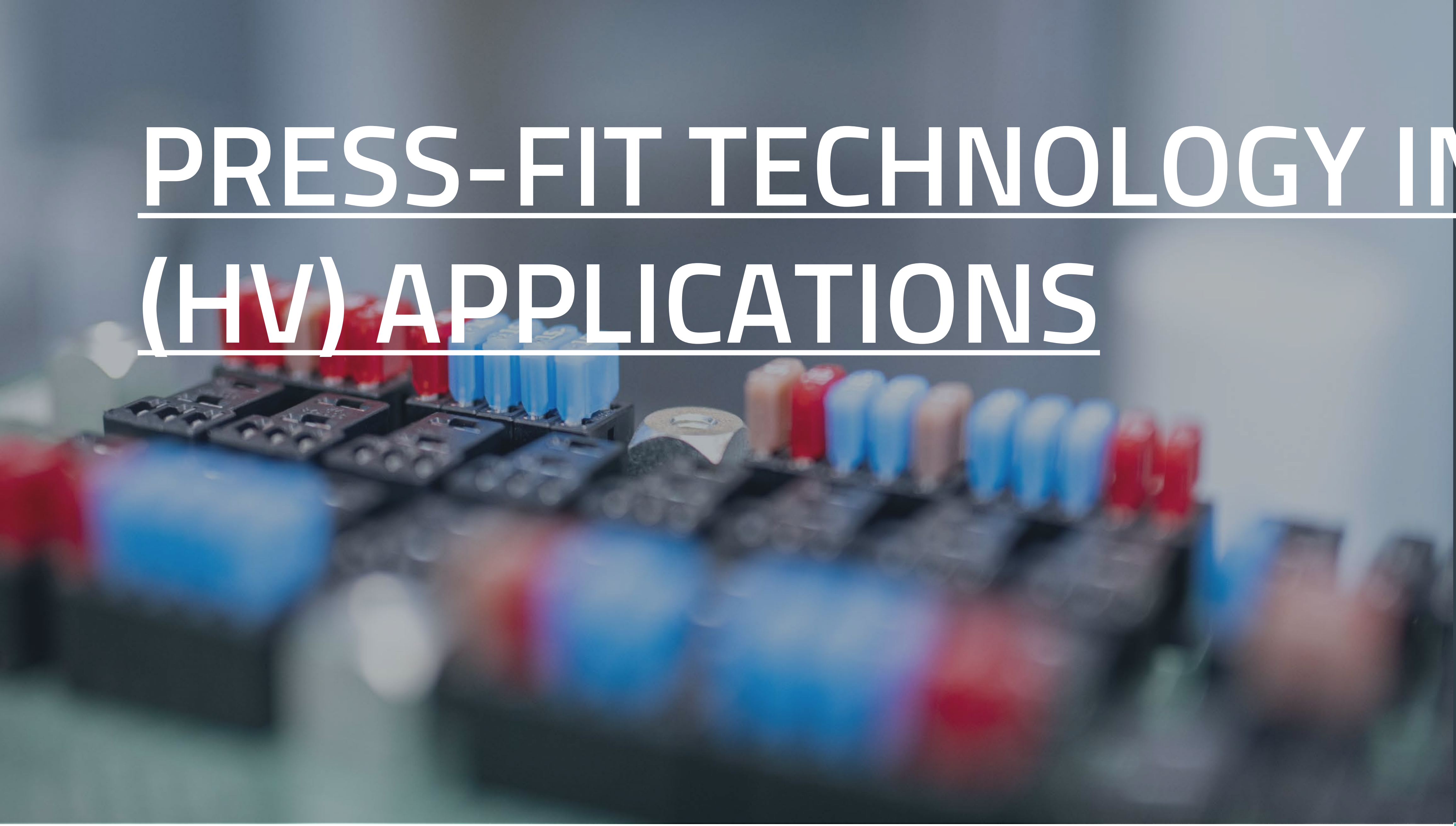
PowerCover



Also available as lead-free version



PRESS-FIT TECHNOLOGY IN (HV) APPLICATIONS

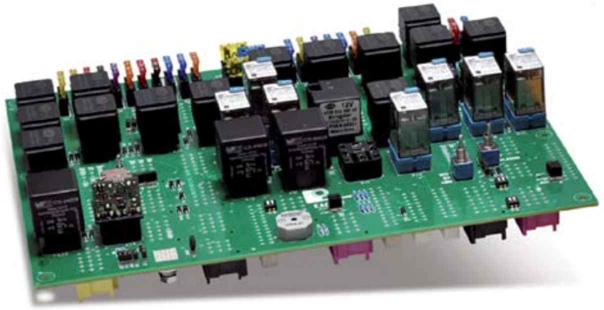


Press-Fit Technology in (HV) Applications

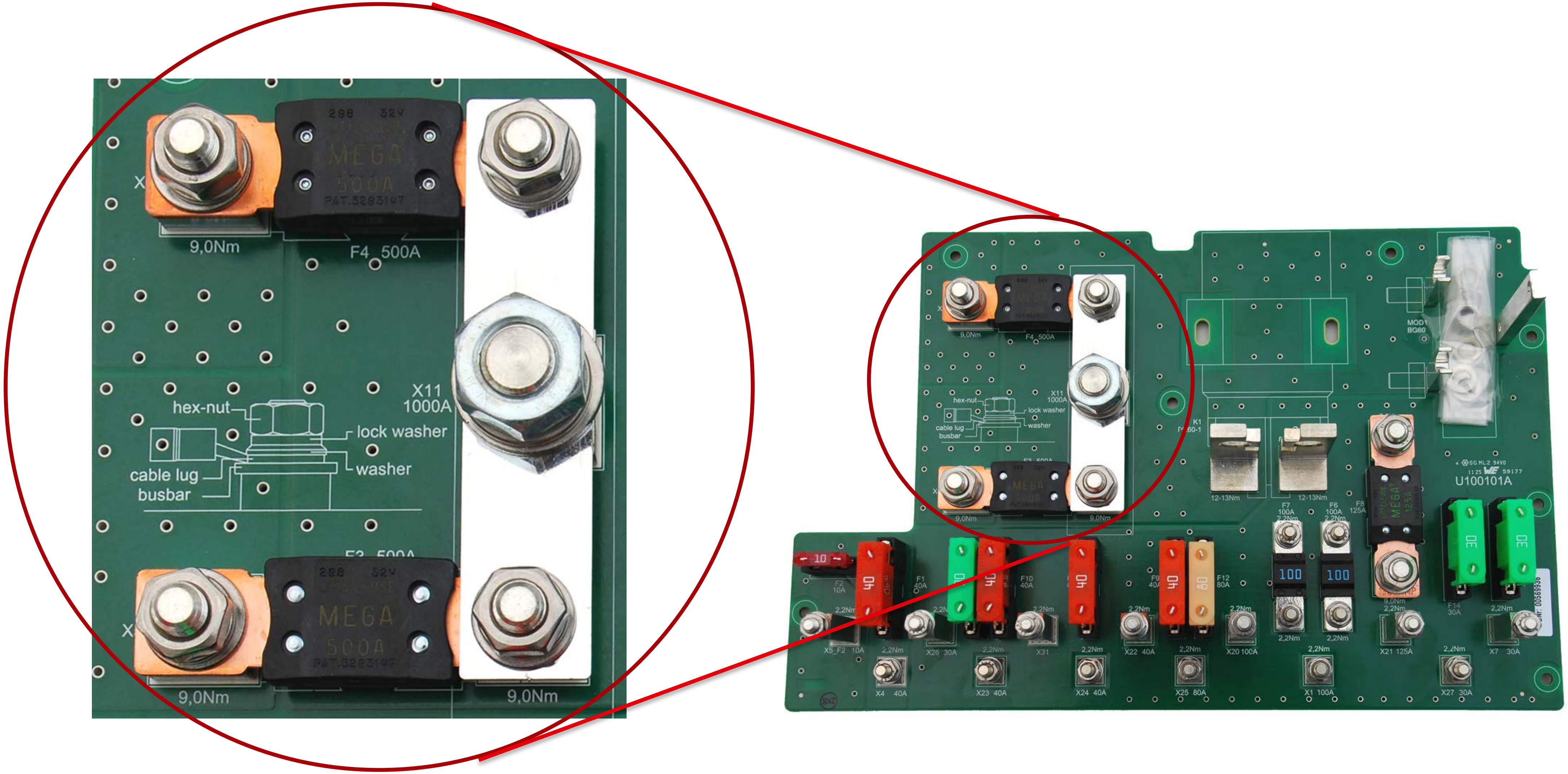
USE CASES

Suitable for a wide range of applications

- For **high current and high voltage applications**, e.g. high current and HV PDU's, due to the high current carrying capacity
- For **high-frequency applications**, as PCB impedances can be used selectively
- For use under **extreme environmental conditions**, as very robust and vibration-resistant
- For **installation in limited space**, as the double-sided assembly allows for a very compact realization of the modules
- For **reducing costly and error-prone** wiring harnesses



PDU COMPONENTS - EXAMPLES

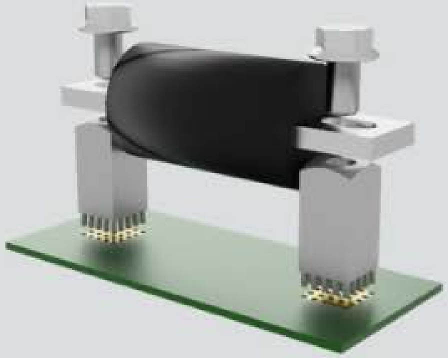


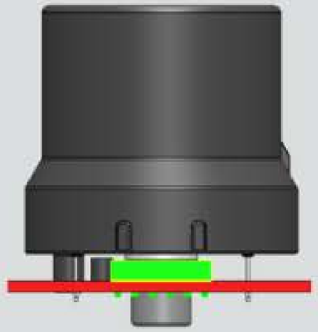
Press-Fit Technology in (HV) Applications

PDU COMPONENTS - EXAMPLES

CONTACTORS & FUSES

- Integration of different types of contactors and fuses (from different brands) with direct contact to PCB over Powerelements
- Connection of coils and auxiliary contacts with direct contact to PCB or small wire harness (depending on contactor type)



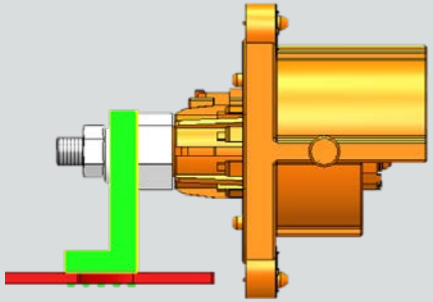


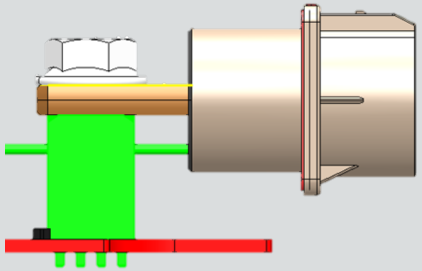
Press-Fit Technology in (HV) Applications

PDU COMPONENTS - EXAMPLES

CONNECTORS

- Integration of different types of connectors (from different brands)
- Advantage: busbar output of the connector allows to connect to the PCB without HV cables

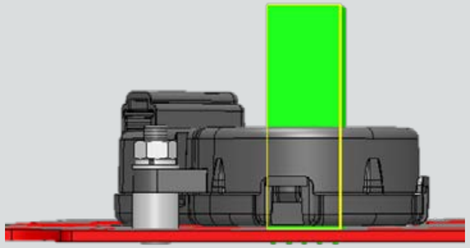


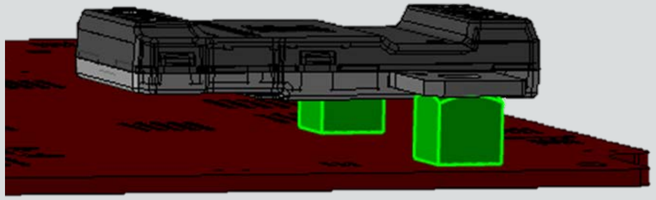


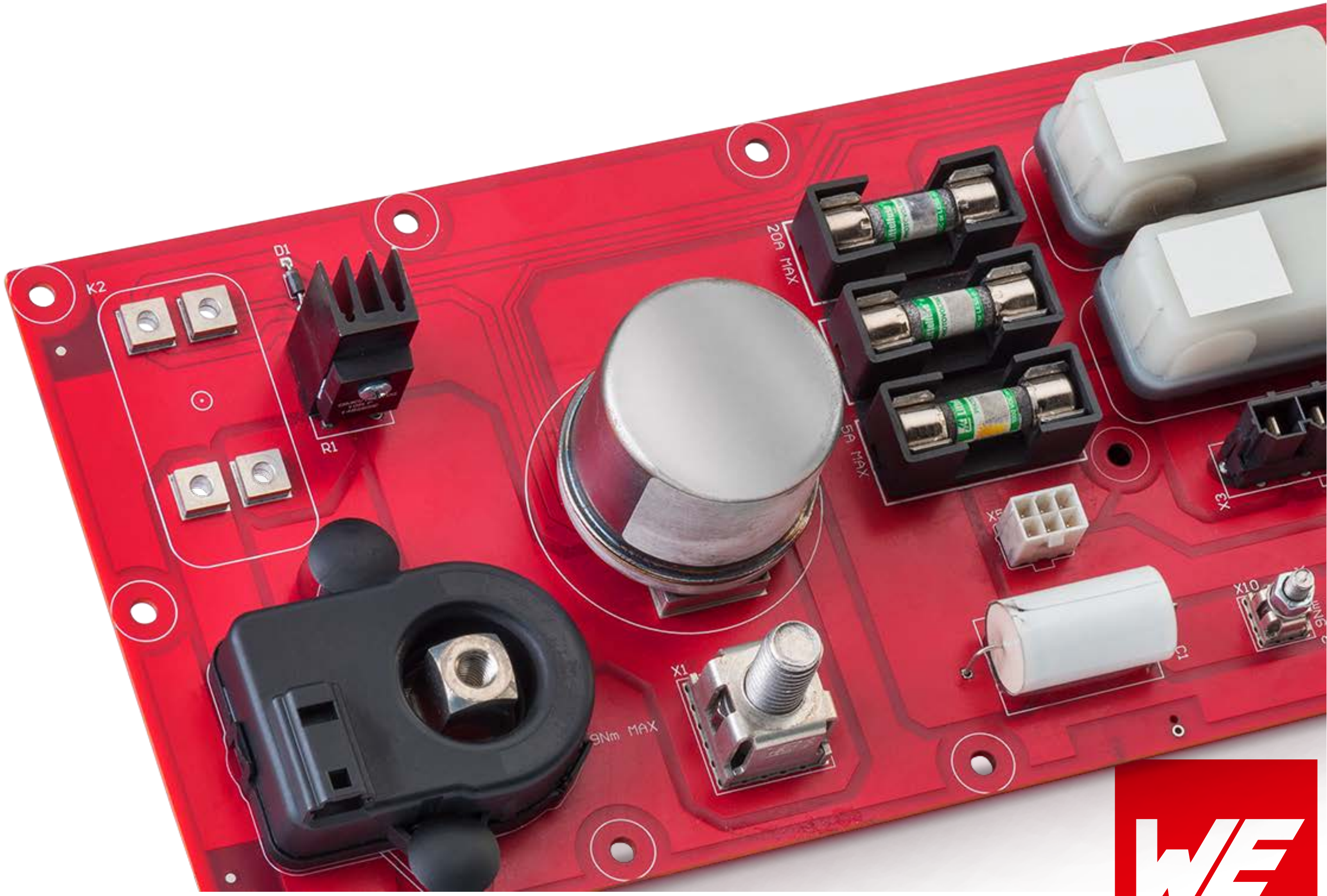
PDU COMPONENTS - EXAMPLES

MEASUREMENTS & MONITORING

- Possibility to integrate current or voltage measurement from the market
- Possibility to integrate isolation monitoring modules from the market



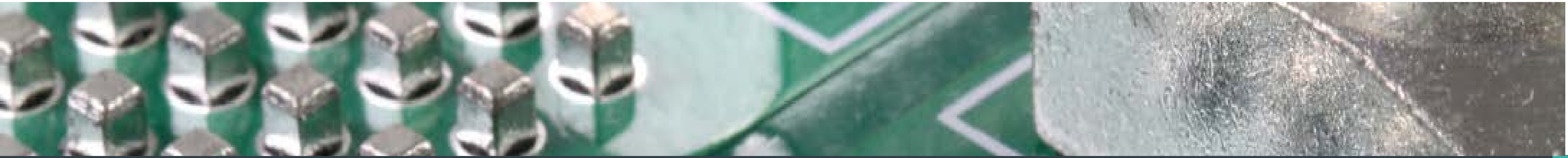




Press-fit Technology

CONCLUSIONS

- **High Current Capacity**
- **Gas-tight connection**
- **Excellent mechanical stability** and **vibration resistance**
- **No thermal stress** during assembly
- **Significantly lower contact resistance**
- **No danger of cold solder joints**
- **Easy Double Sided PCB assemblies**



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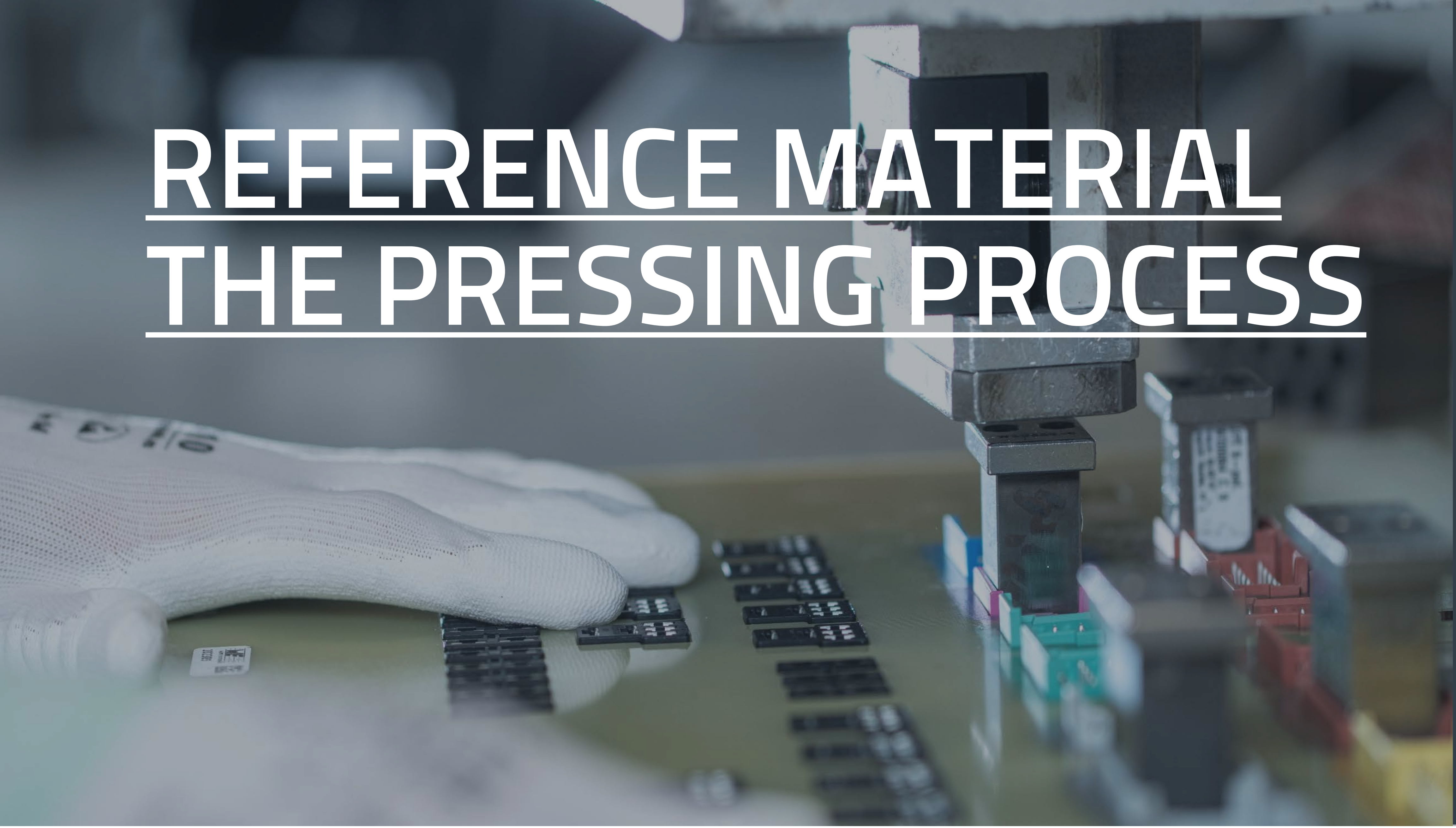
REFERENCE MATERIAL
THE PRESSING PROCESS



The Pressing Process

PRINTED CIRCUIT BOARD

Specifications

- Three parameters have to be taken into account when manufacturing the PCBs to ensure suitability for the press-fit technology:
  - Drill diameter and final diameter of the metallised hole
  - Design of the copper layer in the press-fit hole
  - Condition of the PCB surface
- Optimum PCB thickness is between 2.0 mm and 3.2 mm, but must be at least 1.5 mm.
- Proven finishes include chemical tin (preferred), chemical silver, chemical nickel/gold, HAL and lead-free HAL.

Würth Elektronik ICS – Press-fit Specification 5.1		
Drill Ø	drill tool drill hole	1,60 mm 1.60 – 0.025 mm
Cu	Cu – in Hole Annular Ring	Average 30 – 60 µm min 25 µm, max 80 µm * 125 µm
End Ø	**depends on surface** **HAL** **chem. surfaces**	 (1.45 +/- 0.05 mm) (1.475 +/- 0.05 mm)
Note:	**For Press-fit Technology drill diameter an copper thickness are fix** **End Ø for reference only**	

* single measurement points in microsection

Priority	Basic data of the printed circuit board	
1	Tool diameter Hole diameter	+ 0.00 / - 0.025 mm
2	Cooper in Hole	30 - 60 µm
3	Final diameter	serves only for orientation
4	Final diameter tolerance	serves only for orientation

Further information on processing instructions can be found online

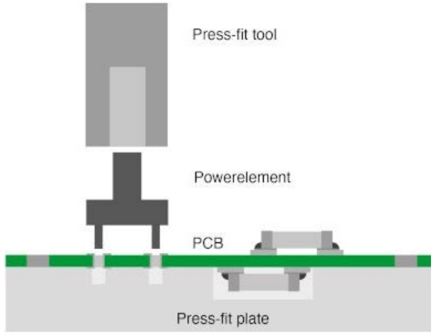
The Pressing Process
PRESS-IN TOOLS

Manual pressing-in

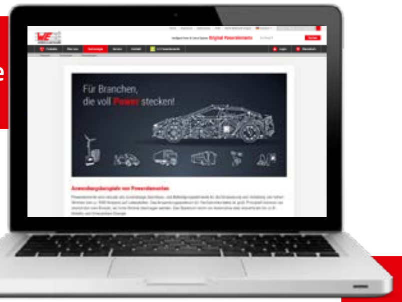
- Components such as Powerelements, sockets and connectors can be pressed into the PCB manually in a simple and uncomplicated way; a simple toggle press is sufficient.
- The PCB is supported by a pad during the press-fit process to prevent bending.
- With the appropriate tools, several Powerelements can be pressed-in at the same time.

Processing instructions and features

- Press-in force: min. 60 N, max. 250 N per pin
- Holding forces 60 % to 80 % of the press-in force
- Press-in speed 100 – 250 mm/min
- Application temperature range: -40 °C to +150 °C



Further information on processing instructions can be found online



Basics of Press-fit Technology

QUALIFICATION

Standard tests according to applicable standards

Climatic tests

- IEC 60068-2-1 Cold and -2 Dry heat
- IEC 60068-2-11 Salt spray and -52 Salt spray, cyclic
- IEC 60068-2-14 Change of Temperature
- IEC 60068-2-30 Damp heat, cyclic and -78 steady state
- IEC 60068-2-38 Temperature/humidity cyclic
- IEC 60068-2-60 Flowing mixed gas corrosion

Mechanical tests

- IEC 60068-2-6 Vibration (Sinusoidal)
- IEC 60068-2-27 Shock and -29 Bump
- IEC 60068-2-32 Free fall
- IEC 60068-2-64 Vibration, broadband random and guidance
- IEC 60068-2-80 Vibration – Mixed mode

International standard norm for road vehicles

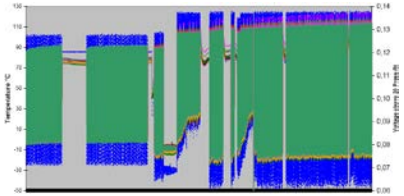
- ISO 16750: Environmental conditions and electrical testing for electrical and electronic equipment

Standards for connectors

- IEC 60512-2-2 Contact resistance
- IEC 60512-2-5 Electrical continuity and contact resistance tests

Degrees of protection provided by enclosures (IP Code) according to IEC 60529

Press-in connections IEC 60352-5



Basics of Press-fit Technology

QUALIFICATION

Own tests or tests carried out by the customers

Press-in zone

- Drill diameter
- Copper thickness of the sleeve (comparison PTH*/NPTH**)
- Holding forces as a function of copper thickness in the sleeve
- Correlation between holding forces and current carrying capacity
- Holding forces before and after vibration
- Torques
- Sleeve surfaces
- Cold welding
- Diffusion Cu/Sn

Simulations

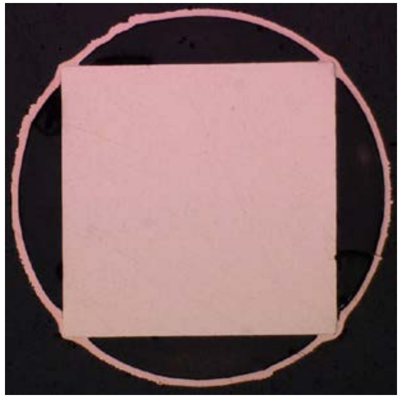
- Current carrying capacity of the press-in zone
- Torque load of Powerelements

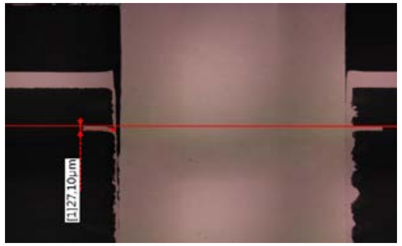
Manufacturing technologies

- Pressing-in before and after coating the assembly
- Influence of potting
- RoHS conformity

Complete assemblies

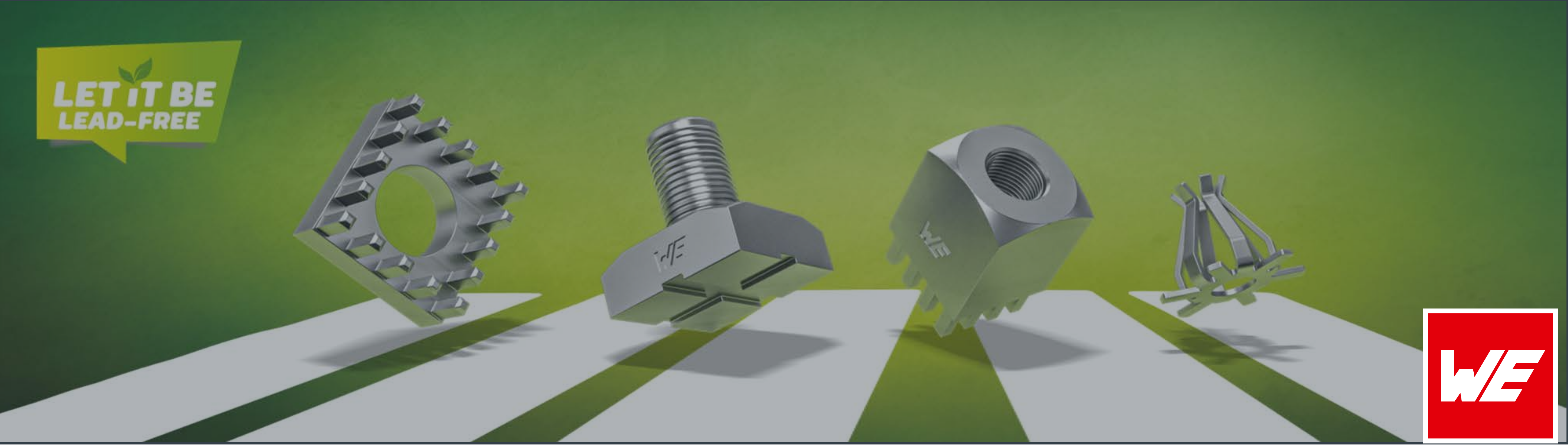
- Insertion and withdrawal forces
- Long-term stability
- Arc testing
- Comparison of press-fit technology and soldering technology





**PTH= plated-through hole*
***NPTH= not plated through hole*

REFERENCE MATERIAL
LEAD-FREE POWERELEMENTS



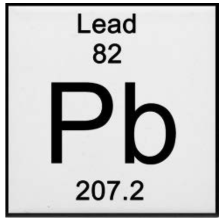
DIRECTIVES

Directives

BACKGROUND TO LEAD

Lead …

- is a heavy metal and
- is generally classified as toxic
- in the human body, it damages the nervous system, various organs or even the hematopoietic system
- has been used for years with increasing restrictions but with exceptions



Lead has advantageous properties like …

- flexibility & corrosion resistance
- improved sliding and friction behavior
- excellent machinability as a component of copper alloys

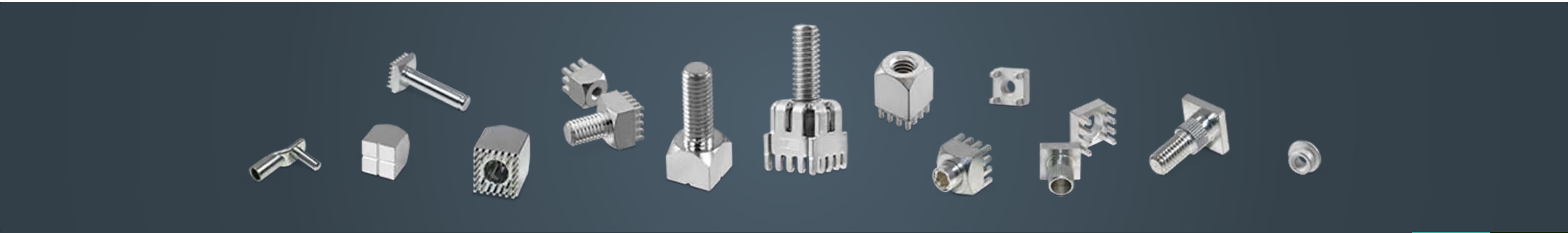
Directives

BACKGROUND TO LEAD

Lead is present in the copper alloy "**machining brass**" (CuZn39Pb3) in many high current contacts (incl. Original Powerelements) with approx. **3 % mass content**.

Explanation of terms

- **Lead-Free:** Elimination of lead additive, for example in copper alloys, with a minor limit of maximum 0.1 % lead content
- **Conformity:** Conformity is given if the approved limits for the hazardous substances are complied with.



Directives

ROHS DIRECTIVE

RoHS Directive (Restriction of Hazardous Substances) 2011/65/EU serves to restrict the use of hazardous substances such as lead in **electrical and electronic equipment** (EEE).

- Compliance with RoHS is a prerequisite for the application of CE markings on equipment
- Lead as a substance of the RoHS restrictions has a defined permissible concentration of **max. 0.1 %.** of value by weight in homogeneous materials
- RoHS **exemption 6c:** allows up to 4 % lead content in copper alloys

Extract from RoHS Directive 2011/65/EU | Version from 01/09/2020

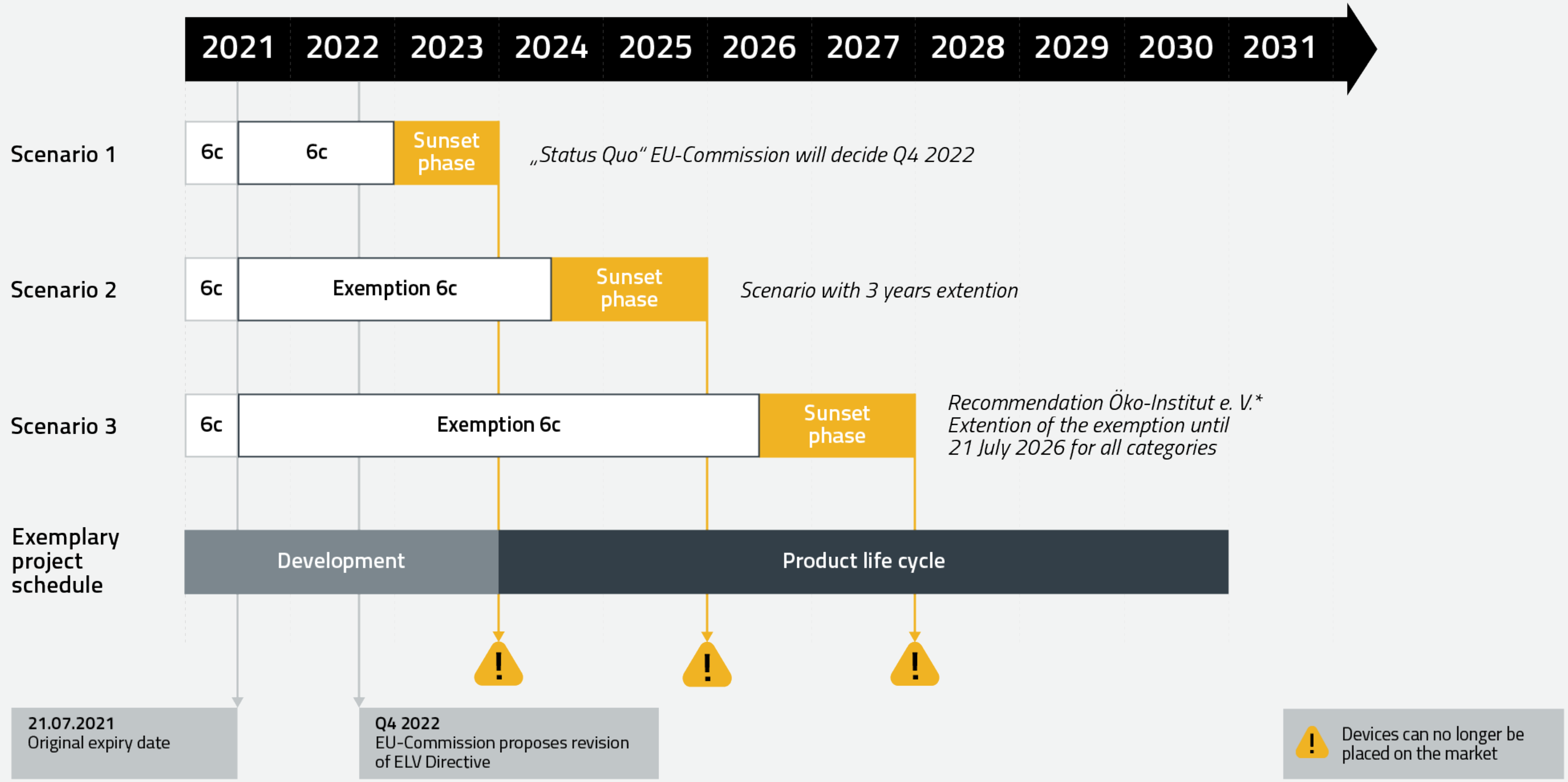
6(c)	Copper alloy containing up to 4 % lead by weight	Expires on: — 21 July 2021 for categories 1-7 and 10, — 21 July 2021 for categories 8 and 9 other than *in vitro* diagnostic medical devices and industrial monitoring and control instruments, — 21 July 2023 for category 8 *in vitro* diagnostic medical devices, — 21 July 2024 for category 9 industrial monitoring and control instruments, and for category 11.

Update 21st July, 2021:

Due to some requests for extension, exemption 6c will remain valid beyond July 21, 2021 until the EU Commission has made a decision on these requests.

Directives

IMPACT ON PROJECTS & PRODUCTS



*https://rohs.exemptions.oeko.info/news

Was does it mean for my project?

- Re-Design?
- Qualification?
- Effort & Cost?

Directives

REACH

REACH Regulation (**R**egistration, **E**valuation, **A**uthorisation and **R**estriction of **Ch**emicals) EC 1907/2006 regulates the production, marketing and use of chemical substances and mixtures made from them.

- REACH maintains a candidate list of substances of very high concern **SVHC** (**S**ubstance of **V**ery **H**igh **C**oncern)
- According to Article 33, this results in an **information obligation** along the supply chain for semi-finished products or other products containing a substance from the candidate list with a mass content of ≥ 0.1 %.
- **Lead** is on the SVHC list.
- New from 2021: **SCIP database** (**S**ubstances of **C**oncern **I**n articles as such or in complex objects / **P**roducts) for product sellers with the obligation to register in addition to IMDS (part number, designation, proportion of SVHC substance)

Directives

REACH

ELV (**E**nd of **L**ife **V**ehicles) „**End-of-Life Vehicle Directive**" 2000/53/EG regulates the recovery of materials from **motor vehicles** through recycling.

- As a restricted substance, lead has a defined maximum allowable concentration of max. 0.1% (weight percent).
- Exemption II/3 allows up to max. 4% lead content in copper alloys.
- After the expiry of a release, the component may no longer be used in a new vehicle.

„End-of-Live Vehicle Directive" 2000/53/EG (ELV – End of Live Vehicle) | Version of 06/03/2020

3.	Copper alloys containing up to 4 % lead by weight	(1) This exemption shall be reviewed in 2021.

Directives

SUMMARY

Relevant directives & regulations with a limit value of max. 0.1 % lead content

LET IT BE LEAD-FREE

	Scope of application	Criteria	Status	Possible consequence
RoHS	Elelectrical and electronic equipment (EEE)	Maximum concentration value by weight in homogeneous materials	Exemption 6c enables copper alloy containing up to 4 % lead by weight, expires July 2021 (depending on category later)	Without conformity with the applicable RoHS requirements no „making available on the market" for EEE
ELV	Motor vehicles	Maximum concentration value by weight of a component	Exemption II/3 enables copper alloy containing up to 4 % lead by weight; will be reviewed in 2021	No use of component after expiration of exemption in new vehicles
REACH	Chemical substances	Maximum concentration value by weight in the product of the respective value chain	Lead is on the List of Substances of Very High Concern (SVHC). Information along the supply chain is required (Article 33)	Increased documentation effort also for the new SCIP database

There are a large number of additional directives worldwide