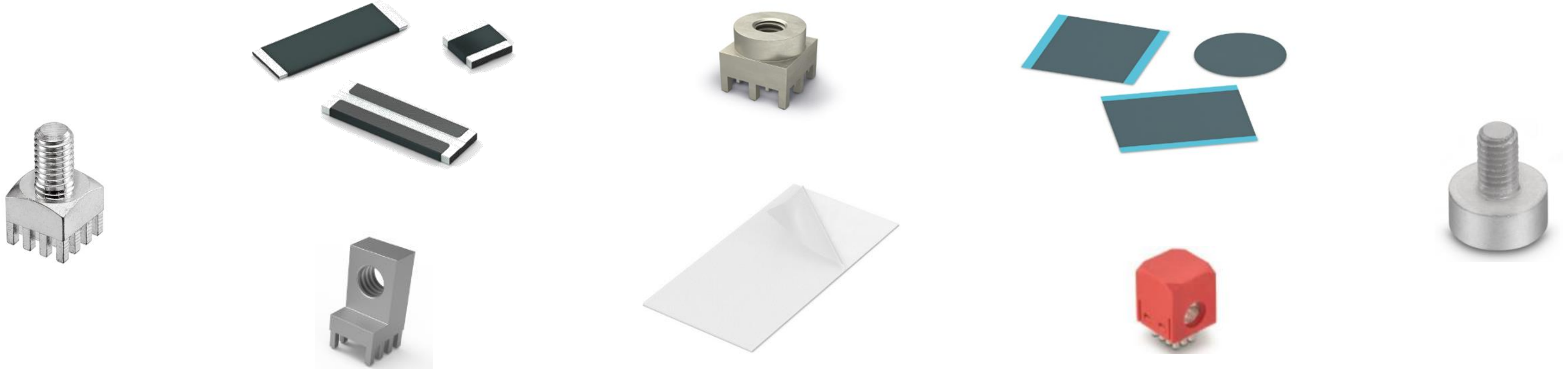

# STAYING COOL WITH HIGH CURRENT

**WÜRTH ELEKTRONIK** MORE THAN YOU EXPECT

PUBLIC

# ABOUT ME

**DON OLMSTEAD**

BSME from South Dakota State University

Applications Engineer

Specialization: Thermal Management & Electromechanical

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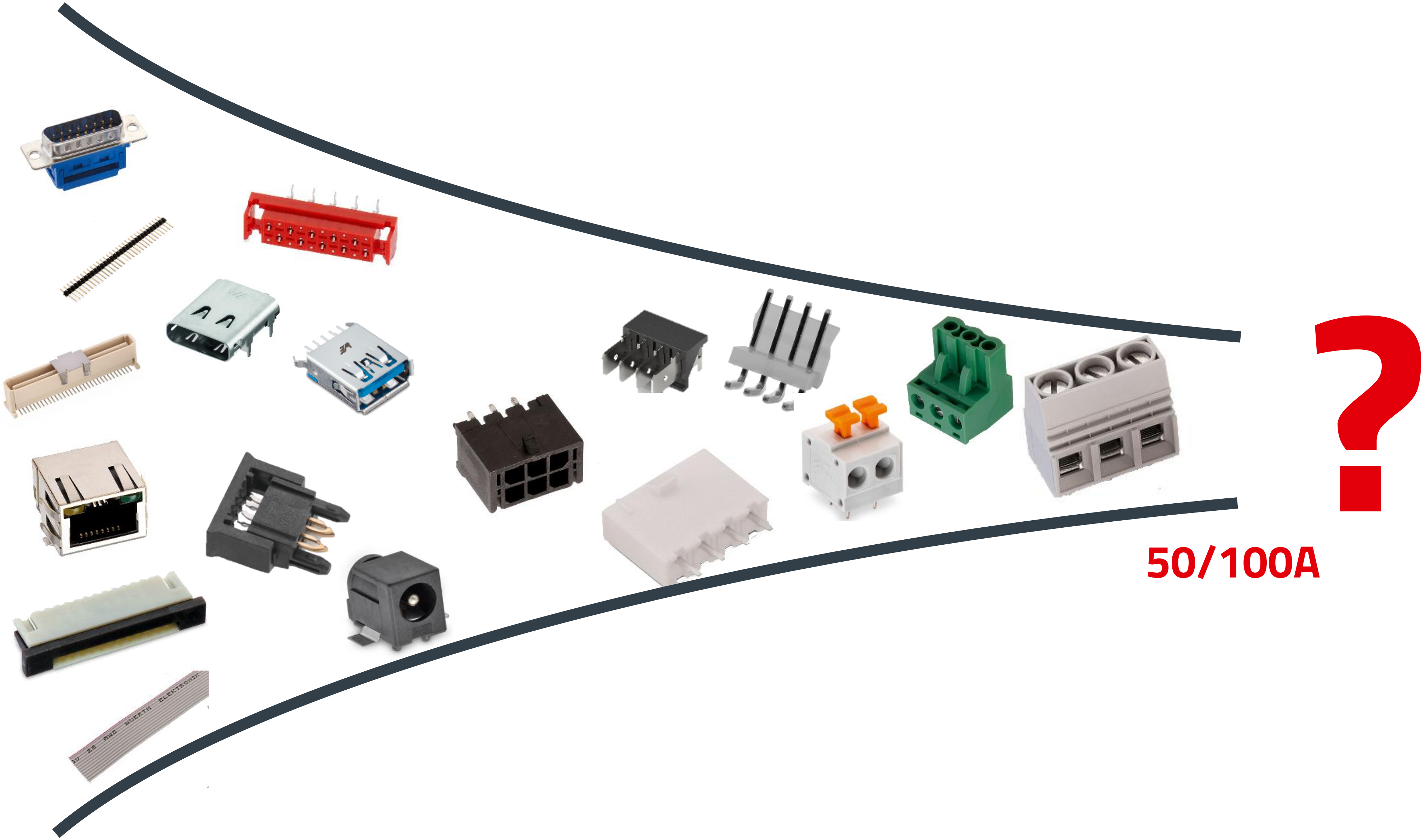
# TABLE OF CONTENTS

- High current connections
  - What is Redcube
  - How they work
  - How to assemble
- How to stay cool
  - Estimating temperature
  - Thermal bottlenecks
  - Increasing heat dissipation


https://pixabay.com/vectors/checklist-lists-business-form-41335/

# HIGH CURRENT CONNECTIONS



?

50/100A

# PARALLEL CONNECTIONS

- For higher currents more connections are needed
- Takes up more space with additional current
- Hard to transfer high currents from board to board
- What if you need more?

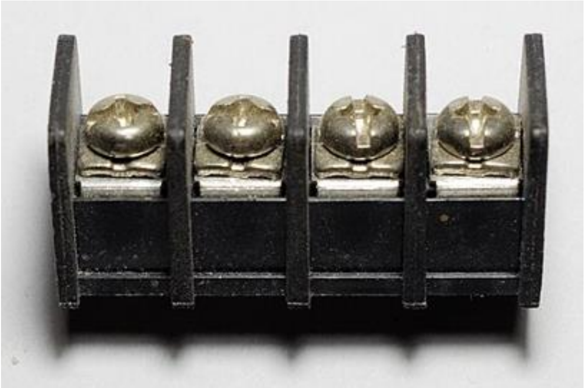


Photo by Retired electrician BB CY

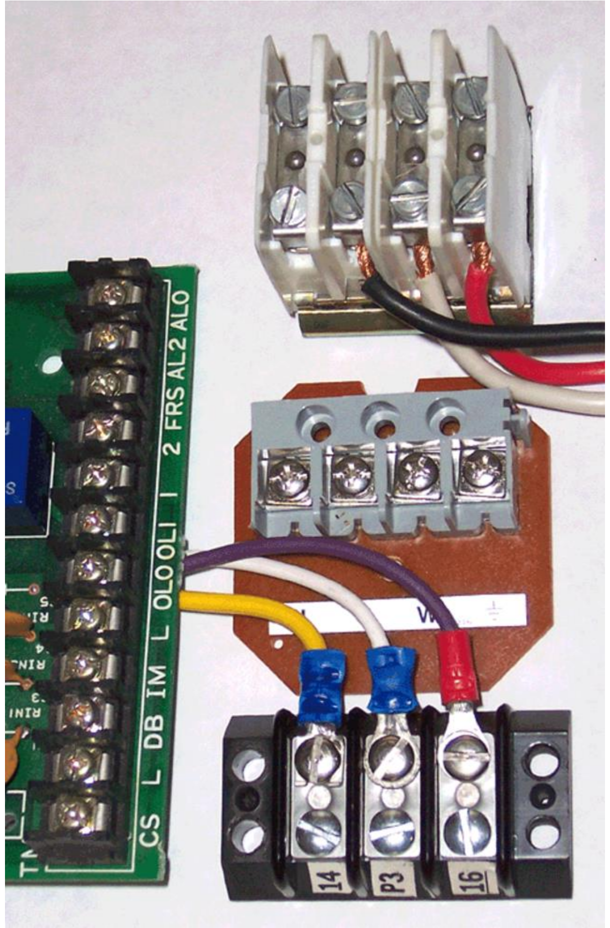
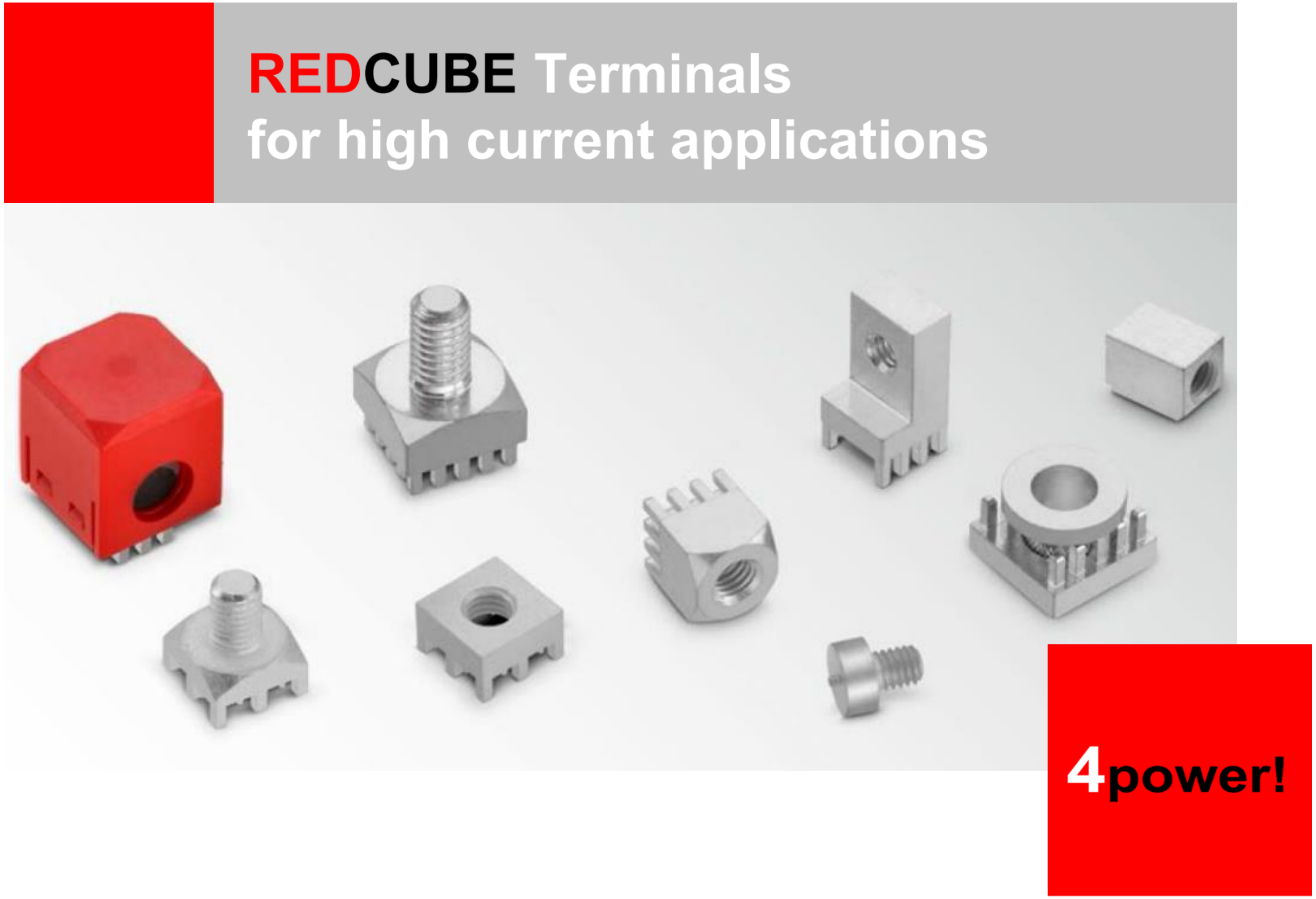


Photo C J Cowie BB CY

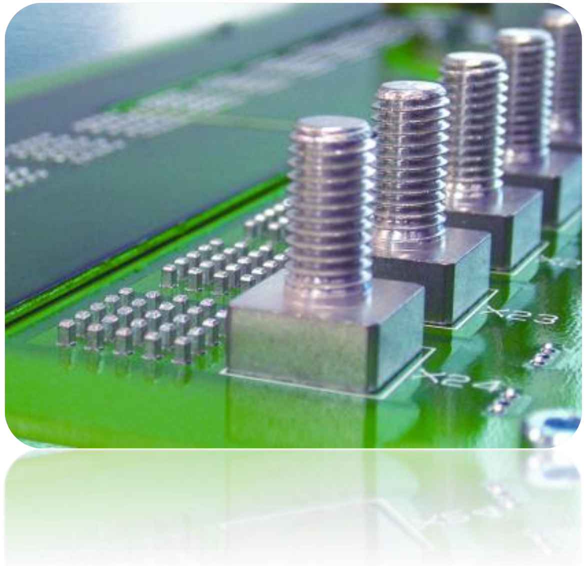
# WHAT ARE REDCUBES

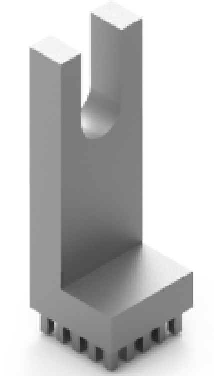
- High Current connectors
- Performance
- Heat dissipation
- Strength

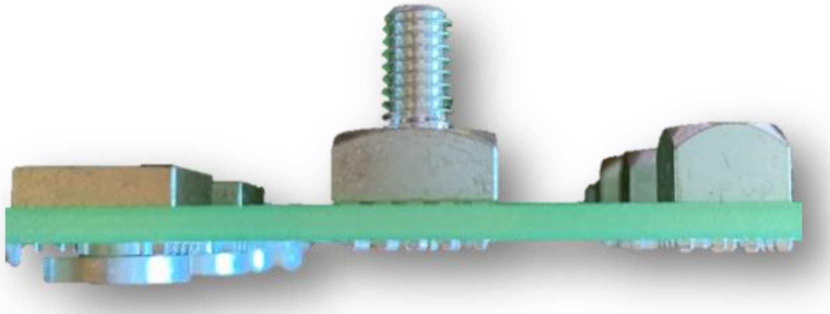


# PRESSFIT SOLUTIONS

- Up to 350A
- Space saving
- Various configurations
- M3-M10
- Extremely high environmental stability
- Lowest FIT value in system





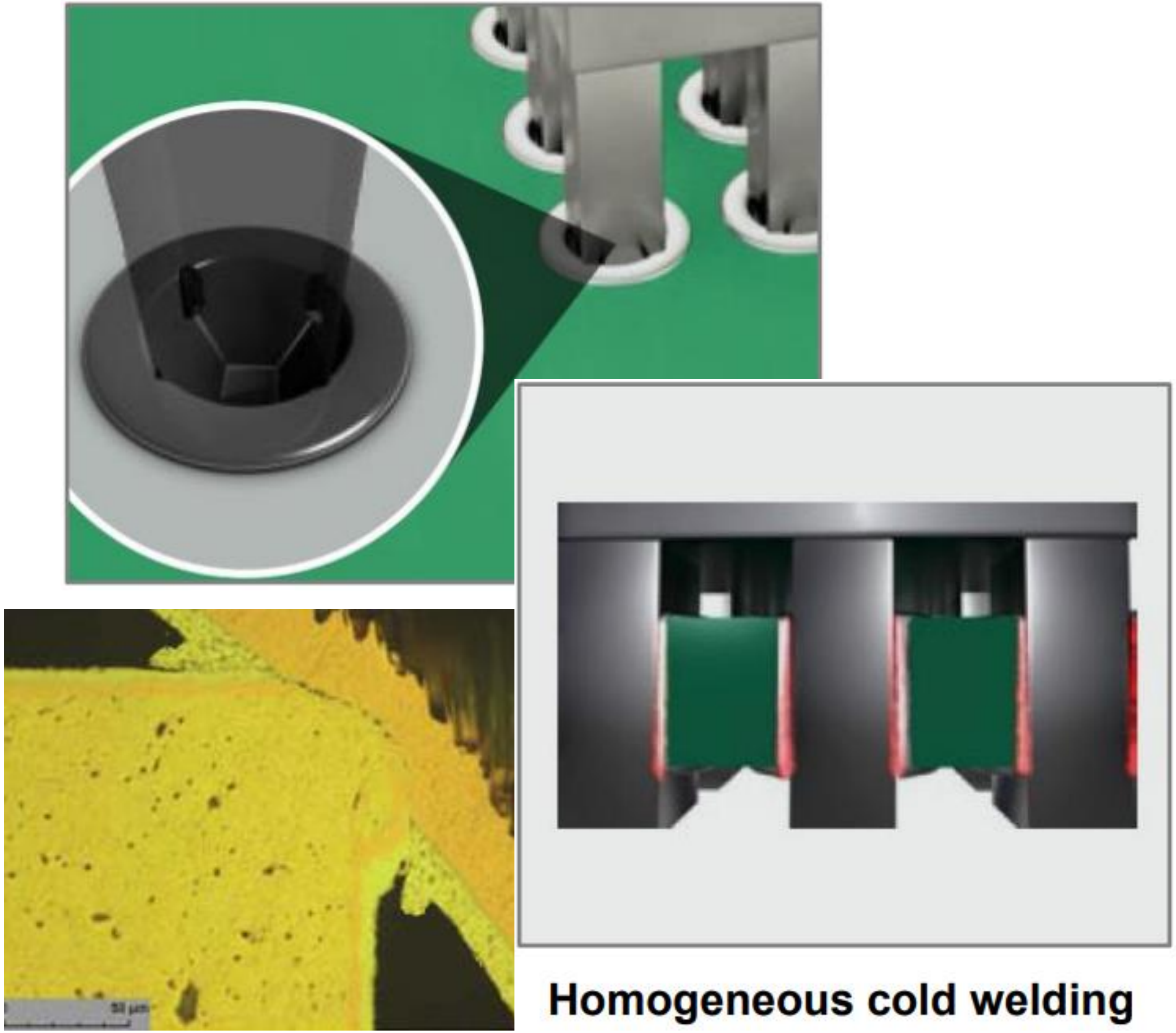


# REDCUBE PULL-OUT/UP? TEST

- Average extraction force of 100N (~22lbf) per pin
- 6-36 pins per connector = up to 810 lbf!
- Excellent in environments with high vibration
- More pins = More current and strength

# HOW PRESSFIT WORKS

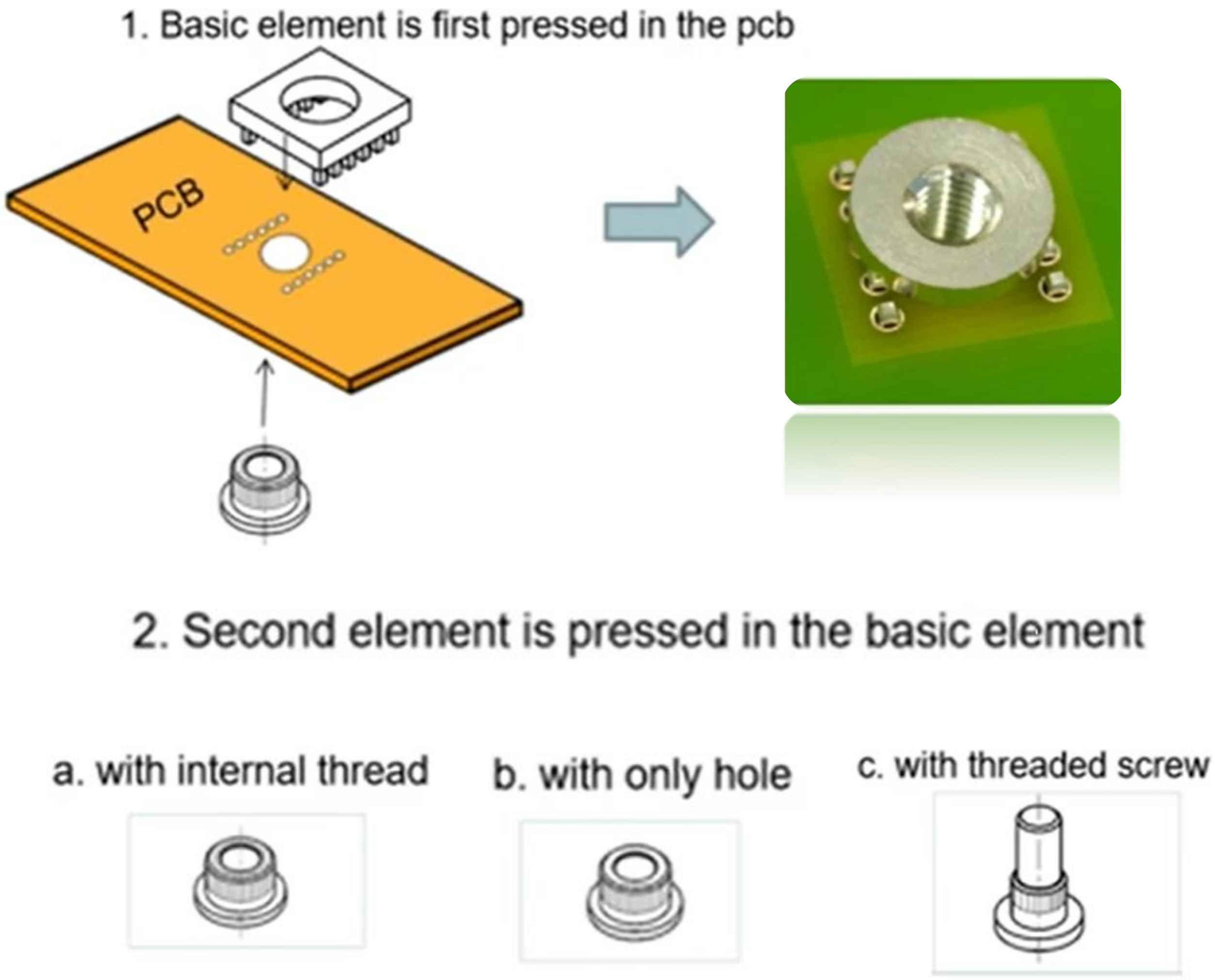
- Pressed into board
- Cold welded connection
- Homogenous connection from pin to copper
- Tin acts as lubrication and sealant
- Very low contact resistance



Homogeneous cold welding

# TWO PART SYSTEM

- Lower profile than traditional Pressfits
- Up to 320A
- Indirect torque on the PCB
- Various thread options
- M3 to M8



1. Basic element is first pressed in the pcb

2. Second element is pressed in the basic element

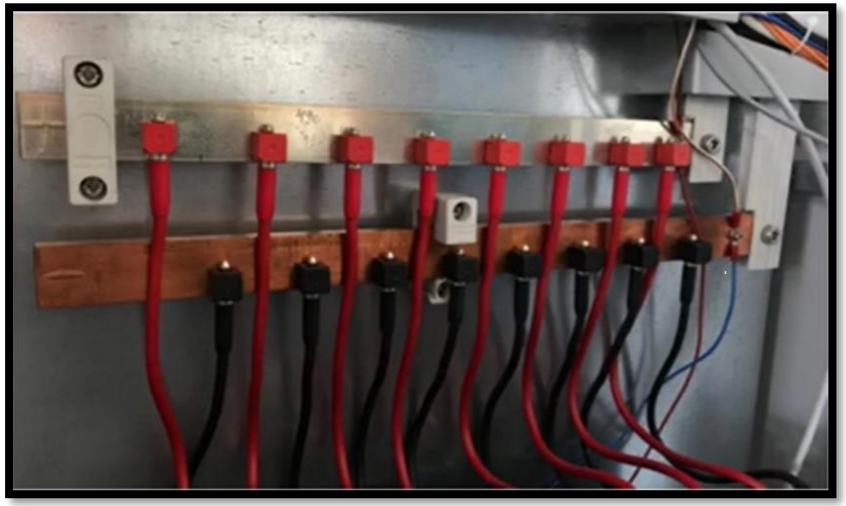
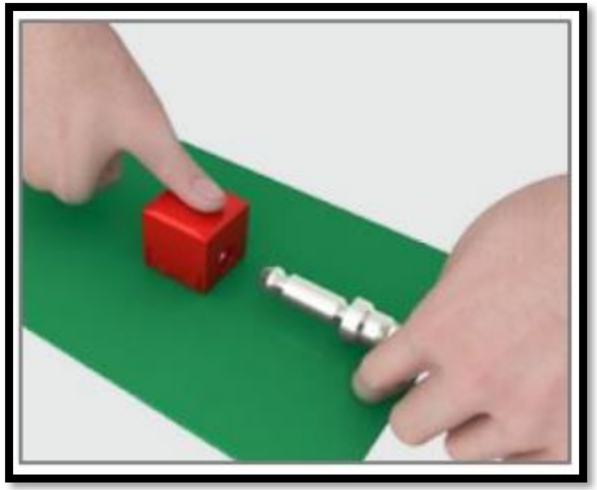
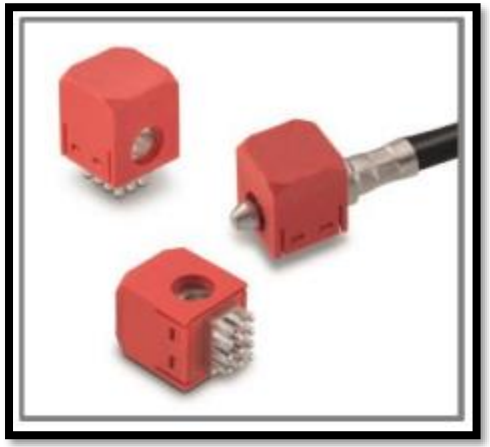
a. with internal thread

b. with only hole

c. with threaded screw

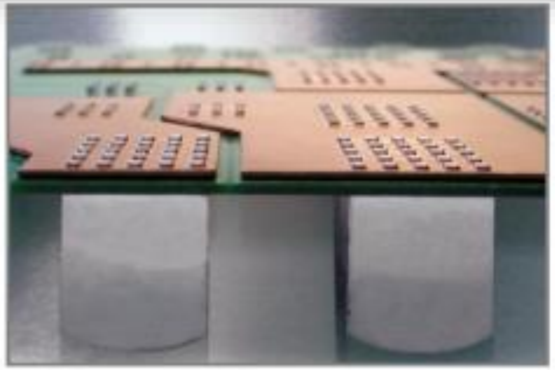
# PLUGGABLE SOLUTION

- Easily pluggable
- Automatic Locking
- Up to 120A
- Standard hexagonal crimp tools used
- Cable can be a limiting factor

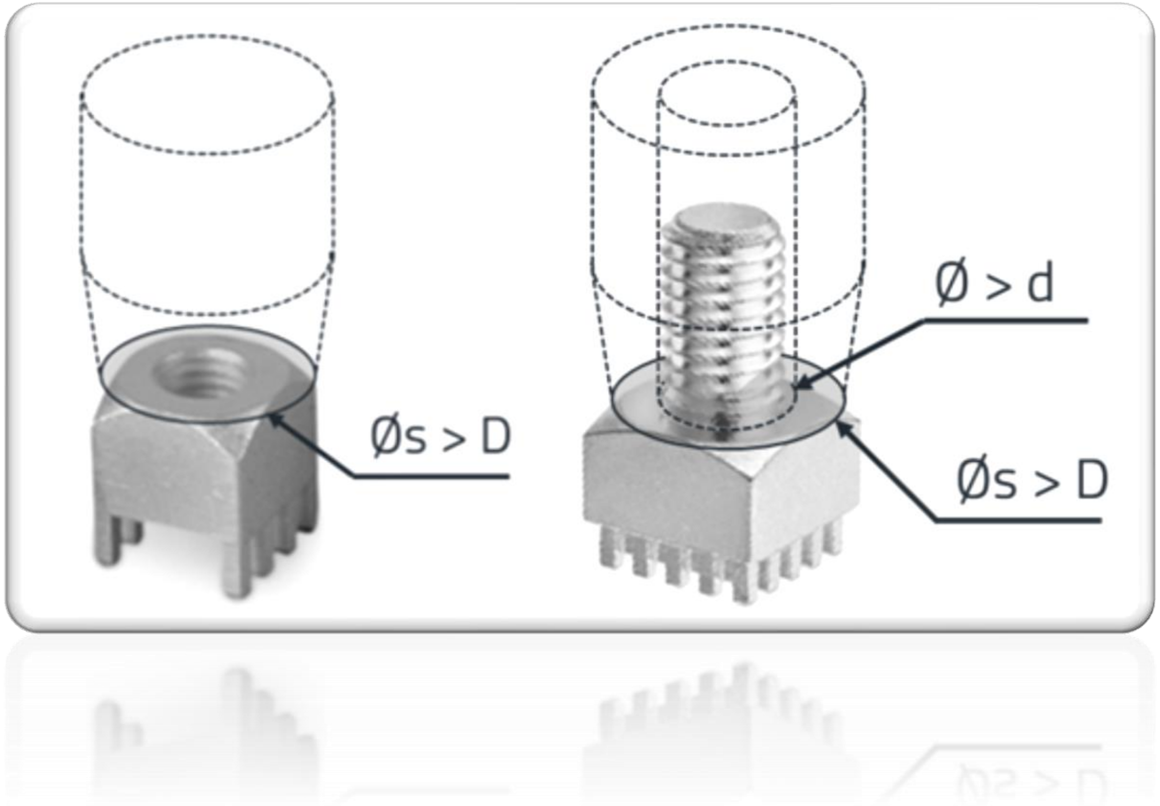

# HOW TO PRESSFIT

- Pressfit after reflow process
- ≥2 Ton Press with end stop
- Support backing required to prevent damage
- Can be pressed into bus bars if max thickness isn't exceeded



Pressing: PCB directly with copper bar

# PRESS FACES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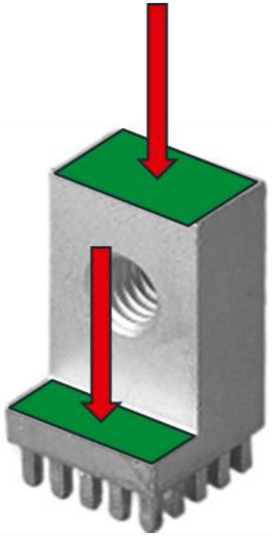
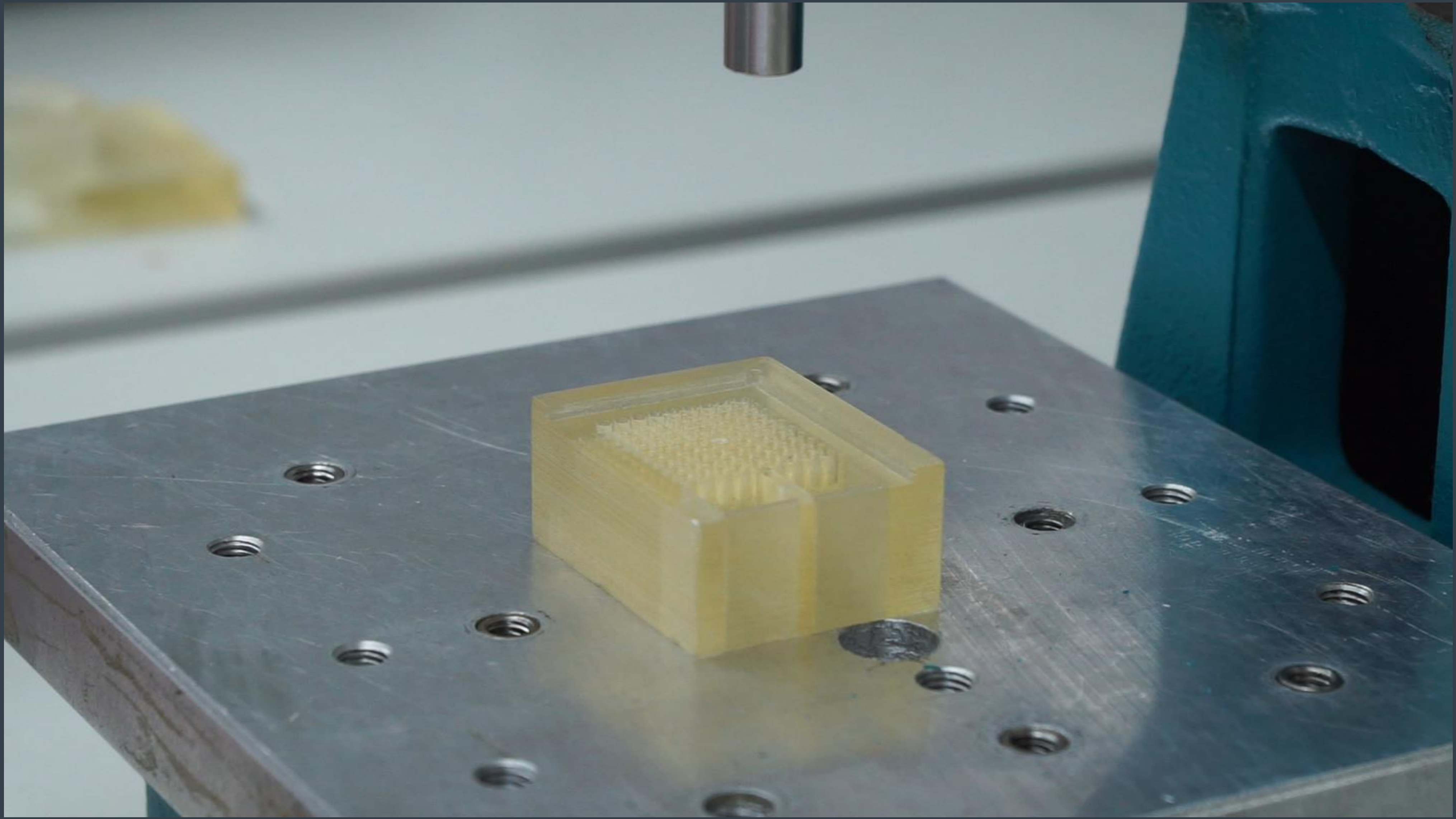
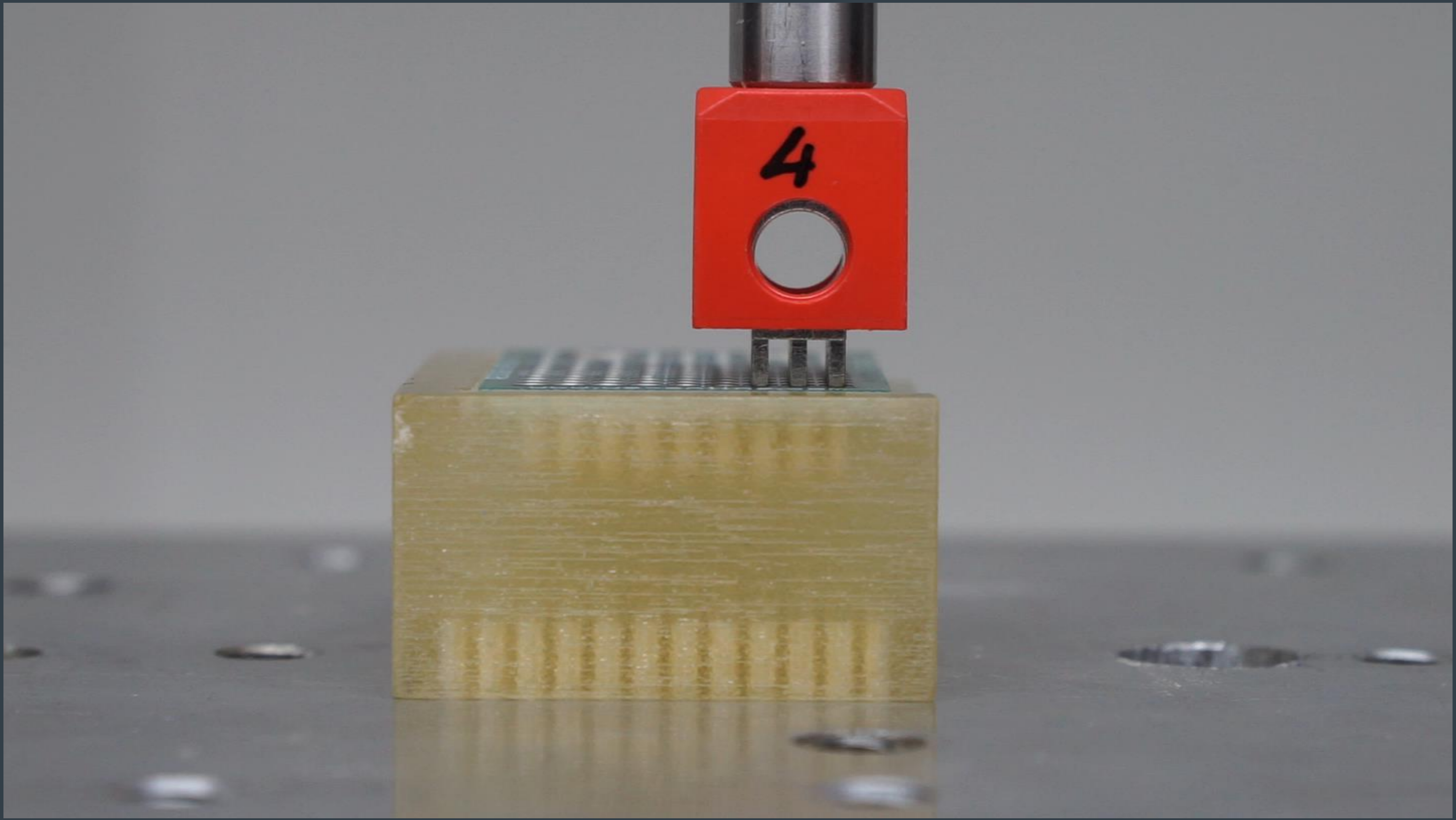



CLOSE
INSTRON
2716-016
MAX LOAD: 1KN
TEMP RANGE: -10°C TO 100°C

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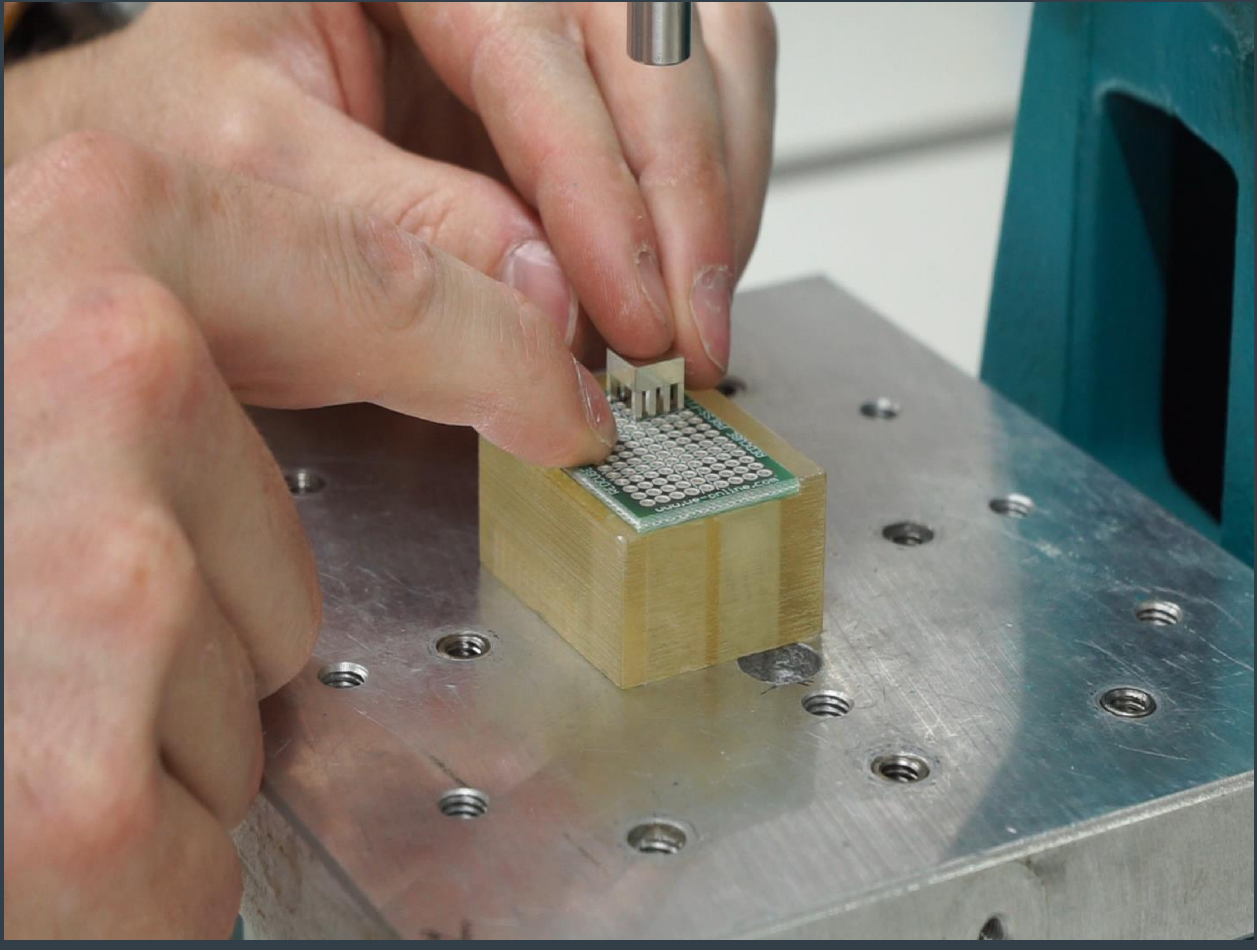
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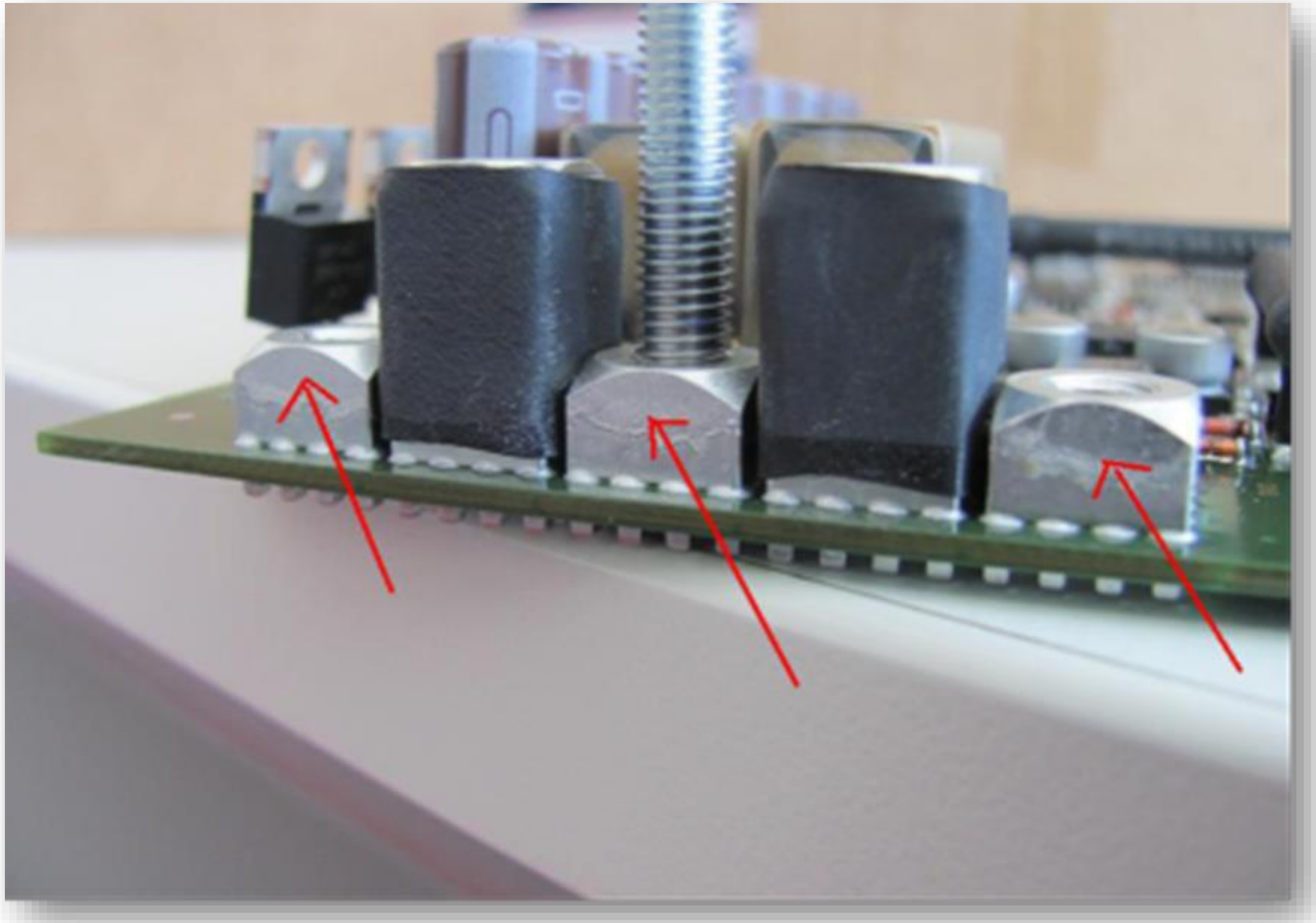
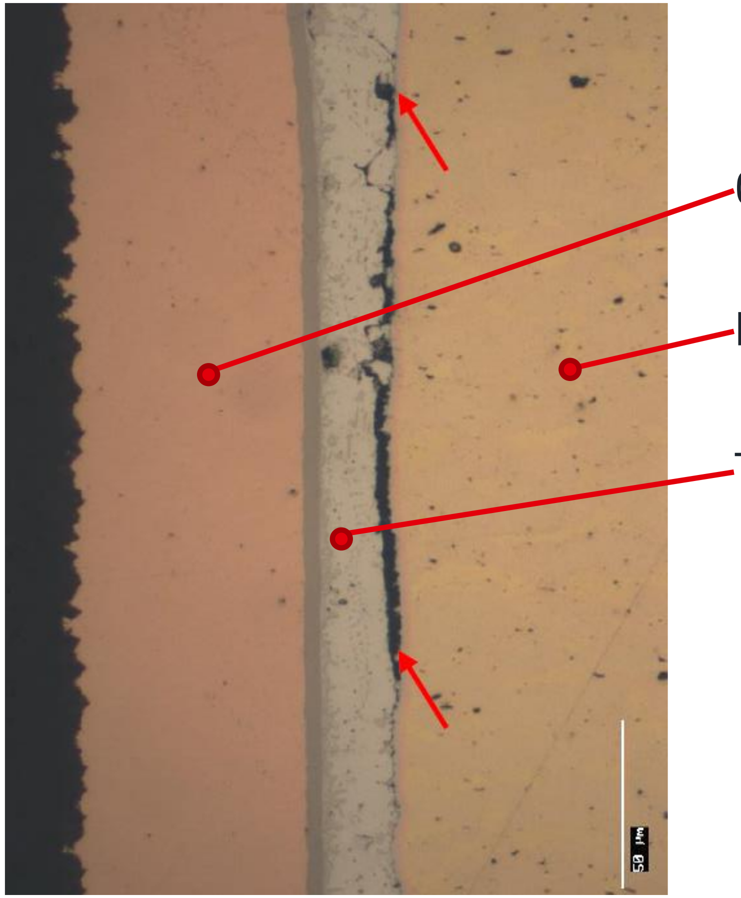
# DON'T SOLDER A PRESSFIT

- Done after soldering processes
- Bad soldering of parts due to thermal absorption
- Melts tin coating of Redcube
- Problematic for threads



# THERMAL EXPANSION

- Reflow temperatures can destroy cold weld
- Different thermal expansion coefficients
- Increased resistance
- Reduced mechanical stability



Copper - $16{,}5 \times 10^{-6}\ K^{-1}$

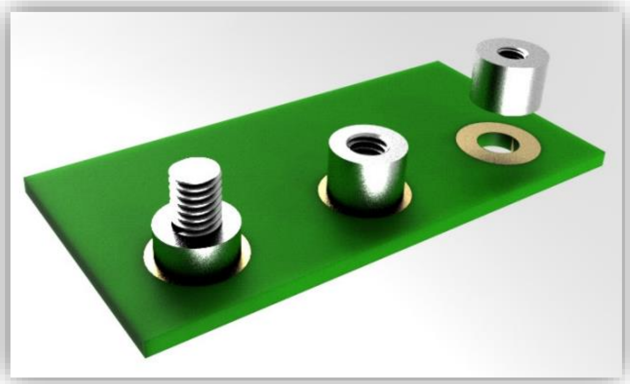
Brass - $18{,}4 \times 10^{-6}\ K^{-1}$

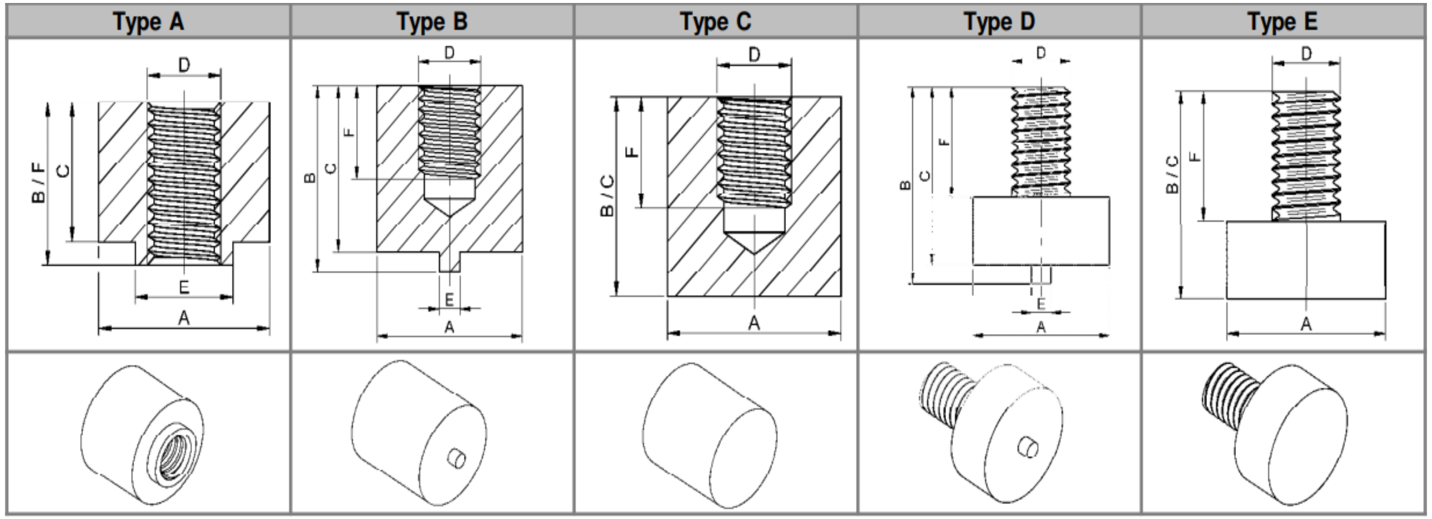
Tin - $26{,}7 \times 10^{-6}\ K^{-1}$

# EASY PROCESSING

Redcube SMT

- Easy pick and place manufacturing
- Up to 85A
- High packing density
- Vertical or right angled
- Allows mechanical mounting to enclosure
- Styles have different shear strength

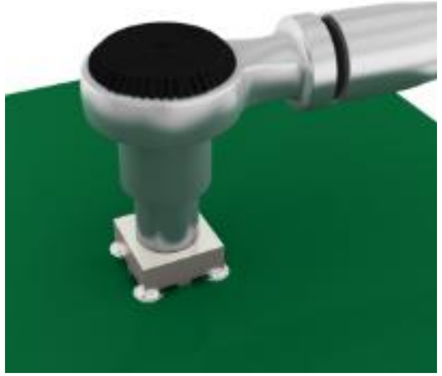


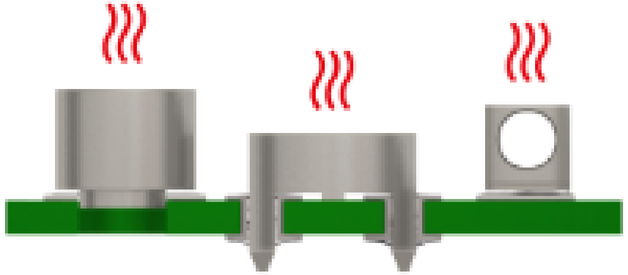


# HYBRID SOLUTION

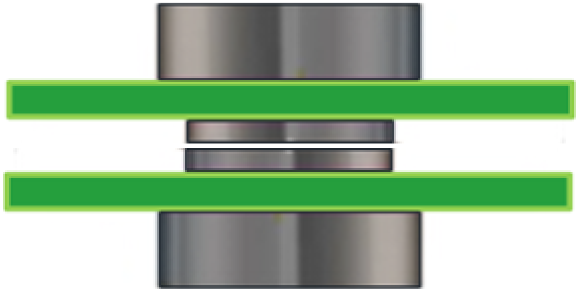
Redcube THR

- Greater mechanical stability than SMT
- Optimal current distribution for multilayer applications
- Allows for automation
- Up to 85A
- M3 – M5

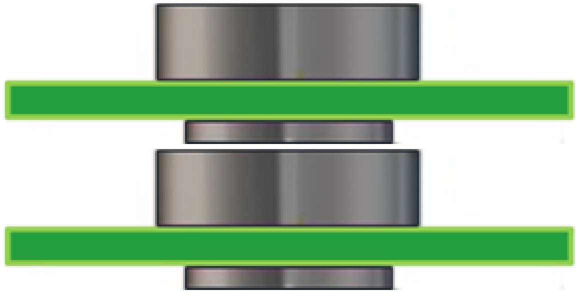




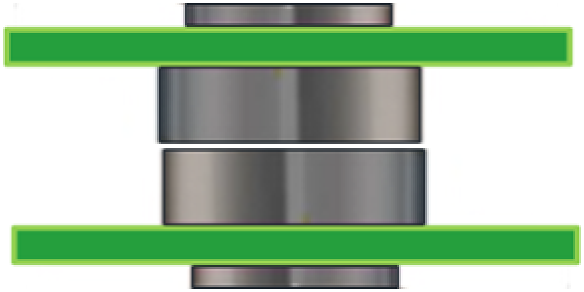
# SMT APPLICATIONS



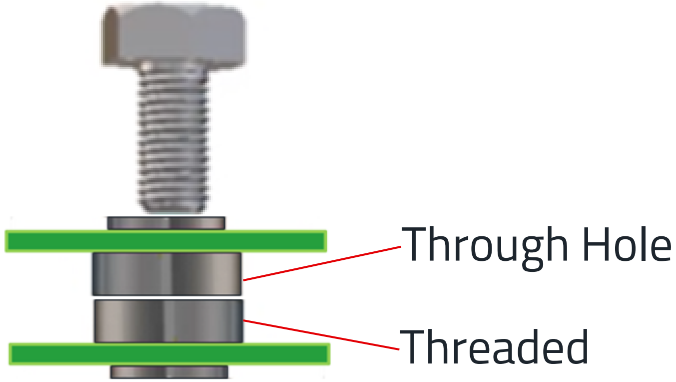
2 mm



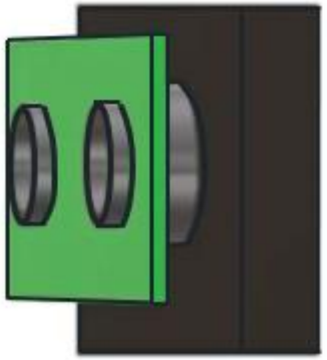
4 mm



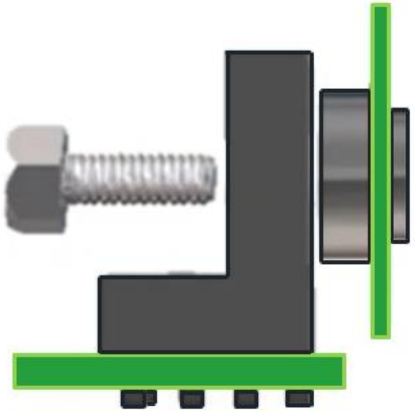
6 mm



90° SMT + THR



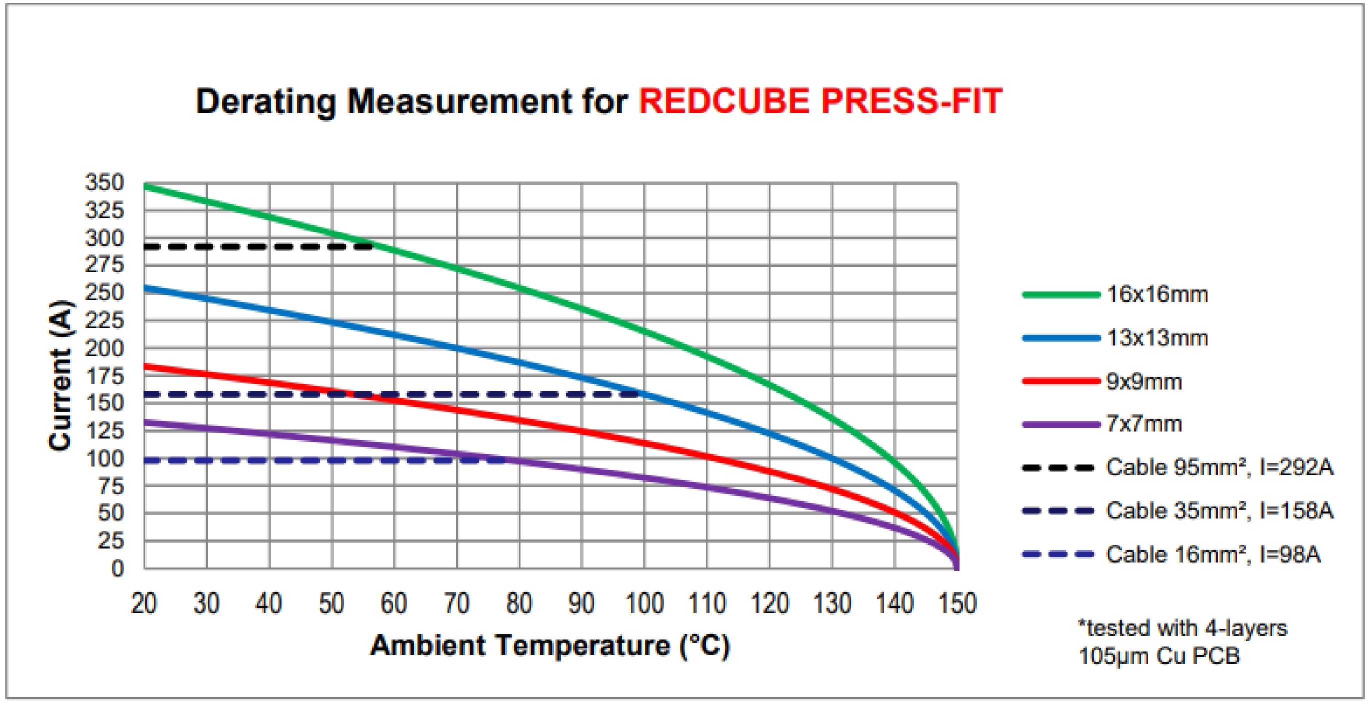
Attachment to backplane or housing



90° Pressfit + SMT with thread

# DERATING DUE TO TEMPERATURE

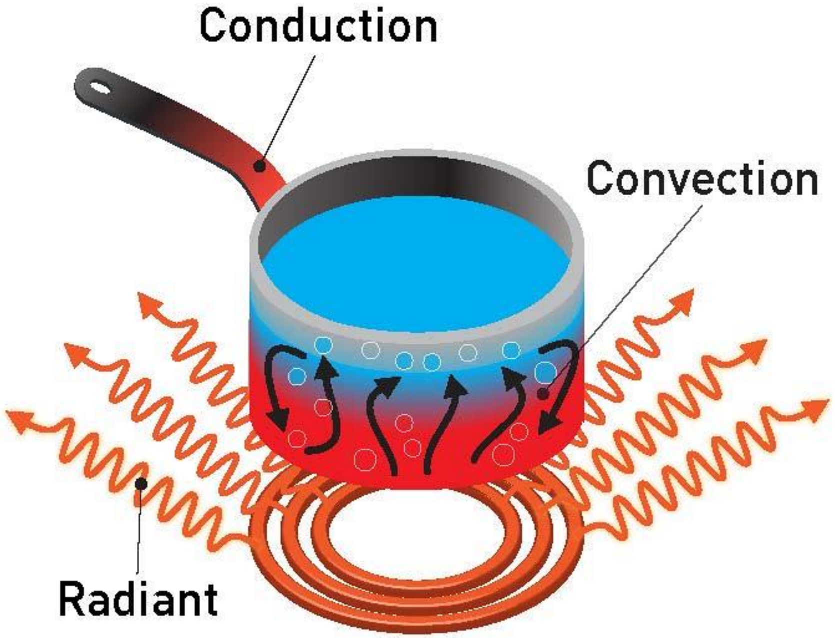
- Max current decreases with ambient temperature
- Ambient temp means surrounding air not outside air
- Enclosures can act like ovens for parts



# STAYING COOL

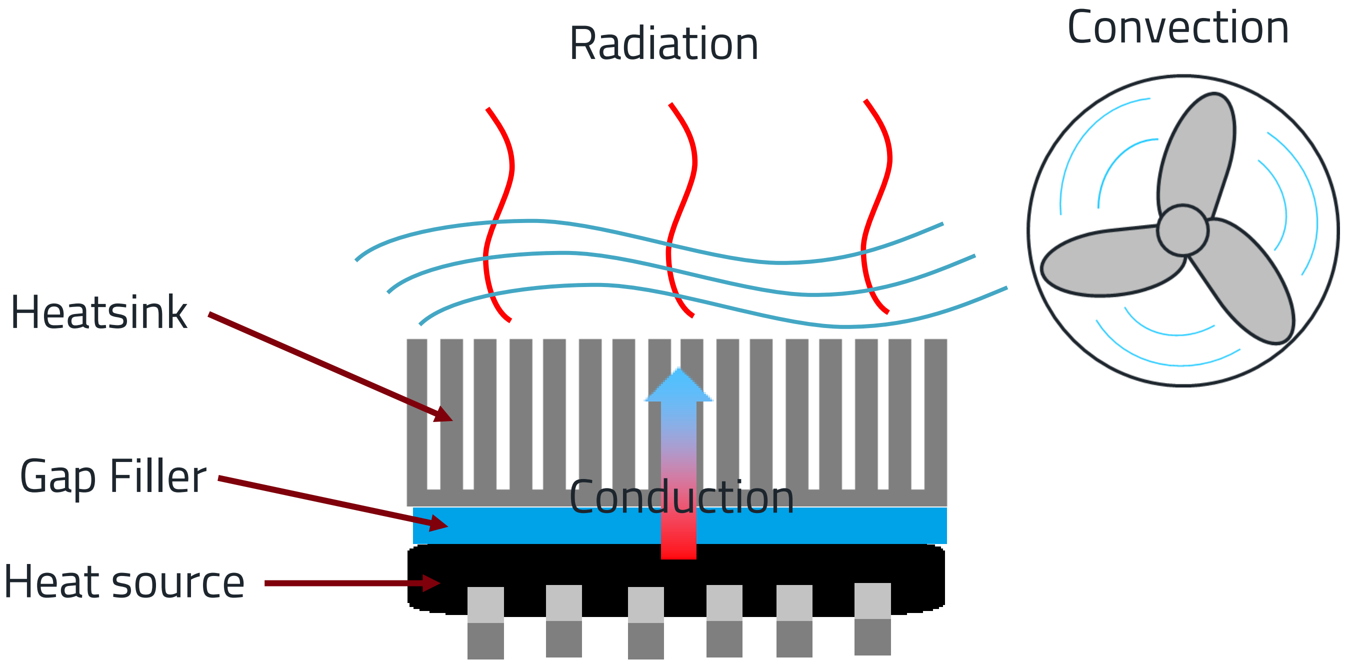
# HOW HEAT IS TRANSFERRED

- Conduction
  - Heat flow through a medium
  - ~ 80% of heat flow
- Convection
  - Transportation of heat due to a moving fluid
  - ~ 10% of heat flow
- Radiation
  - Heat transported through electromagnetic waves
  - ~10% of heat flow



# HEAT DISSIPATION

- Heat causes performance or safety issues
- Conduct heat a to exterior surface
- Heat is dissipated by Radiation and Convection
- Thermal materials assist with heat dissipation



# HEAT TRANSFER FORMULAS

- Long, complicated, and time-consuming equations
- Simplify to an easier 1D model
- **Thermal Conductivity** $(k)$, **Area** $(A)$, and **Distance** $(d)$ are driving factors for conduction
- **Surface area** $(A_s)$ is driving factor for dissipation

## Conduction

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) \qquad Q = \frac{kA(T_2 - T_1)}{d} \qquad q_v = \rho c_p \frac{\partial T}{\partial t}$$

## Convection

$$\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} \qquad Q = hA_s(T_s - T_\infty) \qquad v\frac{\partial^2 T}{\partial z^2}\right) + \mu\Phi + \dot{q}$$

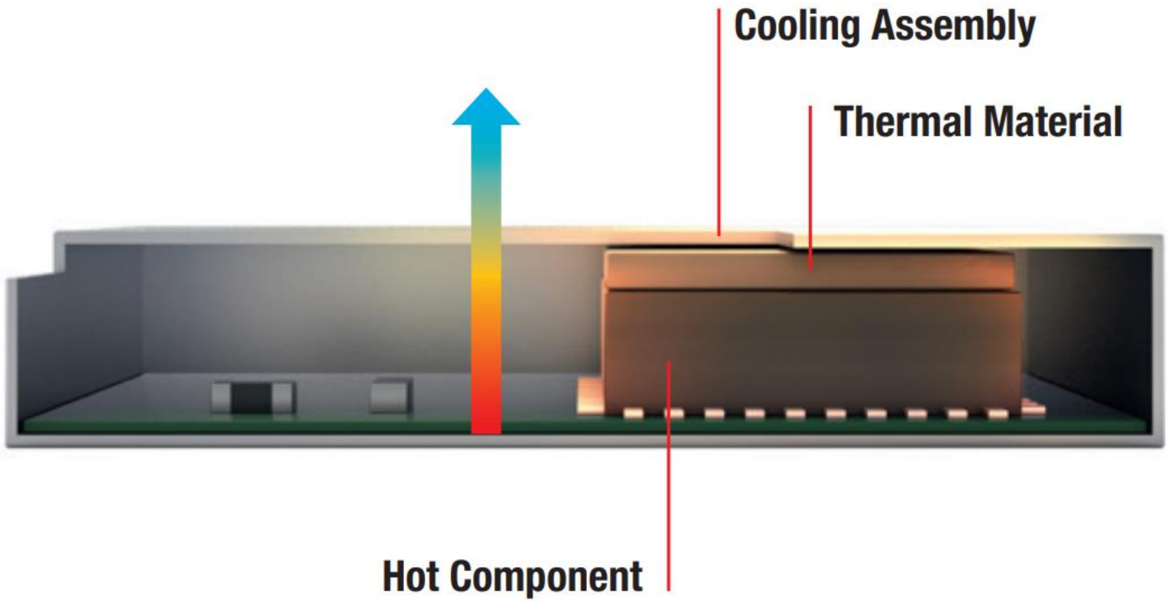
## Radiation

$$Q_{12} = \frac{}{1} \qquad Q = \sigma\varepsilon A_s(T_s^4 - T_\infty^4) \qquad (T_1^4 - T_2^4)$$

$$_{12}\frac{}{A_2}$$

# CONDUCTION

- Enclosures can act like ovens
- Heat needs to be moved to a desirable area
- Thermal interface materials (TIM) used to conduct heat
- Many resistances to heat flow
- Thermal conductivity $(k)$ = How easily heat is transferred



$$Q = \frac{kA(T_2 - T_1)}{d}$$

# THERMAL RESISTANCES

- Commonly given for ICs, MOSFETs, and Heatsinks
- Rarely given for TIMS due to height and area variations
- Can be calculated with variables given in datasheets
- Can substitute into conduction formula

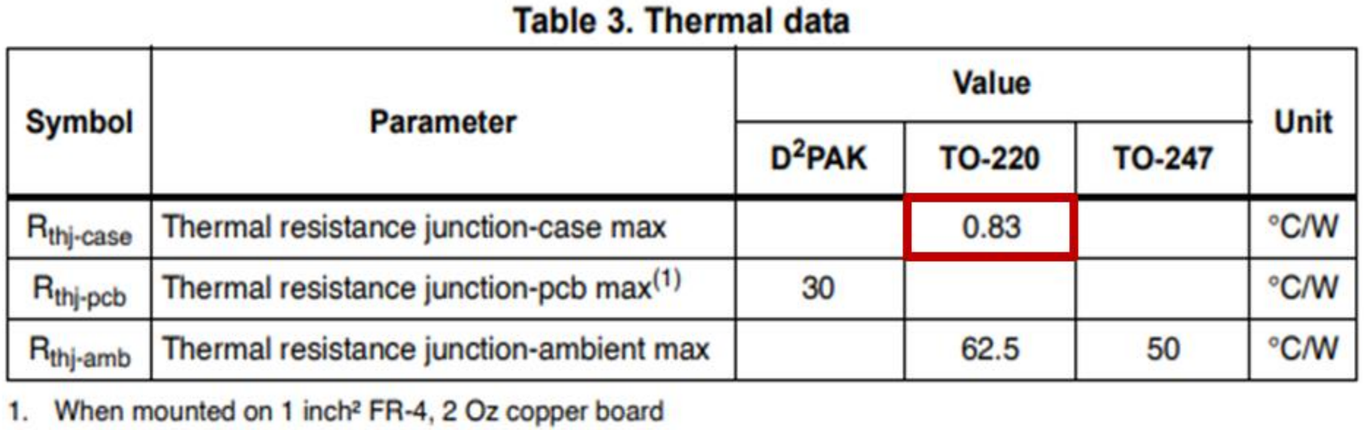


**Table 3. Thermal data**

| Symbol | Parameter | Value | | | Unit |
|---|---|---|---|---|---|
| | | $D^2PAK$ | TO-220 | TO-247 | |
| $R_{thj\text{-}case}$ | Thermal resistance junction-case max | | 0.83 | | °C/W |
| $R_{thj\text{-}pcb}$ | Thermal resistance junction-pcb max(1) | 30 | | | °C/W |
| $R_{thj\text{-}amb}$ | Thermal resistance junction-ambient max | | 62.5 | 50 | °C/W |

1. When mounted on 1 inch² FR-4, 2 Oz copper board

$$R_t = \frac{d}{kA}$$

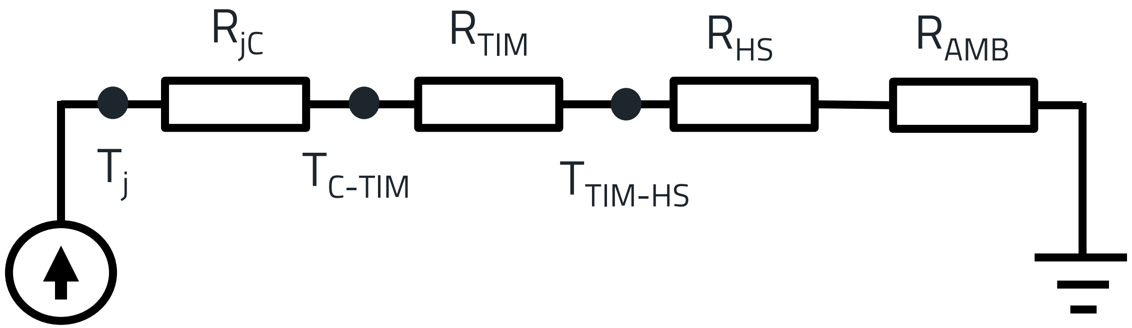
$$Q = \frac{kA(T_2 - T_1)}{d} \longrightarrow Q = \frac{(T_2 - T_1)}{R_t}$$

# SERIES HEAT RESISTANCE

- Similar to Ohms Law
- Can be modeled as series resistors
- Simplified model for estimation
- Can estimate the temperature at each contact surface
- Gives a rough estimate of temperature

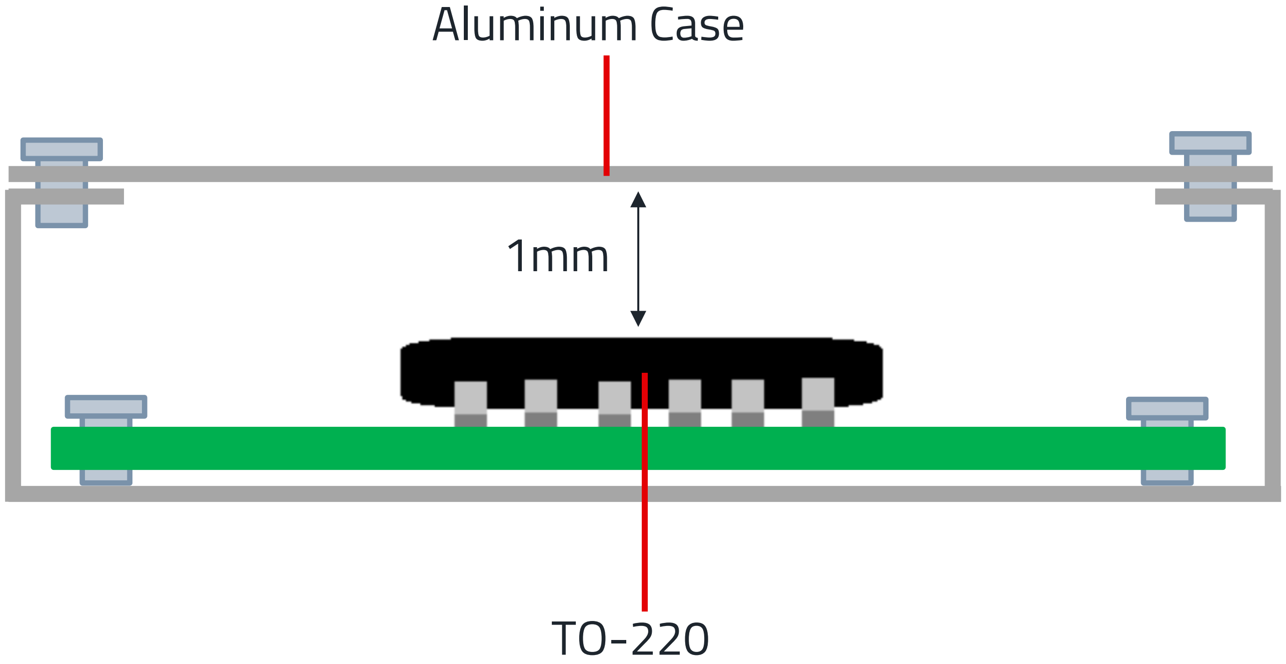
$$Q = \frac{(T_2 - T_1)}{R_t}$$

$$I = \frac{(V_2 - V_1)}{R}$$



# EXAMPLE: GAP FILLING

- TO-220 dissipating 6W inside enclosure
- TO-220 is 10x15mm
- 1mm gap
- 0.5mm thick aluminum



# OUR TIM PORTFOLIO

Thermal Gap Filler: **WE-TGF**

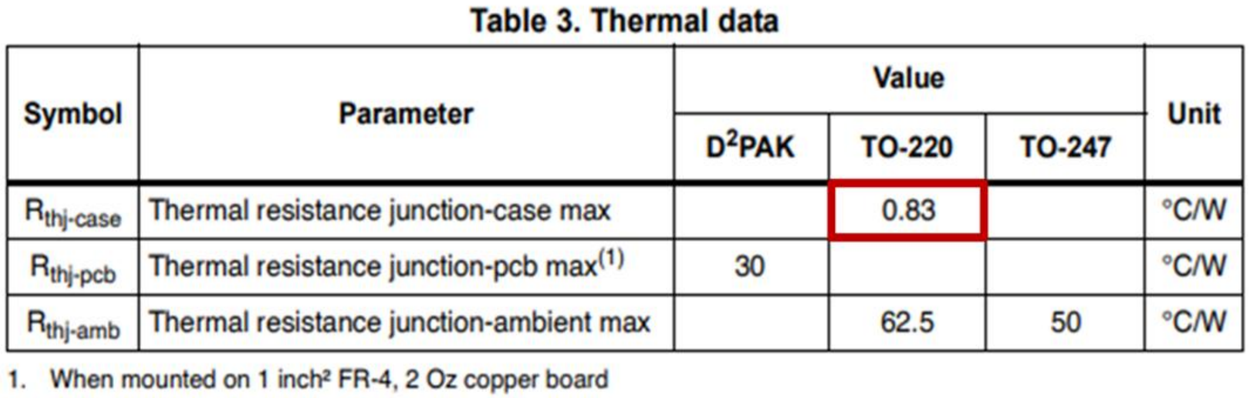
**General Purpose Gap Filler**

- Thermal Conductivity = 1 - 10 (W/m·K)
- Soft and conformable
- Naturally tacky, self adhesive
- Optimal performance: compression 10-30% or 10-30 psi

# CALCULATING RESISTANCE OF TIM

- Thermal conductivities
  - Al = 237 W/m*K
  - TIM = 3 W/m*K

$$R_t = \frac{d}{kA}$$



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| $R_{thj\text{-}amb}$ | Thermal resistance junction-ambient max | | 62.5 | 50 | °C/W |

1. When mounted on 1 inch² FR-4, 2 Oz copper board

$$237 \frac{W}{m * K} * \frac{1}{1000} = 0.237 \frac{W}{mm * K}$$

$$3 \frac{W}{m * K} * \frac{1}{1000} = 0.003 \frac{W}{mm * K}$$

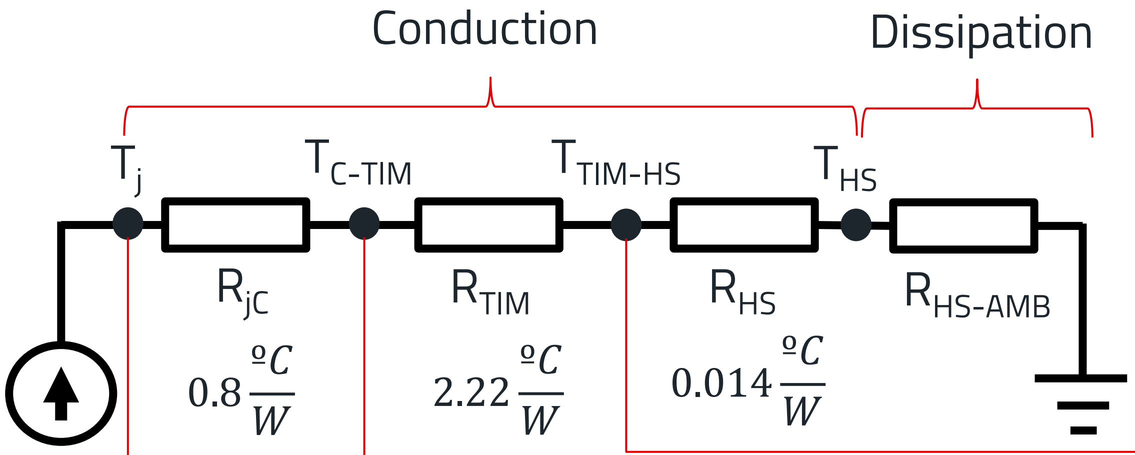
$$R_{Al} = \frac{0.5mm}{(0.237 \frac{W}{mm * K})(10mm * 15mm)} = 0.014 \frac{ºC}{W}$$

$$R_{TIM} = \frac{1mm}{(0.003 \frac{W}{mm * K})(10mm * 15mm)} = 2.22 \frac{ºC}{W}$$

# CALCULATION WITH TIM

- Calculate backwards from heatsink ($T_{HS}$ = 87°C)

$$Q = \frac{(T_2 - T_1)}{R_t} \Longrightarrow T_2 = Q * R_t + T_1$$



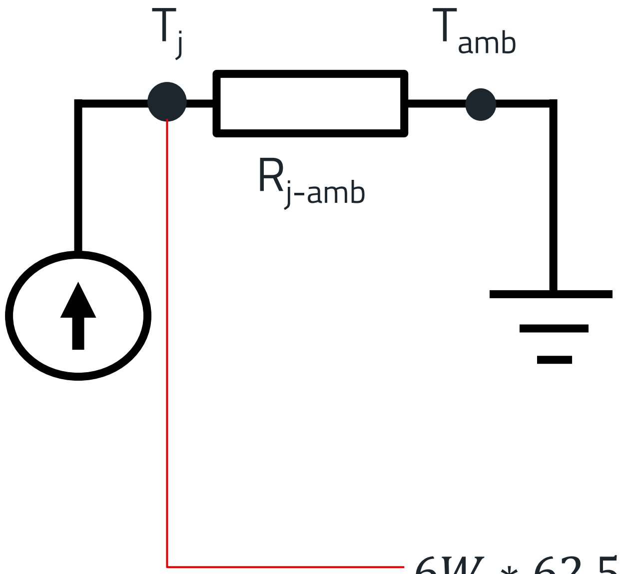
$$6W * 0.014\frac{^{\circ}C}{W} + 87^{\circ}C = 87.08^{\circ}C$$

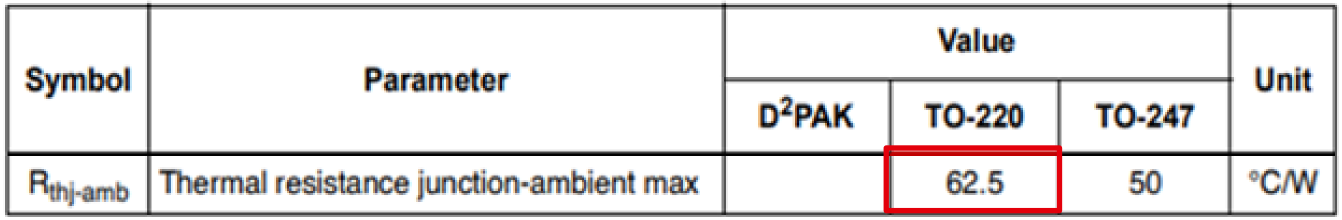
$$6W * 2.22\frac{^{\circ}C}{W} + 87.08^{\circ}C = 100.42^{\circ}C$$

$6W * 0.8\frac{^{\circ}C}{W} + 107.06^{\circ}C = 105.22^{\circ}C$ << **150°C Max. Junction Temp**

# CALCULATION WITHOUT TIM

- Calculate backwards from ambient ($T_{amb}$ = 20°C)





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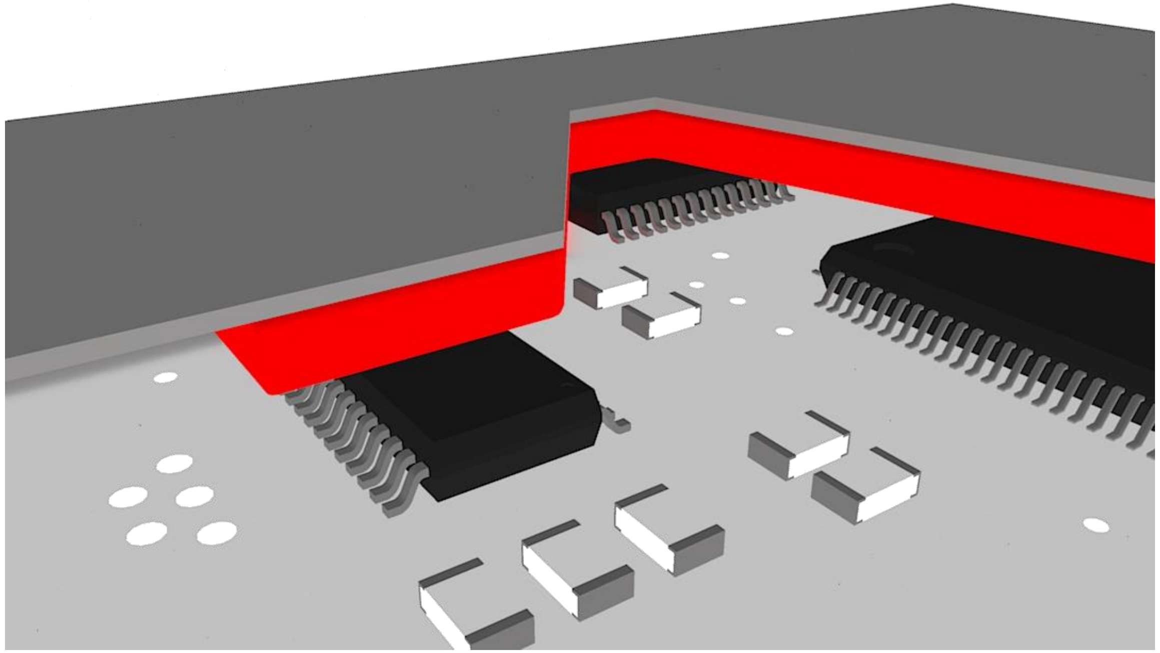
$$Q = \frac{(T_2 - T_1)}{R_t} \Longrightarrow T_2 = Q * R_t + T_1$$

$$6W * 62.5\,\frac{ºC}{W} + 20ºC = 395ºC$$ >> **150°C Max. Junction Temp**

# OUR TIM PORTFOLIO

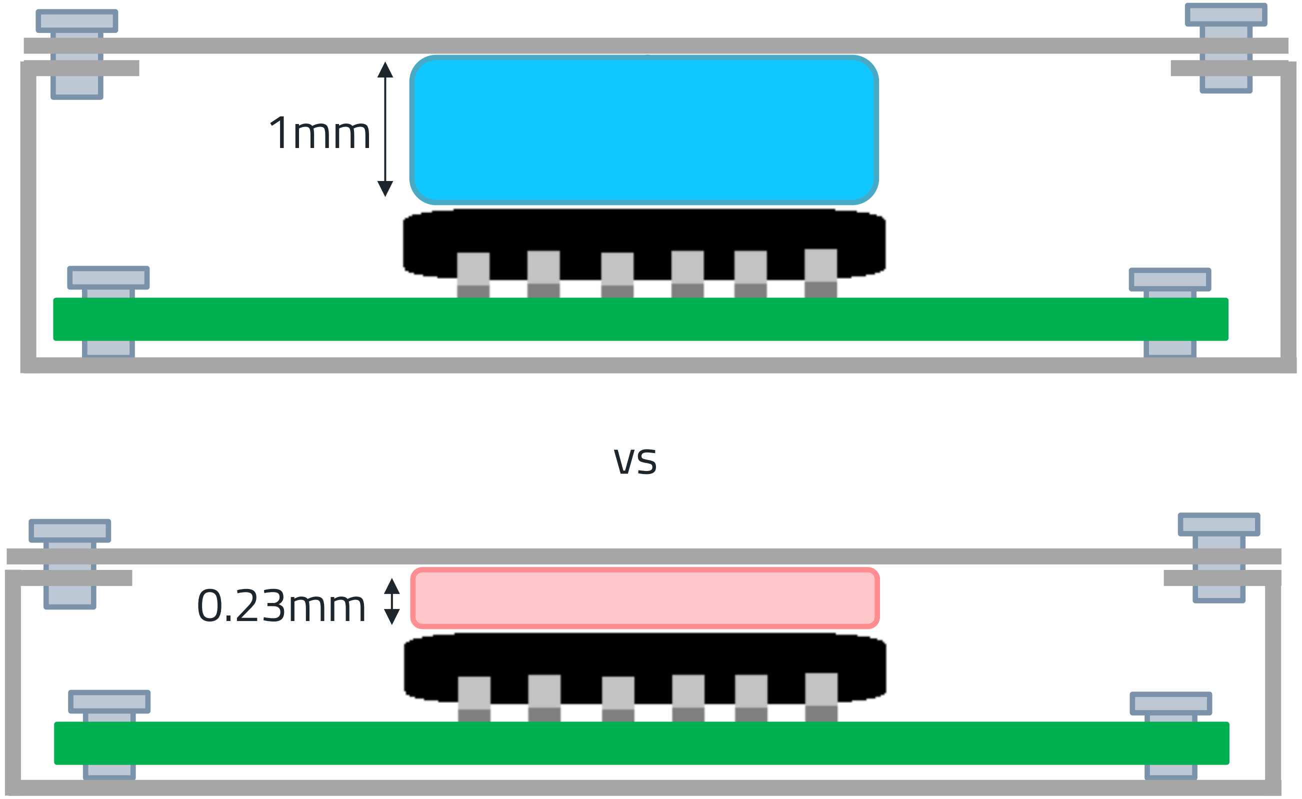
Gap Filling Solutions: **WE-TGF**

- Fills large gaps between hot components and cooling assemblies
- Cover multiple components without worrying about short circuits



# EFFECT OF REDUCING HEIGHT

- 6W Heat loss
- Reduced the gap from 1mm to 0.23mm
- Reduced Conductivity from 3 W/m*K to 1 W/m*K

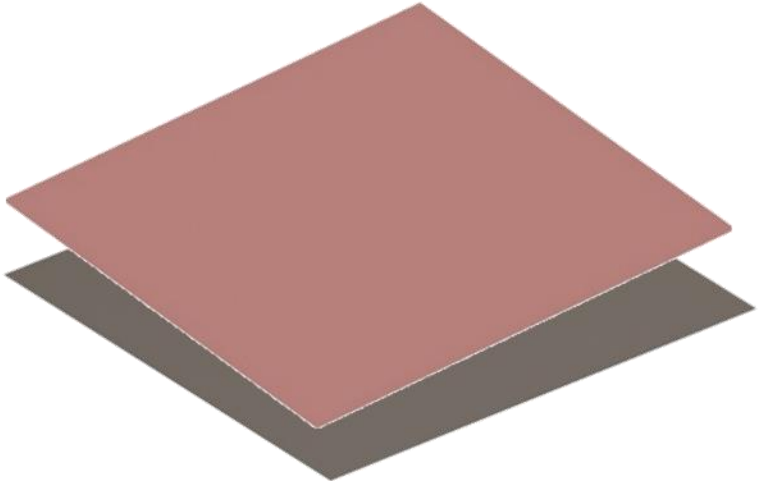


# OUR TIM PORTFOLIO

Thermal Insulating Sheet: **WE-TINS**

**High Mechanical Stress Applications**

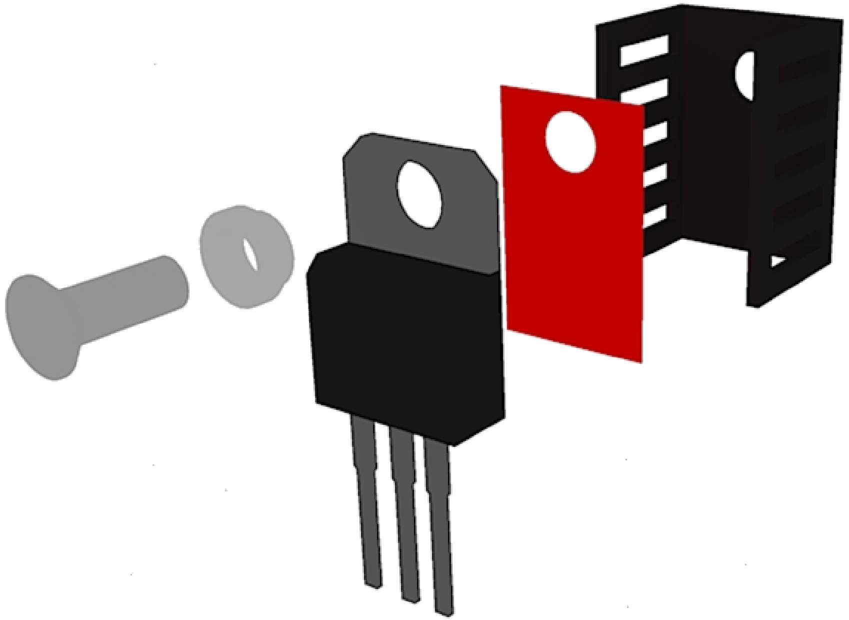
- Electrically insulating
- Withstands high mechanical stress
- Puncture and sheer resistant
- Thermal Conductivity = 1 – 3.5 (W/m·K)

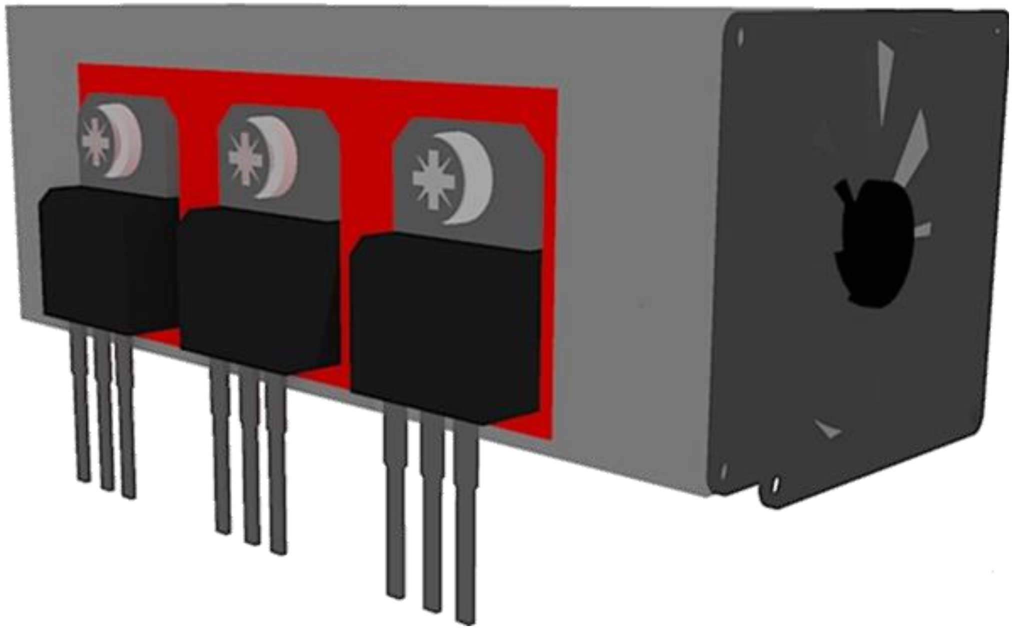


# OUR TIM PORTFOLIO

## Gap Filling Solutions: **WE-TINS**

- Simple interface with electric insulation
- Used mainly in power applications





# THERMAL CALCULATION

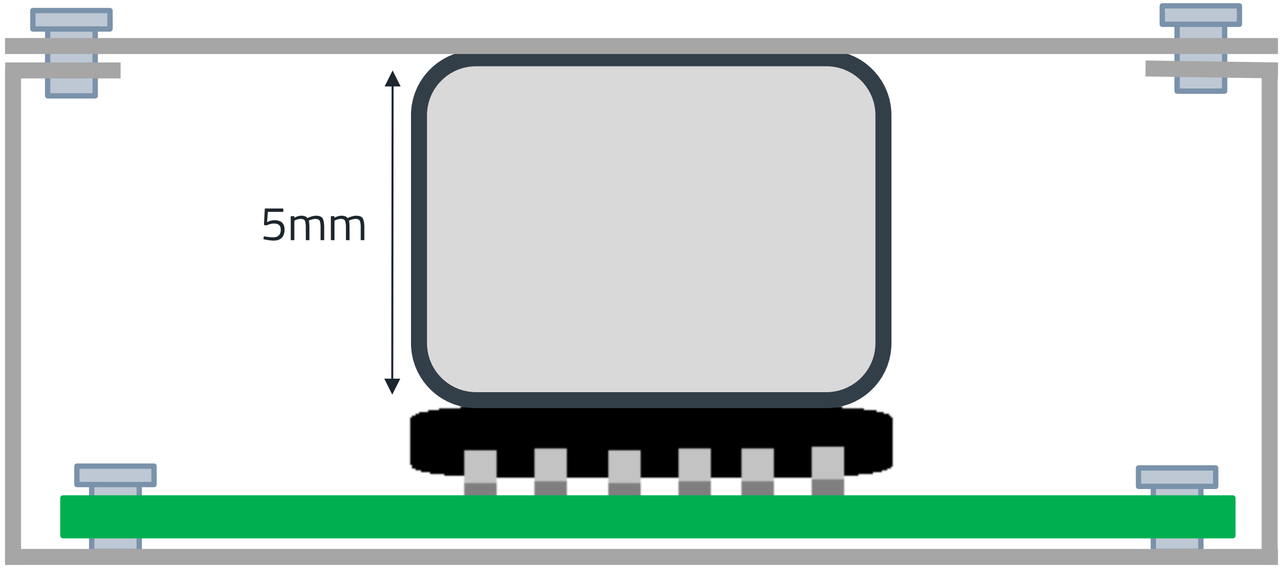
- Thermal resistance is lower
- Temperature is lower
- Higher Thermal Conductivities are exponentially more expensive

| Heat loss (W) | Surface Temp (°C) | Thermal Conductivity (W/m*K) | Gap to fill (mm) | Area (mm^2) | Heatsource Length (mm) | Heatsource Width (mm) | R_HS (°C/W) | R_TIM (°C/W) | R_jC (°C/W) |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 87 | 1 | 0.23 | 150 | 10 | 15 | 0.014 | 1.53 | 0.8 |

| | | |
|---|---|---|
| Temp_HS/TIM | 87 °C | Vs 87.08°C for 3 W/m*K @ 1mm |
| Temp_C/TIM | 96 °C | Vs 100.42°C for 3 W/m*K @ 1mm |
| Temp_j | 101 °C | Vs 105.22°C for 3 W/m*K @ 1mm |

# FILLING LARGE GAPS

- What if you need to fill large gaps
- Large gaps lead to larger thermal bottleneck
- How can we keep high performance over large gaps?

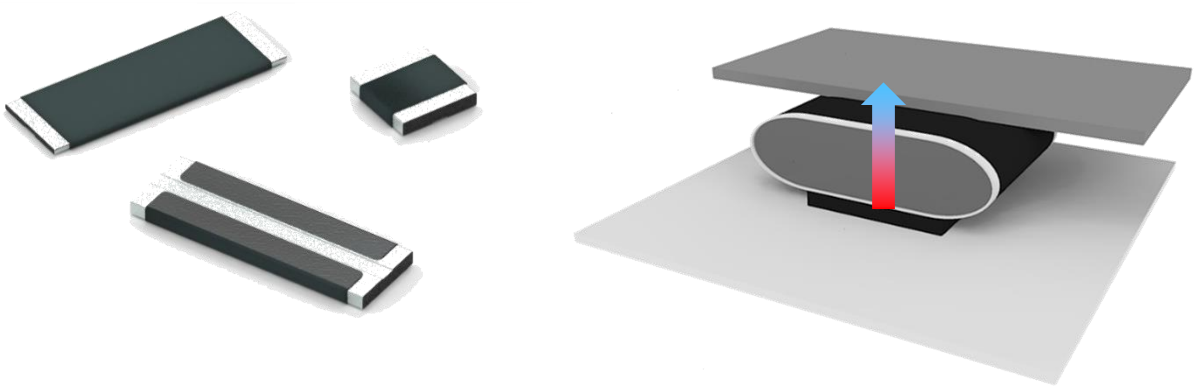


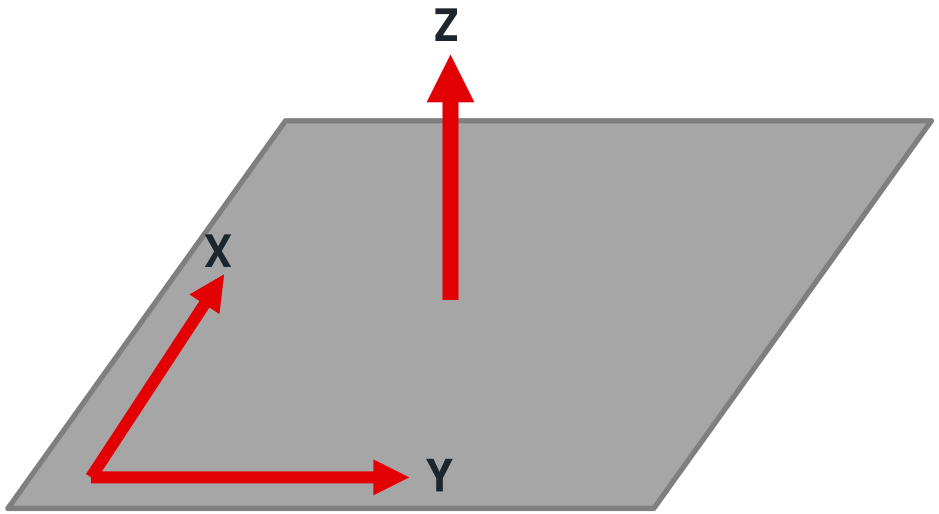
# OUR TIM PORTFOLIO

Thermal Graphite Foam Gasket: **WE-TGFG**

**More Freedom of Creativity**

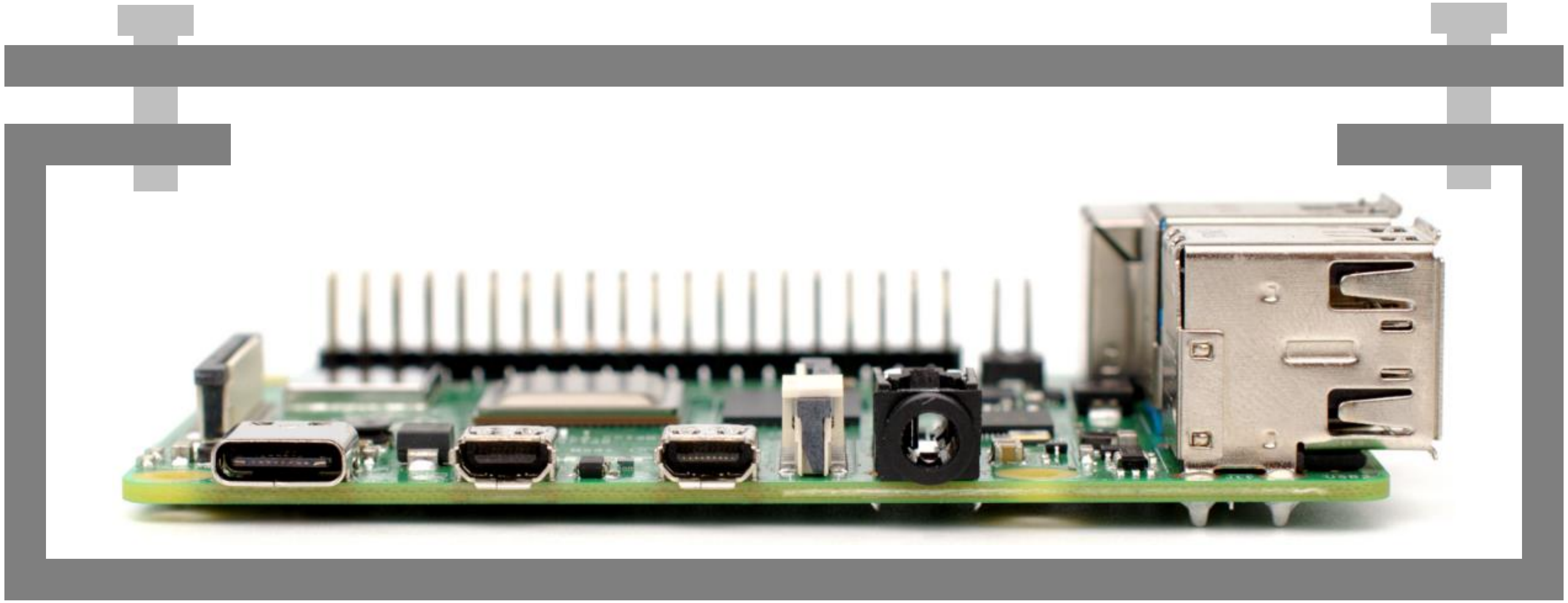
- Thermal Conductivity (X-Y Plane): 400 (W/m·K)
- Natural Graphite wrapped around foam core
- Silicone free alternative to traditional gap fillers
- Can be used for 1.5mm to 25mm gaps



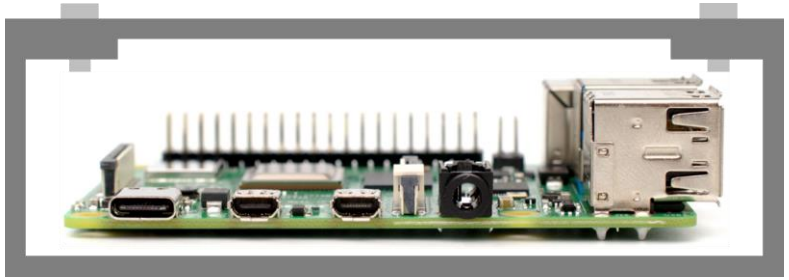


# APPLICATION EXAMPLES

- Raspberry Pi running stress test program
- Built in thermal throttling

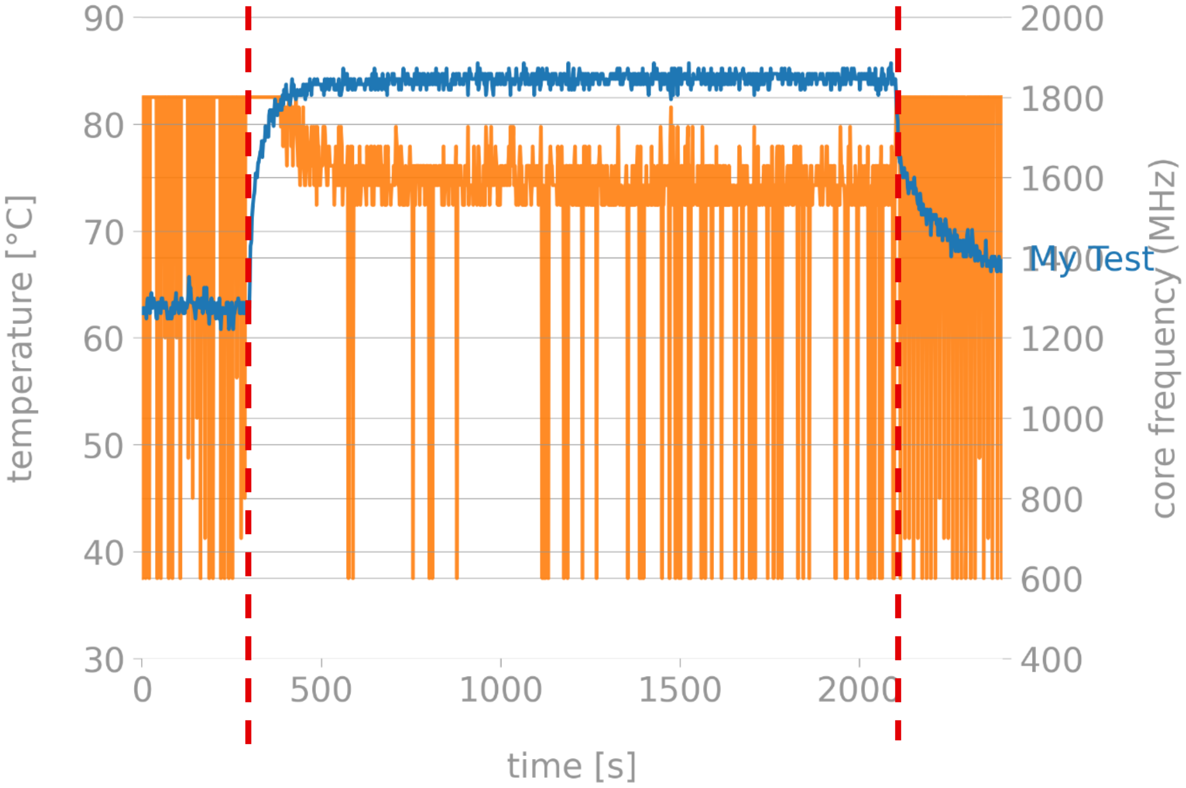


# APPLICATION EXAMPLES



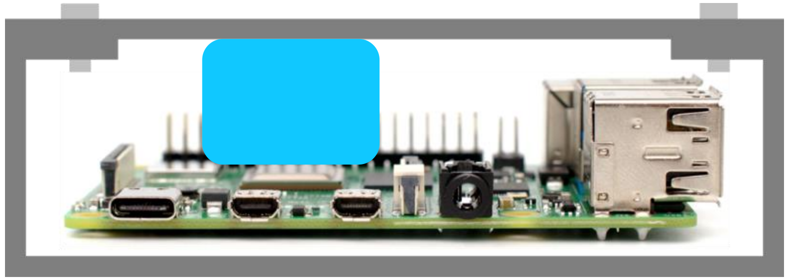
- Baseline test of thermal throttling and temperature profile

**No TIMs**

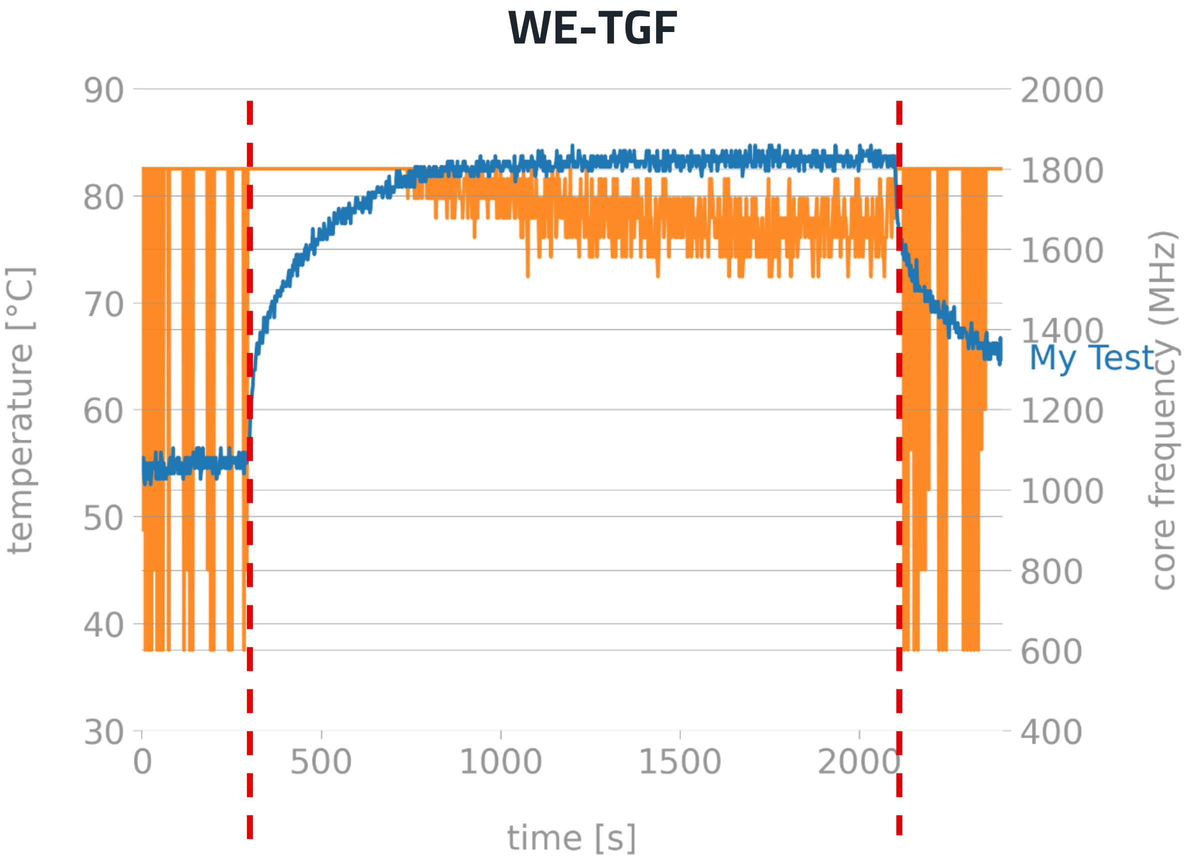


**20% Thermal Throttling**
**Max CPU Temp: 85°C**

# APPLICATION EXAMPLES

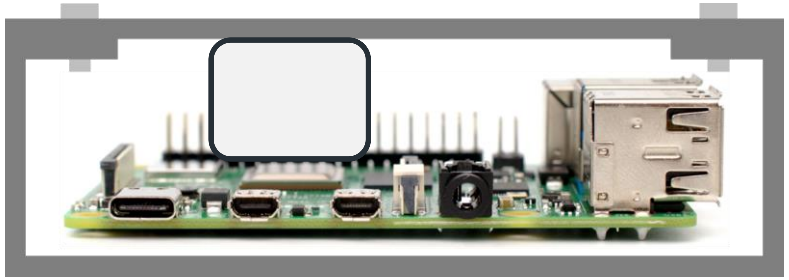


- Thermal gap filler (WE-TGF): 5mm @ 3 W/m*K

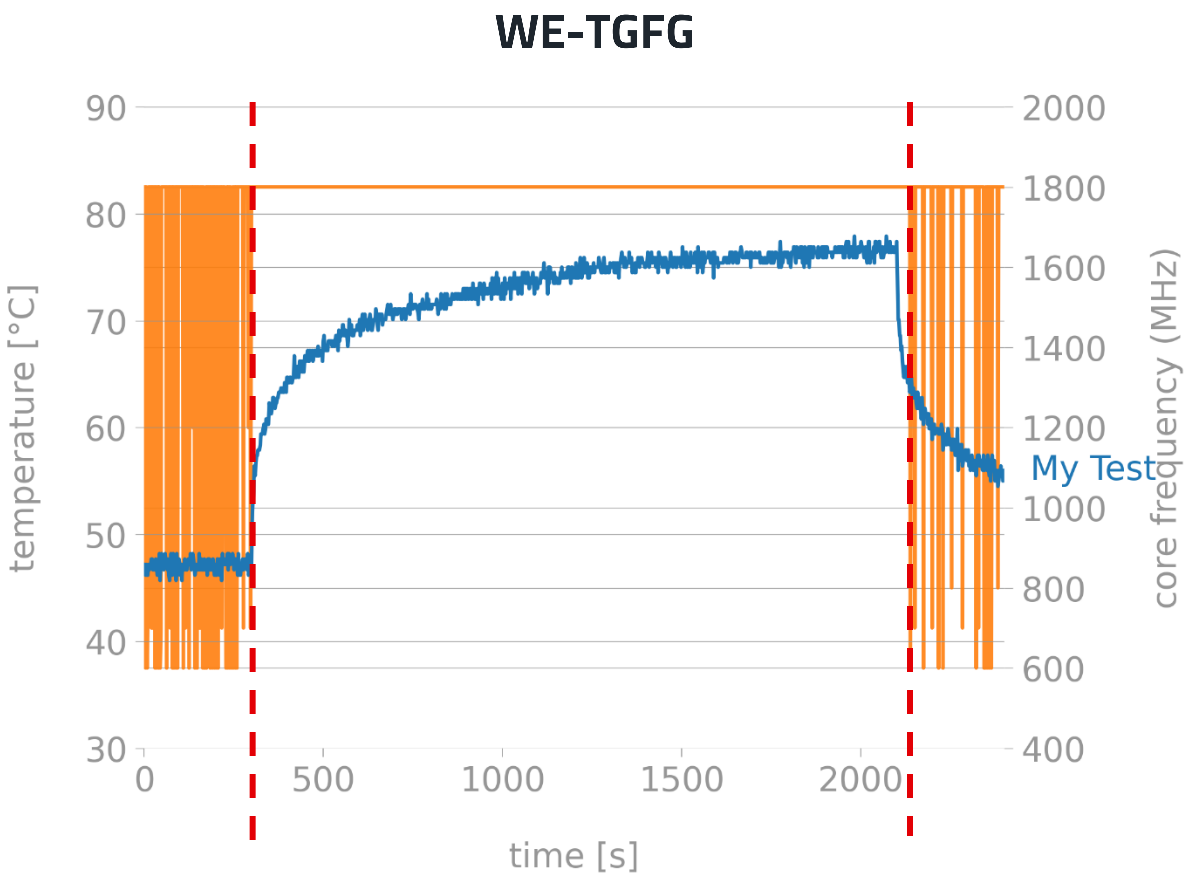


**15% Thermal Throttling**
**Max CPU Temp: 85°C**

# APPLICATION EXAMPLES



- Graphite Gasket (WE-TGFG): 5mm @ 400 W/m*K

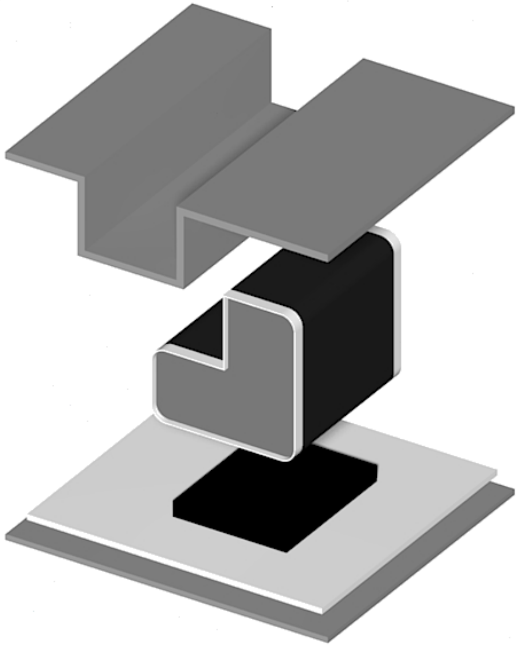


**0% Thermal Throttling**
**Max CPU Temp: 76°C**

# OUR TIM PORTFOLIO

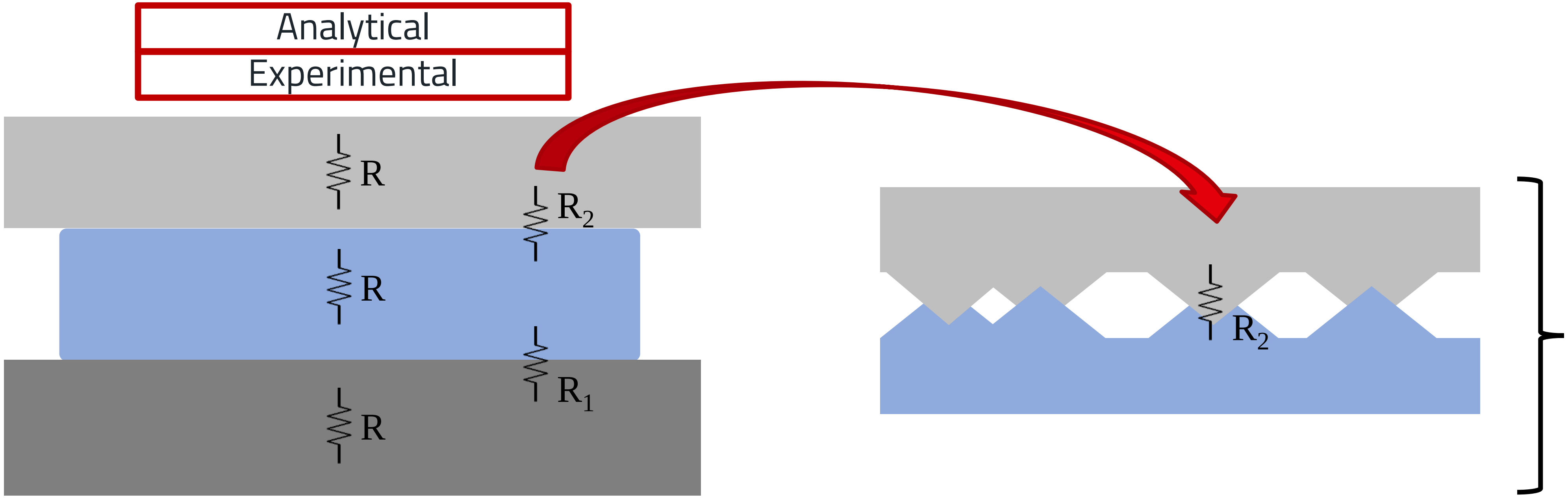
Hybrid Solutions: **WE-TGFG**

- Height/Profile constraints can make difficult the use of a traditional gap filler
- WE-TGFG has customizable shape and height profile



# CONTACT RESISTANCE

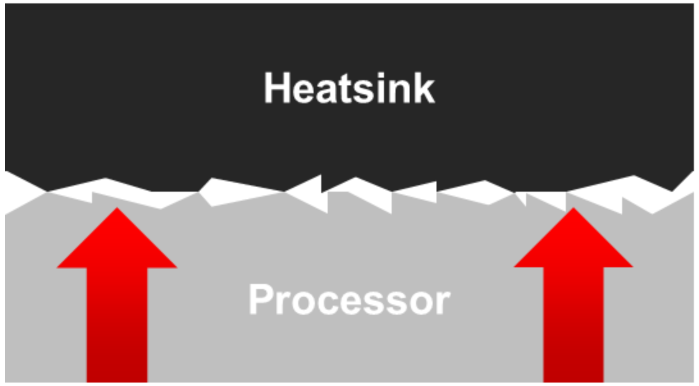
- 1D calculations give idealized models of thermal resistance
- Experimental tests have additional variables that are hard to calculate

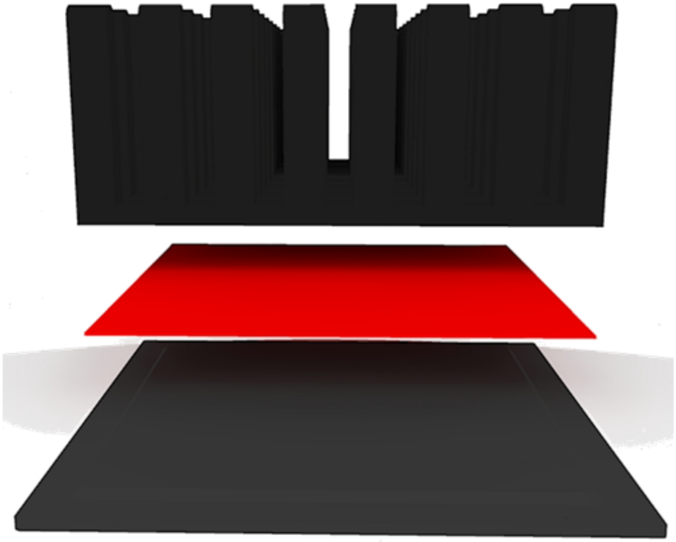


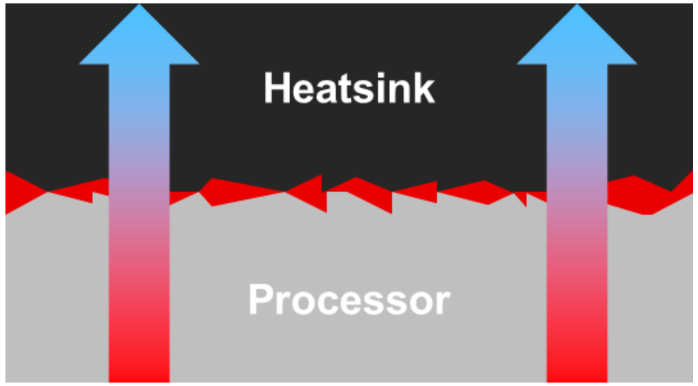
$$R_\theta = R + R_1 + R_2$$

# REDUCING CONTACT RESISTANCE

- Interface materials fill microscopic gaps between surfaces
- Thermal greases common for reducing contact resistance







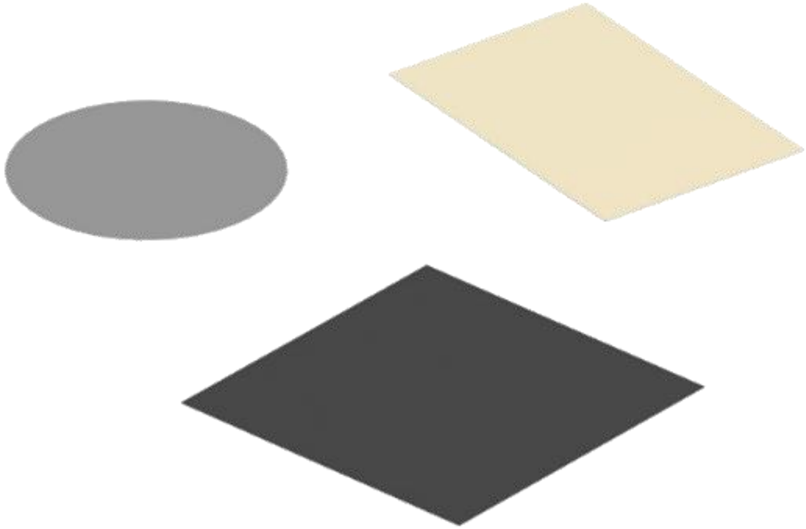
# OUR TIM PORTFOLIO

Phase Changing Material: **WE-PCM**

**Seamless Thermal Interface**

**Alternative to Thermal Pastes**

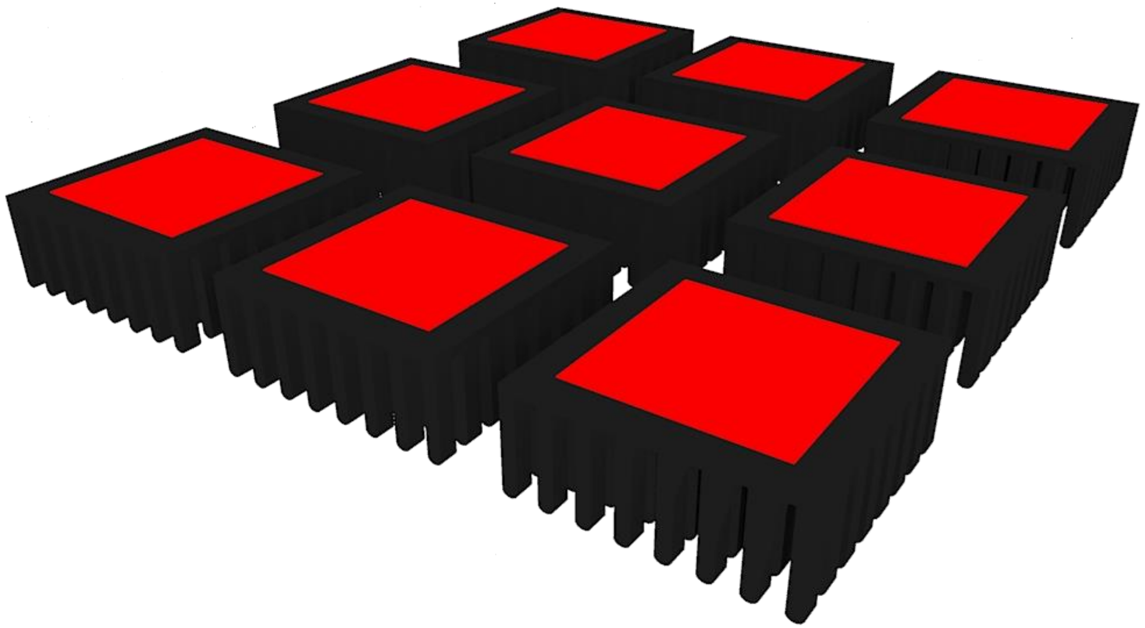
- Comparable to thermal pastes and greases
- Reduces contact resistance
- Phase change temperature: 50-60°C
- Thermal Conductivity = 1.6 – 5 (W/m·K)



# OUR TIM PORTFOLIO

Gap Filling Solutions: **WE-PCM**

- Thermal pastes and greases can be difficult to handle:
  - Special storage conditions
  - Liquids in production lines can be a hassle
- WE-PCM can be pre-applied on cooling assemblies for ease of use
- More pumpout resistance
- Need replaced less often than thermal grease

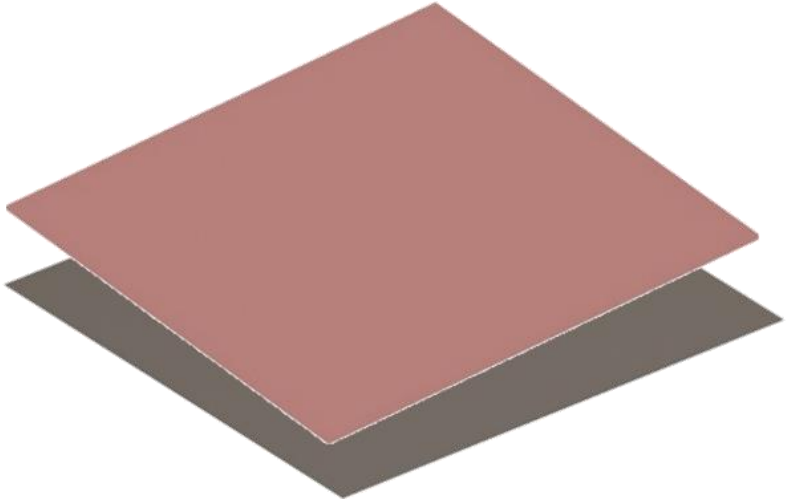


# OUR TIM PORTFOLIO

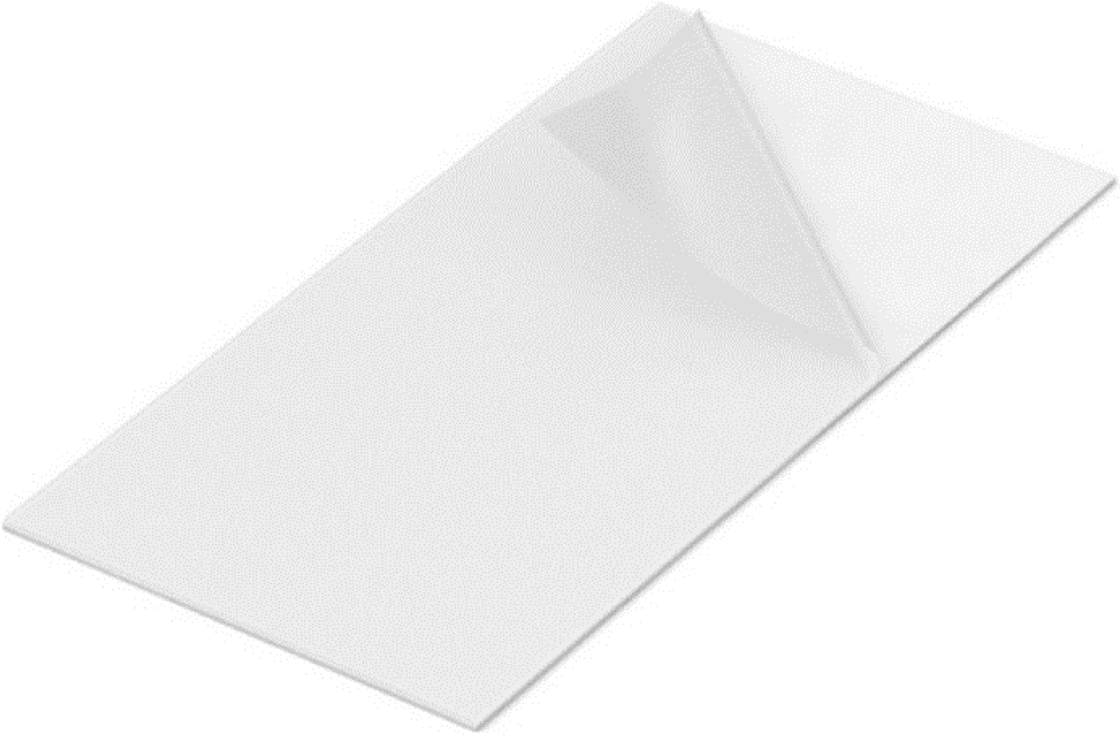
Gap Filling Solutions

- Soft compressible silicon material
- Conforms to uneven contact surfaces

**WE-TINS**



**WE-TGF**



# MECHANICAL COMPRESSION

- Mechanical compression is required
- Second tightening required for WE-PCM after phase change
- For gap fillers 10-30% compression (10-30 psi) is recommended
- Heatsinks usually have fastening devices integrated
- What if they don’t?

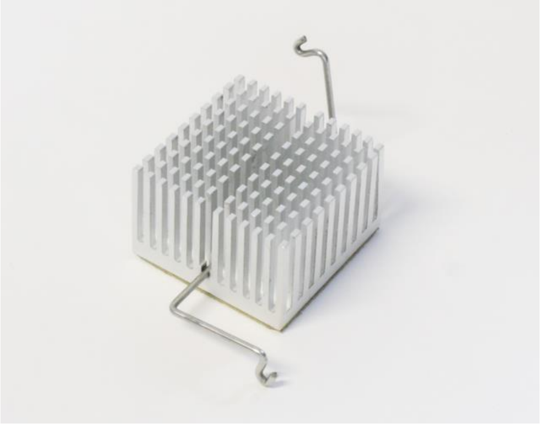


Photo by Own work CC BY

Photo by SparkFun Electronics CC BY

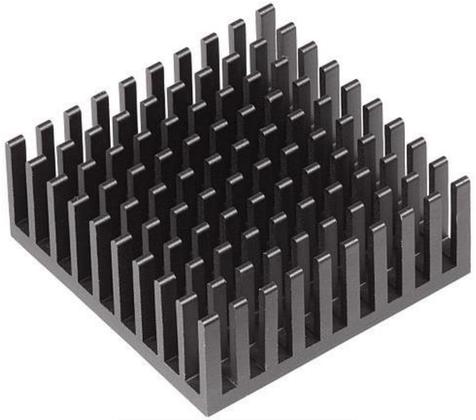


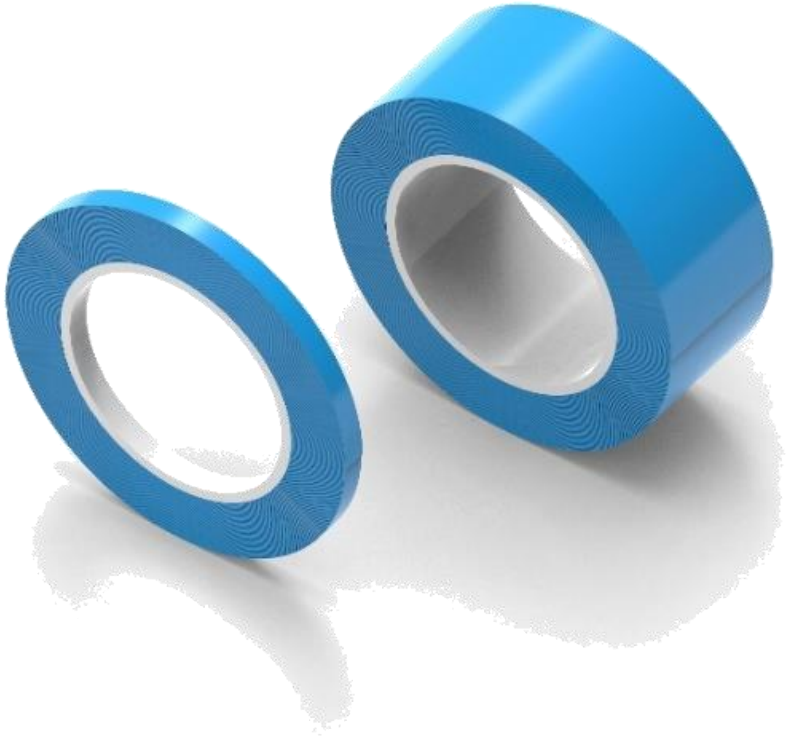
Photo by Lucasbosch CC BY

# OUR TIM PORTFOLIO

Thermal Transfer Tape: **WE-TTT**

**Adhesive Solution**

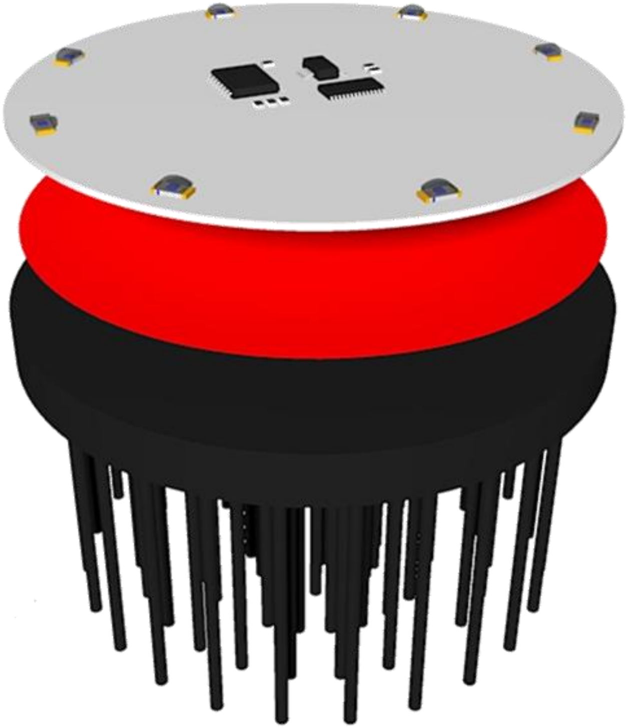
- Strong Adhesive Strength: 5.8 N/cm 3.3 lbs/in
- Thermal conductivity = 1 W/m*K
- Electrically insulating (4 KV/mm)
- 25m roll with a width of 8 or 50mm
- Custom shapes available



# OUR TIM PORTFOLIO

Gap Filling Solutions: **WE-TTT**

- When mechanical fixation of the cooling assembly with screws or clips is not possible



# HEAT DISSIPATION

- Convection and Radiation is how heat is dissipated
- **Emissivity** (ε) and **Convection Coefficient** ($h$) can be modified to increase heat dissipation
- Emissivity = Material properties, Surface finish, Color (Usually hard to change)
- Convection Coefficient = Fluid properties, Flow rate
- **Surface area** ($A_s$) is driving factor for dissipation

**Radiation**

$$Q = \sigma \varepsilon A_s (T_s^4 - T_\infty^4)$$

**Convection**

$$Q = h A_s (T_s - T_\infty)$$

# IMPORTANCE OF SURFACE AREA

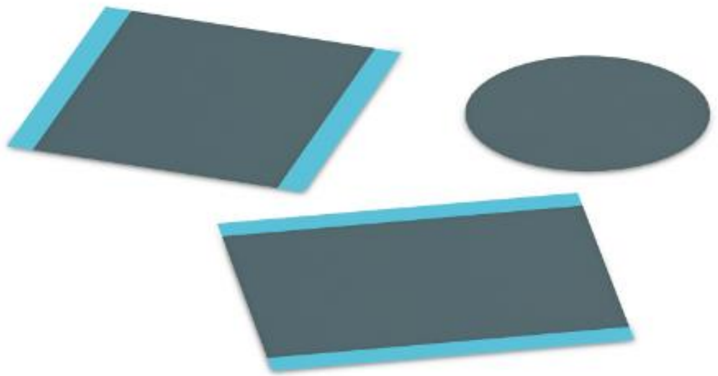
- Heat can be dissipated from enclosure
- Compact devices need to maximize heat dissipation
- Plastic enclosures can localize heat
- We want to increase working surface area

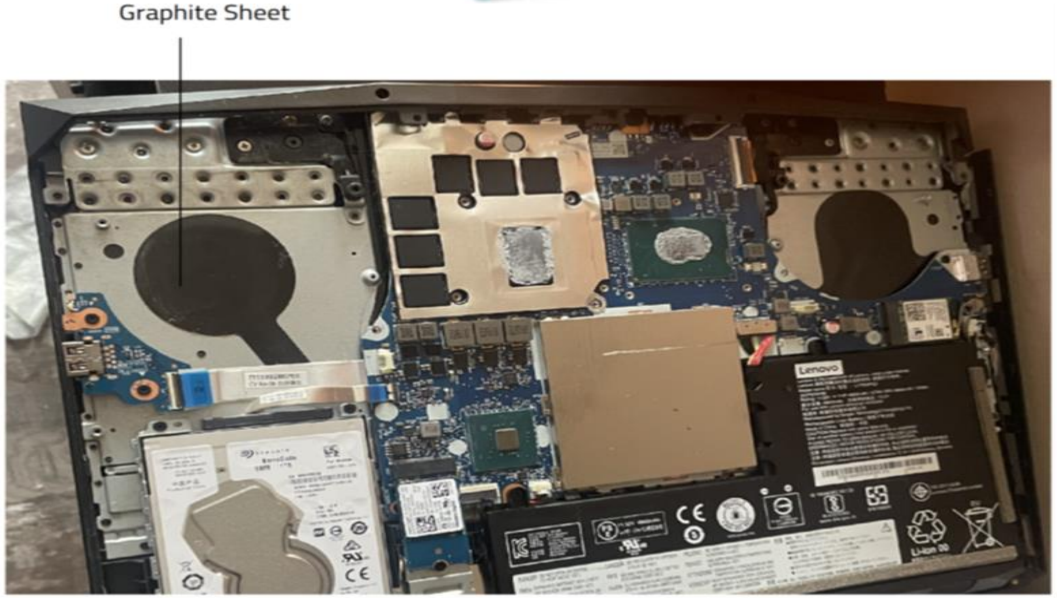
# OUR TIM PORTFOLIO

## Thermal Graphite Sheet: **WE-TGS**

**Heat Spreading Solution**

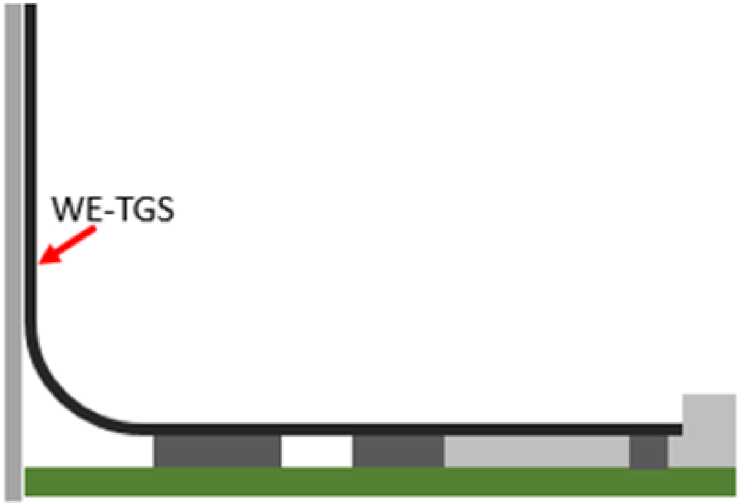
- Used to maximize working surface area
- Synthetic Graphite between acrylic layers
- Thermal Conductivity (X-Y Plane): 1800 W/m·K
- Can be combined with other solutions for further enhancement

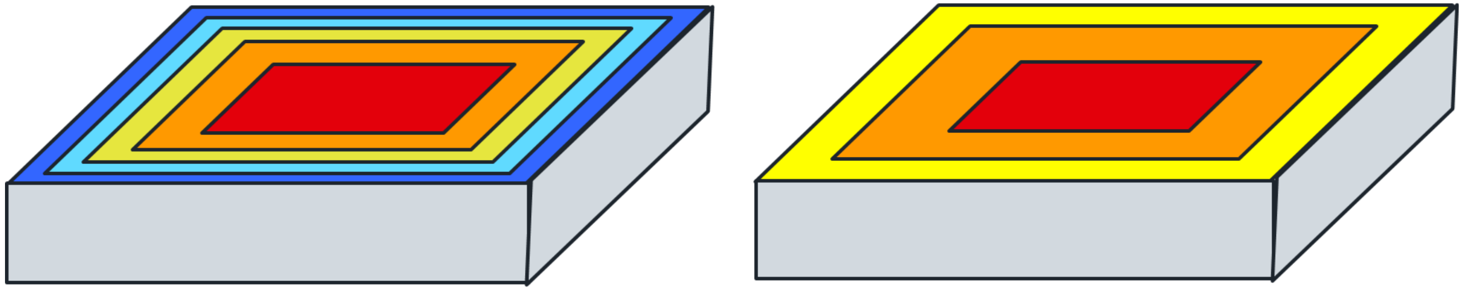


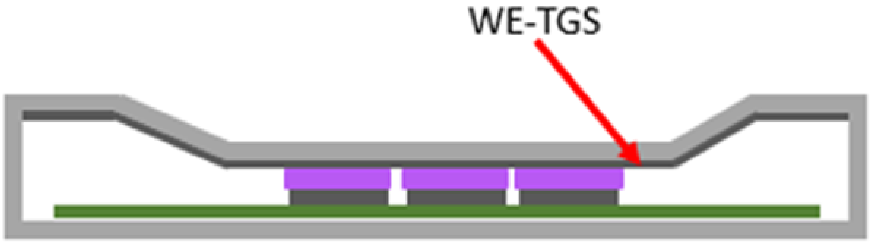


# MAXIMIZING SURFACE AREA

- Decreases the heat gradient across surface
- Efficient lateral transfer of heat
- Can be bend around corners and ridges
- Creasing can create bottlenecks

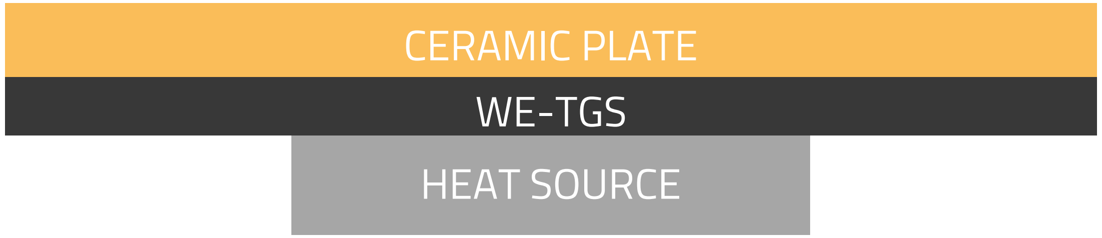






# APPLICATION EXAMPLES

Heat Spreader to enhance *Heat Spreading*

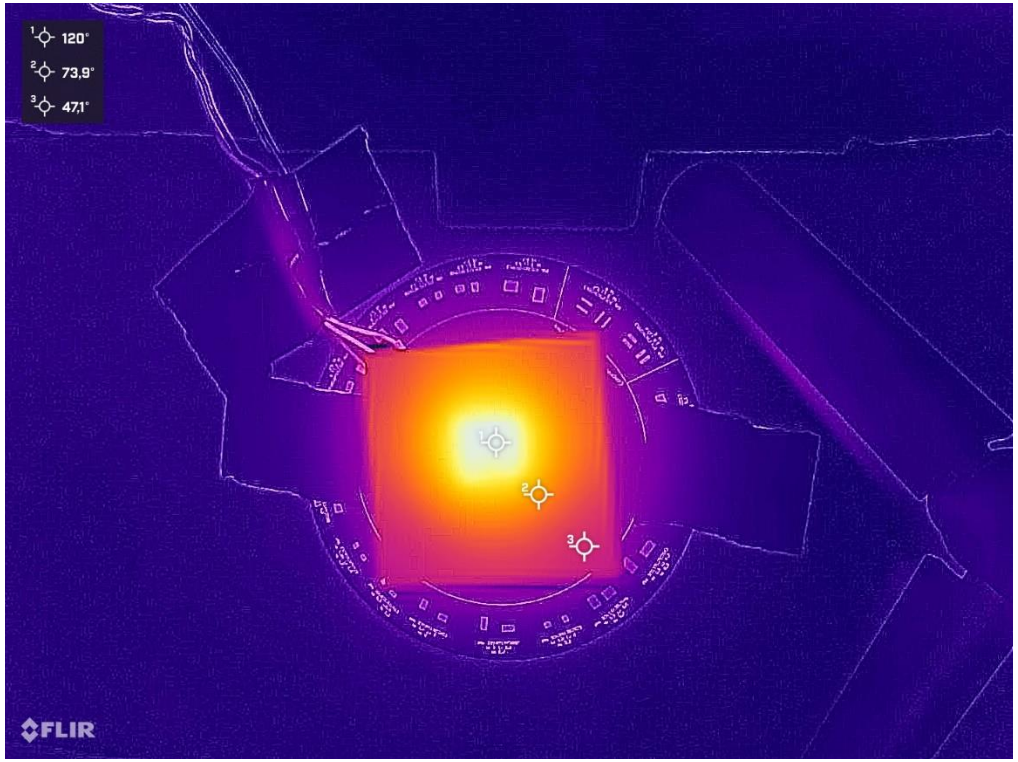

CERAMIC PLATE

WE-TGS

HEAT SOURCE

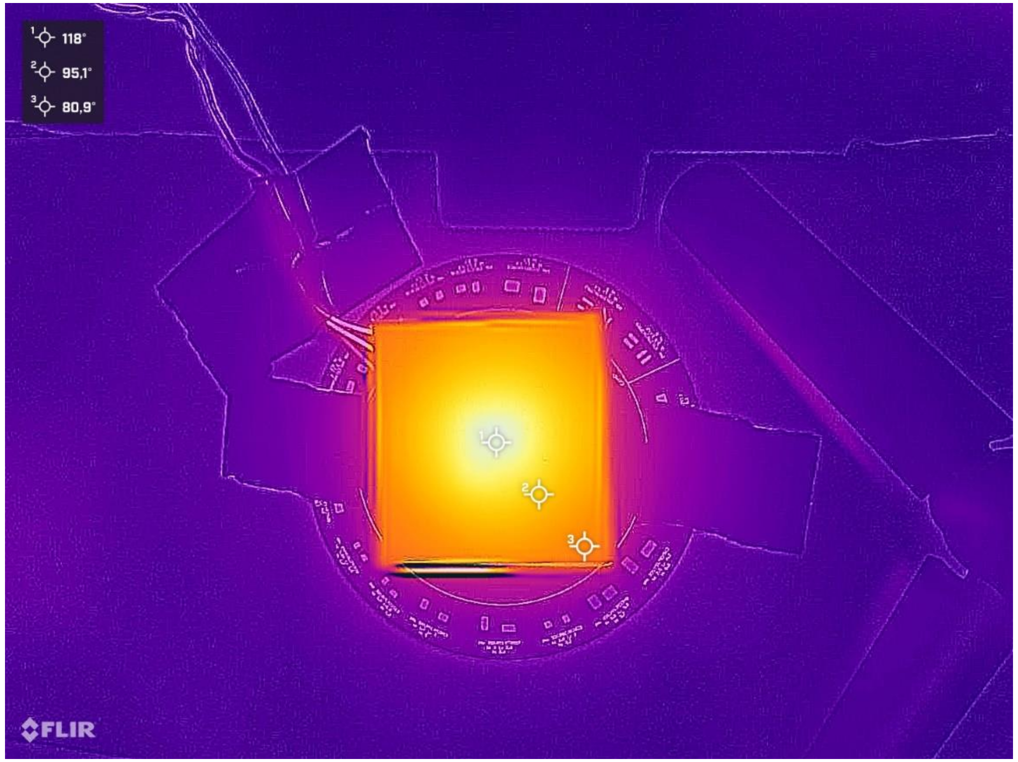
**Scenario 1**

(No heat spreader)



**Scenario 2**

(WE-TGS heat spreader)

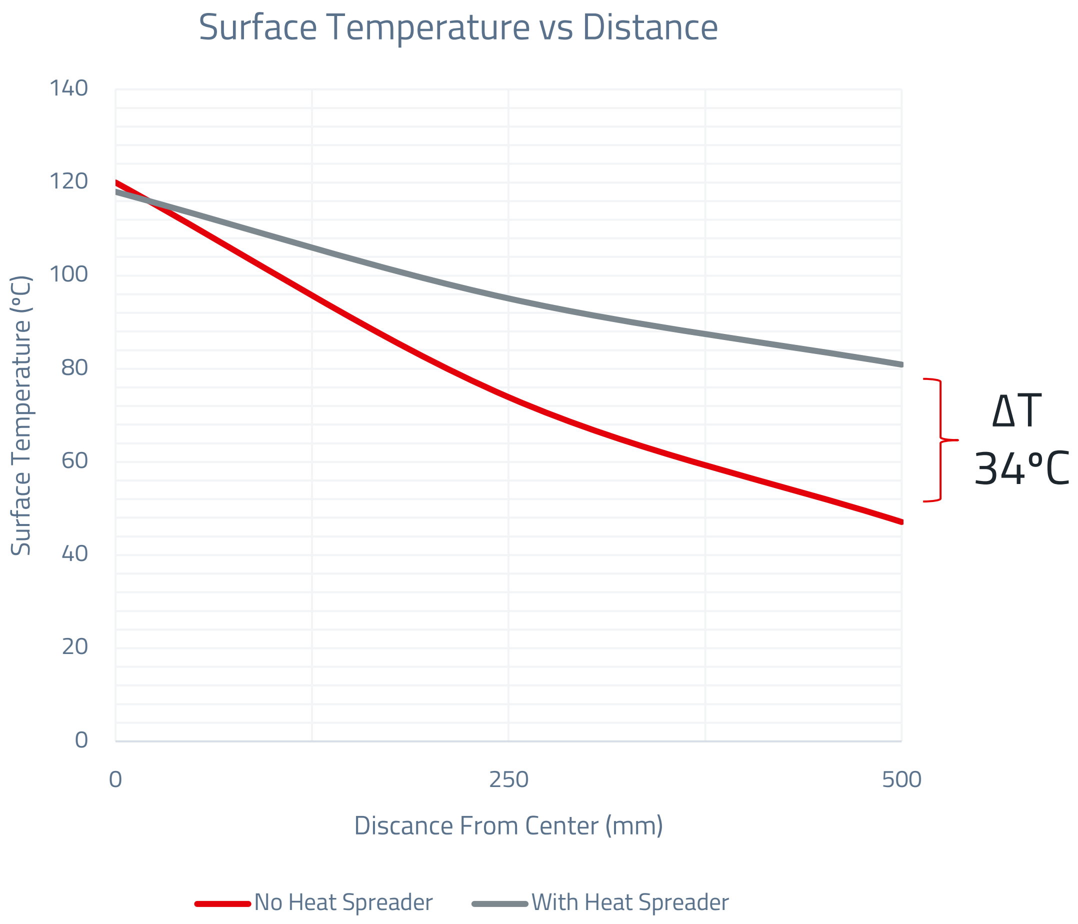


*Both images have been scaled as follows: 120°C (max), 20°C (min)

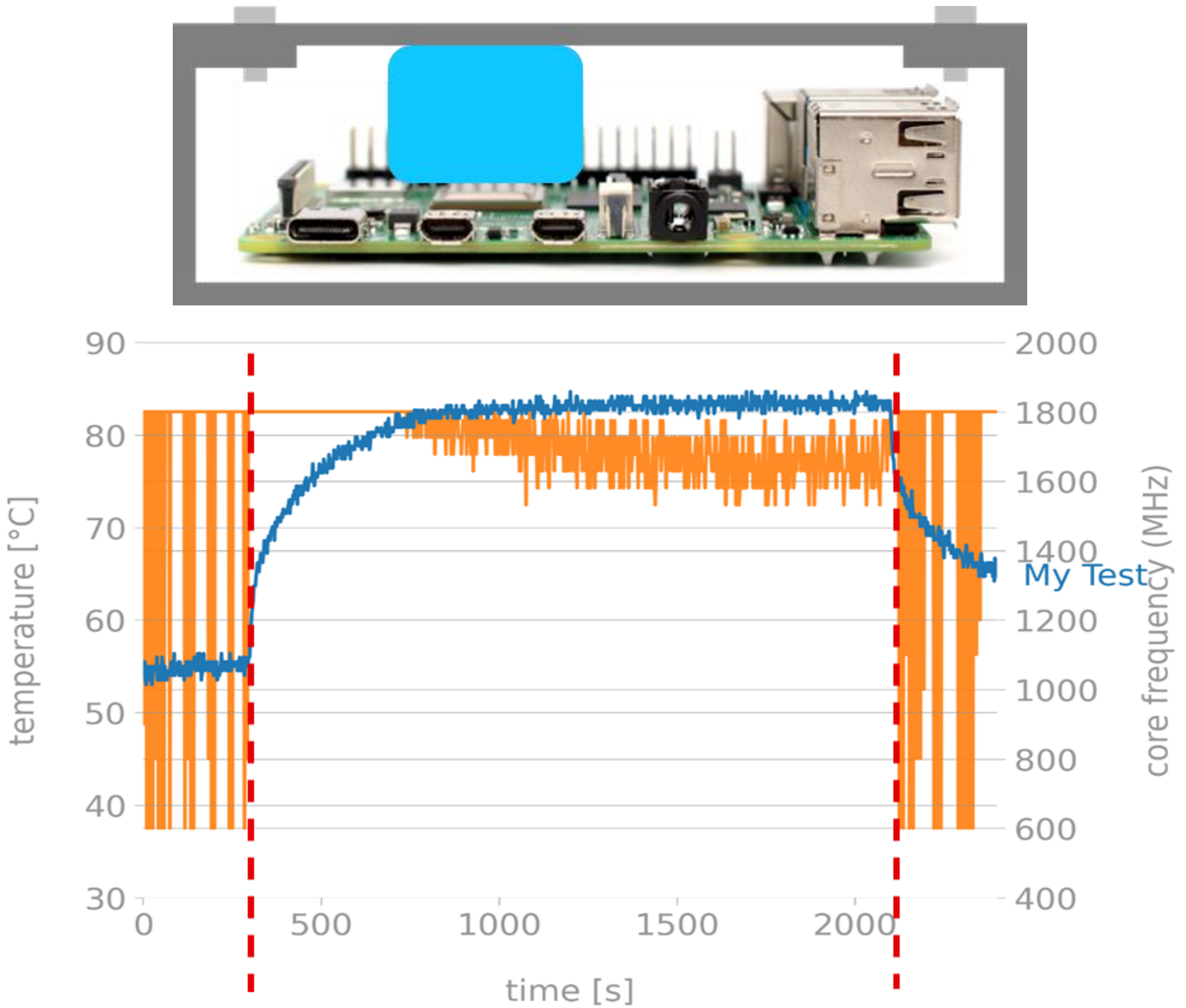
# APPLICATION EXAMPLES

Heat Spreader to enhance *Heat Spreading*

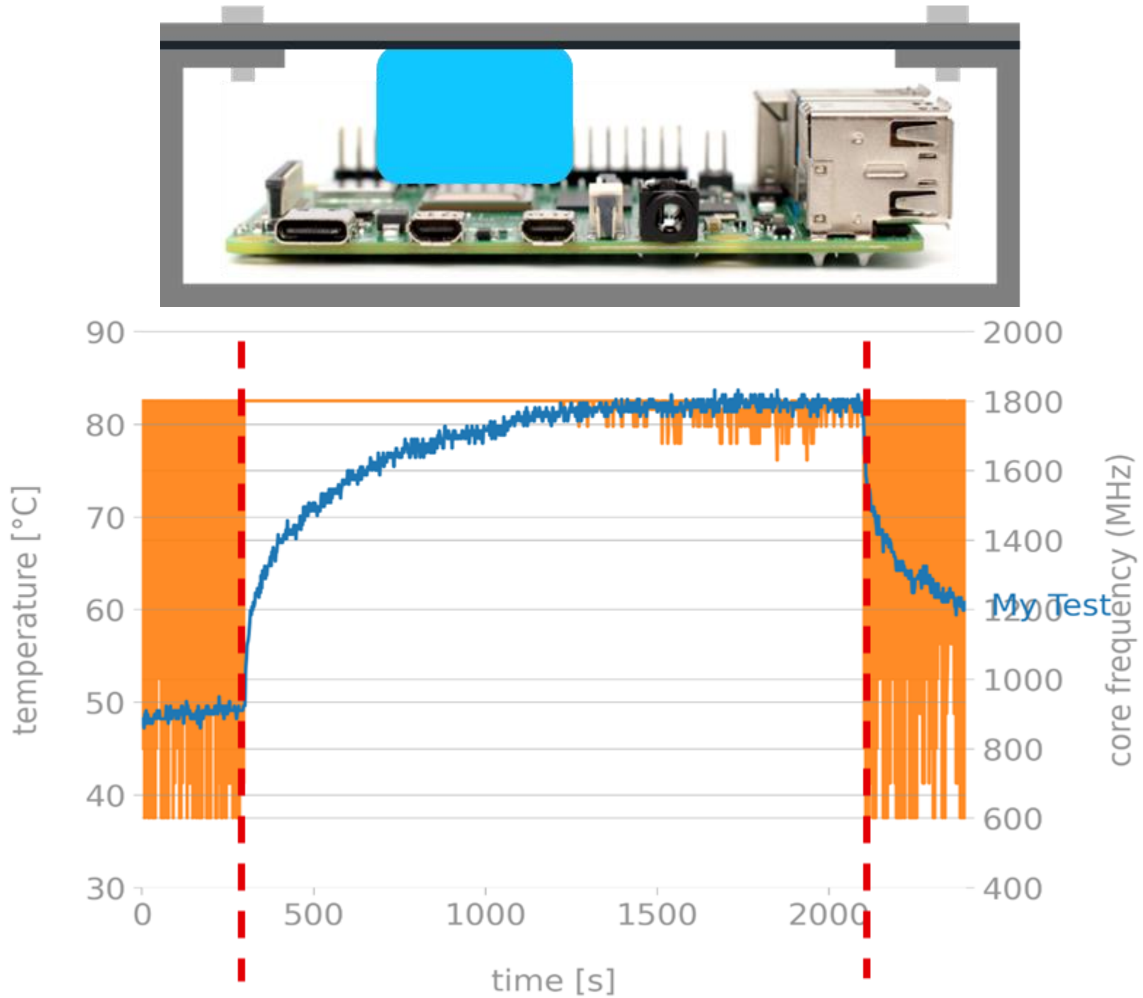
- Gradient significantly reduced with heat spreader
- Larger surface area = More heat dissipation
- Actual transfer rate value would require simulation



# COMBINING THERMAL SOLUTIONS



**WE-TGF = 15% Thermal Throttling**



**WE-TGF & WE-TGS = 5% Thermal Throttling**

# CUSTOMIZATION SERVICE

Tailored to the customer’s needs

- We can customize all materials
  - Dimensions
  - Additional layers (adhesive, electrical insulation…)
  - Profile (WE-TGFG)
  - Easier for a drop in solution for production

# THERMAL MANAGEMENT SAMPLE KITS

more than you expect

WÜRTH ELEKTRONIK

## Heat Spreading Solutions

Heat Spreading Interfaces

**Art. Nr. 400 002**
**Version 1.0**

Distribute the heat evenly throughout the surface of your cooling assembly.

| **WE-TGFG** | **WE-TGS** |
|---|---|
| Graphite Foam Gasket | Graphite Sheet |
| **K:** 400 W/mK<br>**T:** 1.5 – 25 mm | **K:** 1800 W/mK<br>**T:** 0.03 mm |

www.we-online.com

*K = Thermal Conductivity; T = Thickness*

more than you expect

WÜRTH ELEKTRONIK

## Thermal Interface Solutions

Vertical Thermal Interfaces

**Art. Nr. 400 001**
**Version 1.0**

Fill a gap to provide a path for the heat energy to flow.

| **WE-TGF** | **WE-TINS** | **WE-PCM** | **WE-TTT** |
|---|---|---|---|
| Silicone Gap Filler Pad | Thermally Conductive Insulator | Phase Changing Material | Thermal Transfer Tape |
| **K:** 1 – 10 W/mK<br>**T:** 0.5 – 18 mm | **K:** 1.6 – 3.5 W/mK<br>**T:** 0.23 mm | **K:** 1.6 – 5 W/mK<br>**T:** 0.2 mm | **K:** 1 W/mK<br>**T:** 0.2 mm |

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*K = Thermal Conductivity; T = Thickness*