CONNECTOR TEMPERATURE RISE AND DERATING

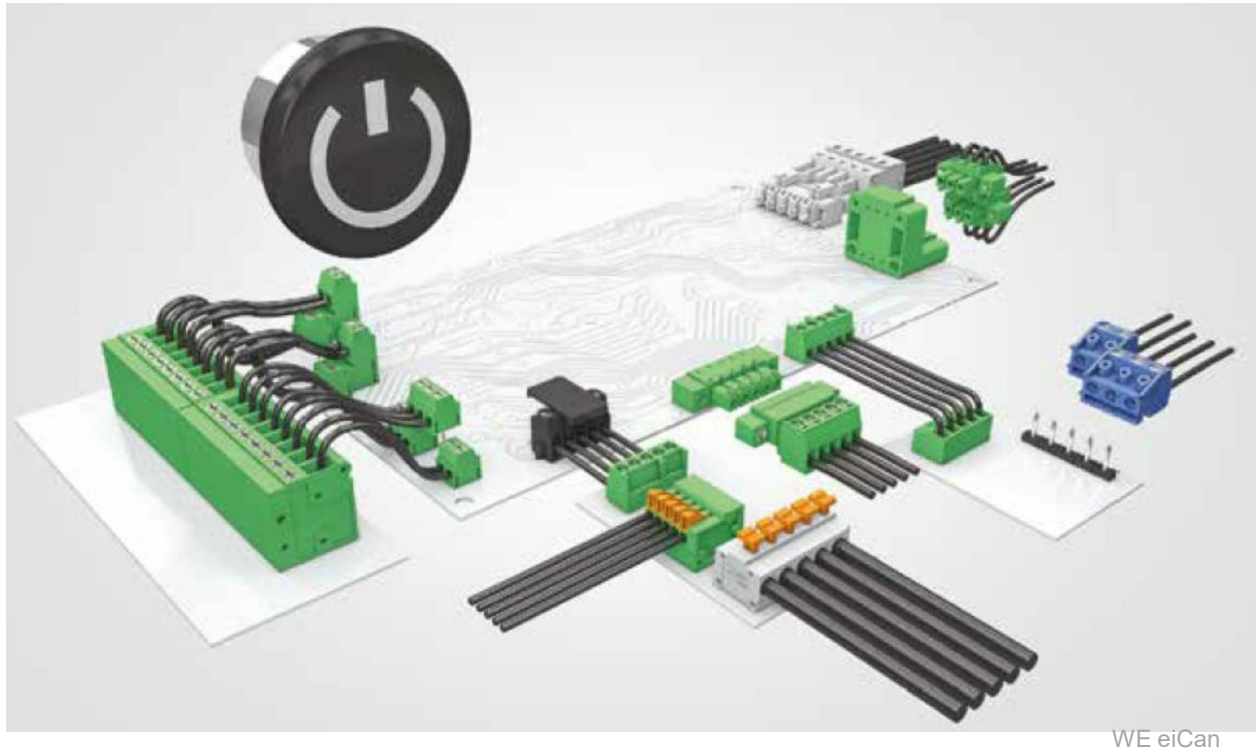
Goetz Schattmann FAE eiCan

WE eiCan

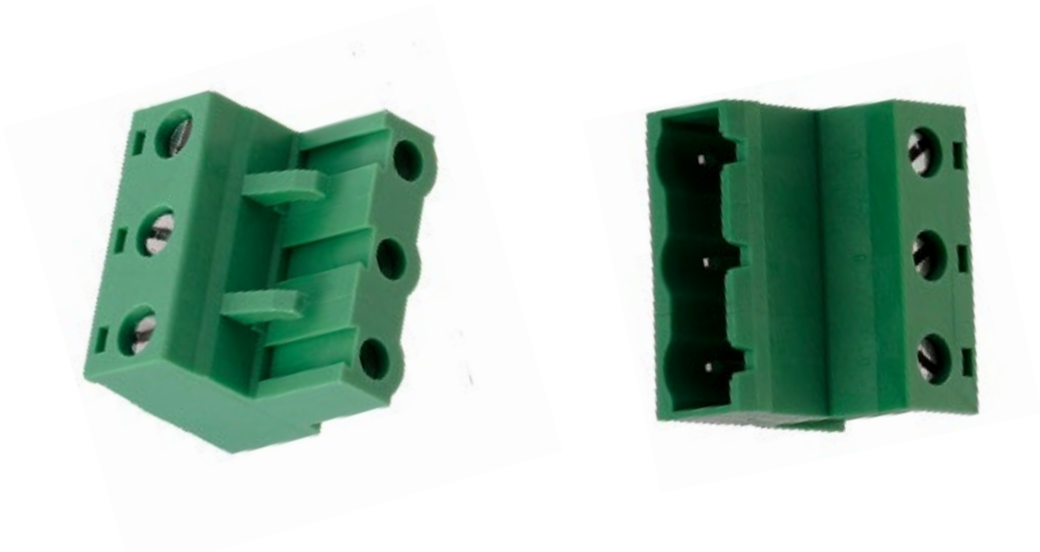
Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

Basic connector use

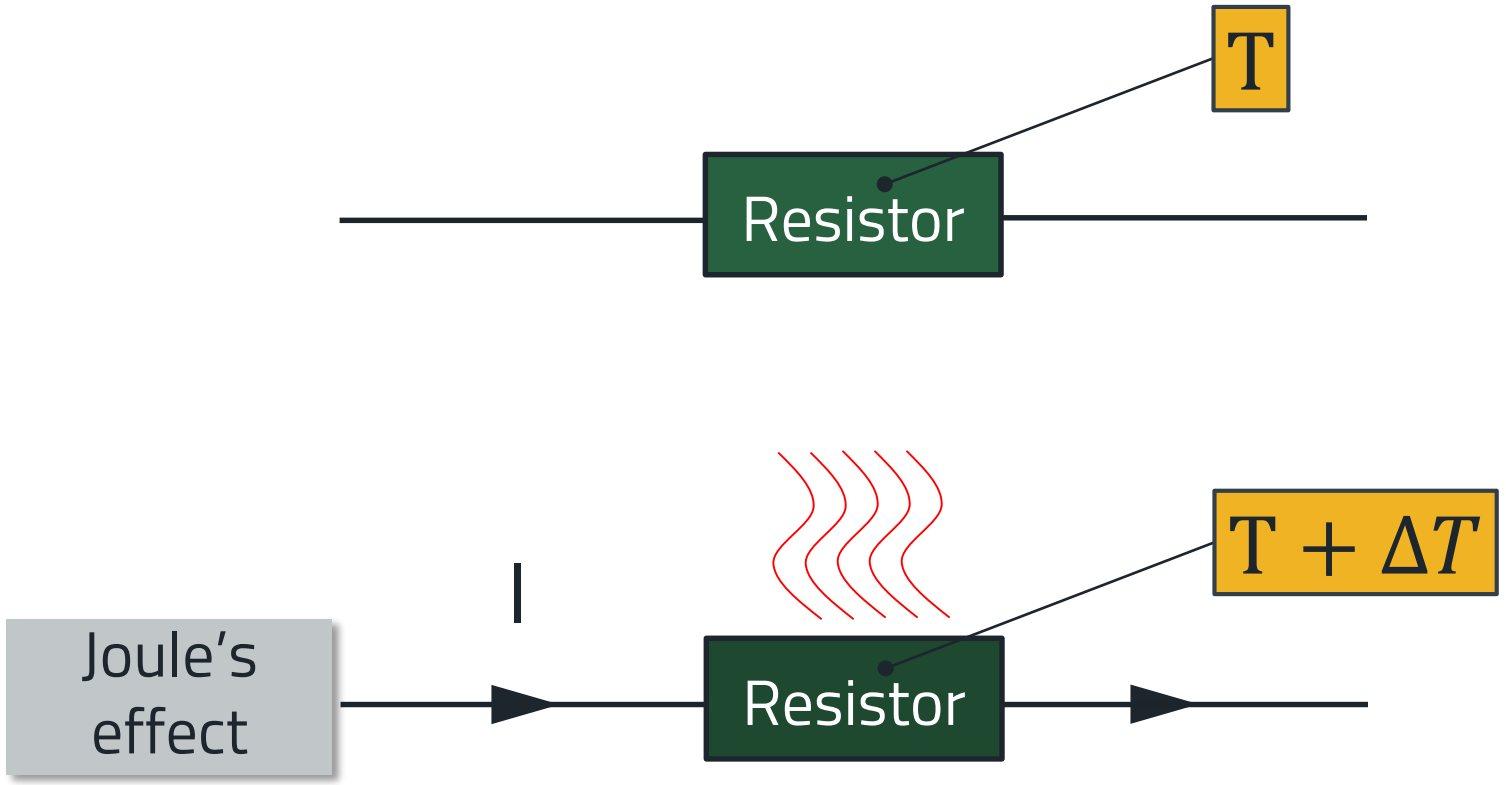


WE eiCan



ENVIRONMENTAL	
OPERATING TEMPERATURE: -40 UP TO 105°C	
COMPLIANCE: LEAD FREE AND ROHS	
ELECTRICAL	cULus
CURRENT RATING:	20 A
WORKING VOLTAGE:	300 VAC
WITHSTANDING VOLTAGE:	1.6 KV
CONTACT RESISTANCE:	20 mOhm max

Electricity and temperature rise

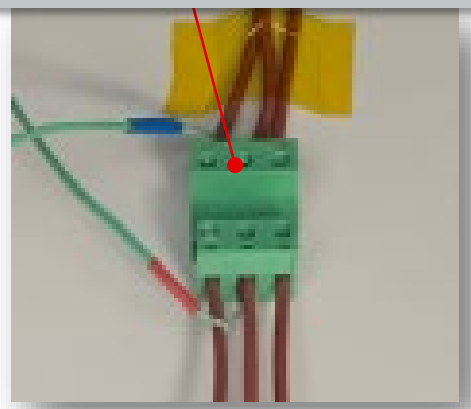


How working current is designed in WE

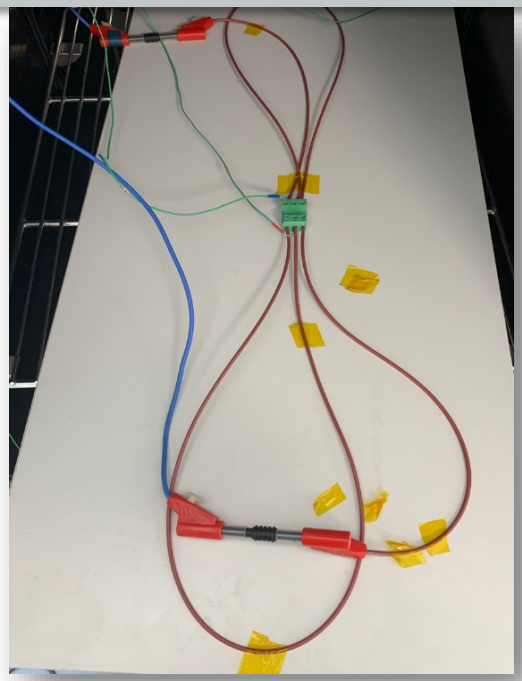
- **Testmethod**

ΔT < 30K at the hottest point

Hottest point



Electrical assembly



Ambient = 21,7 °C

→ ΔT=24,8K

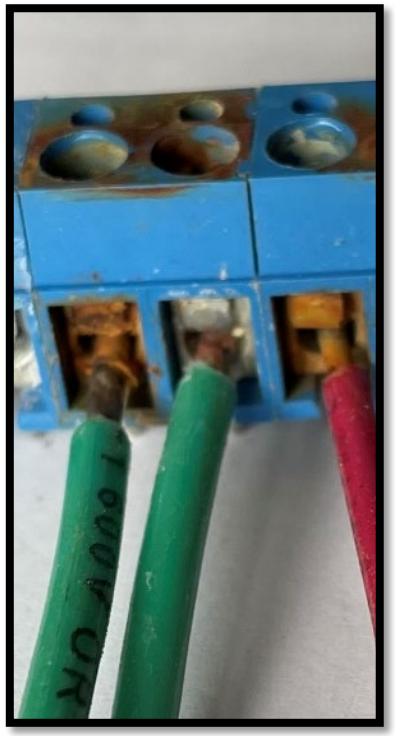
Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

Temperature increase and connectors

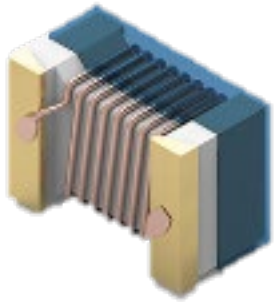
Consequences of high temperature:

- Naturally increase contact resistance
- Increase corrosion speed and consequently increase contact resistance
  > Corrosion speed ~ doubles each 10°C
- Degradate solder joint
- Accelerate plastic aging
- Metal relaxation

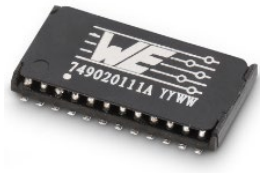


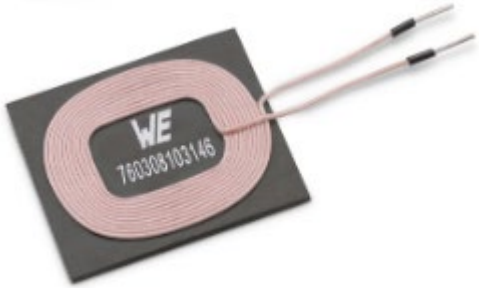
Temperature increase and connectors

Consequences of high temperature:



- Electronic devices lifespan





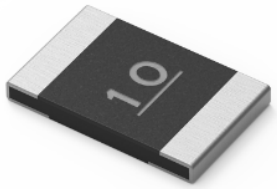
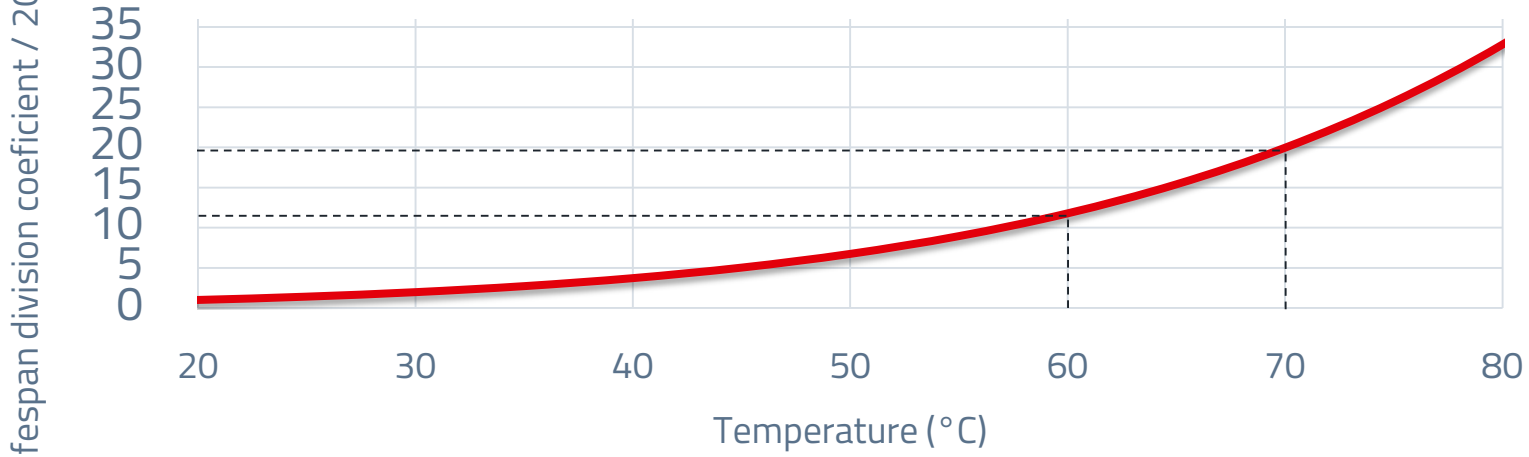


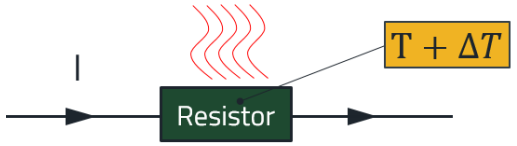
Image of lifespan reduction coeficient vs temperature



Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

Electricity and temperature rise



Joule's law

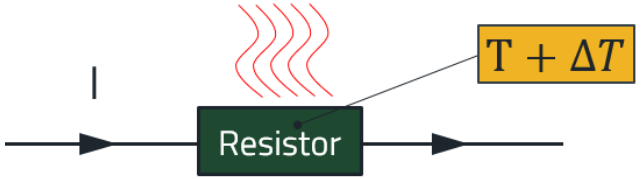
$$P = R \cdot I^2$$

$$\Delta T = k \cdot R \cdot I^2$$

- P (W): power dissipated by the resistor
- R (Ω)
- I (A)
- ΔT (K): data given usually in Kelvin
- k: constant defined by resistance material and environnement

Temperature rise is proportional to the square of the current

Theorical calculation



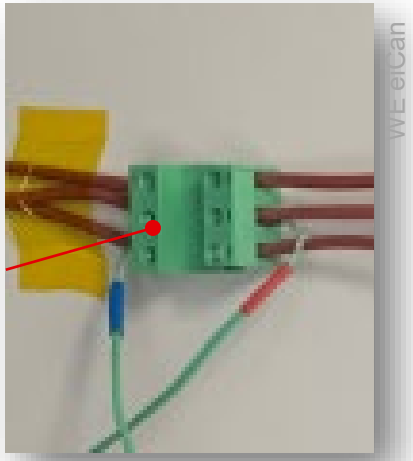
$$\frac{\Delta T_1}{\Delta T_2} \approx \frac{{I_1}^2}{{I_2}^2}$$

Example:

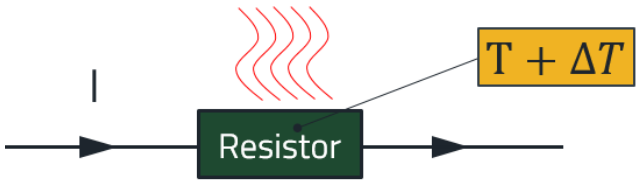
- Measurment: I_1=15A gives $\Delta T_1 \approx 15K$

$$\Delta T = k \cdot R \cdot I^2$$

- At I_2=30A → $\Delta T2 \approx \frac{30^2}{15^2} \cdot 15 \approx \boldsymbol{60K}$



Theorical calculation



$$\frac{\Delta T_1}{\Delta T_2} \approx \frac{I_1^{\,2}}{I_2^{\,2}}$$

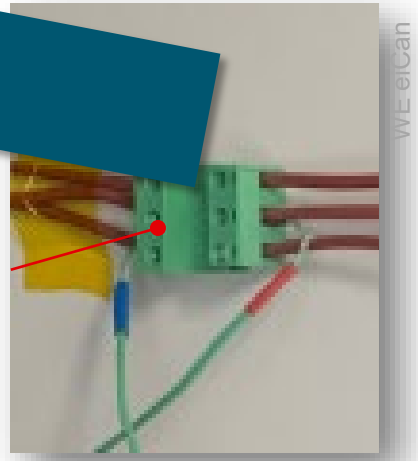
Example:

Current **x 2** → ΔT **x 4**

- Measurment: I_1=15A give

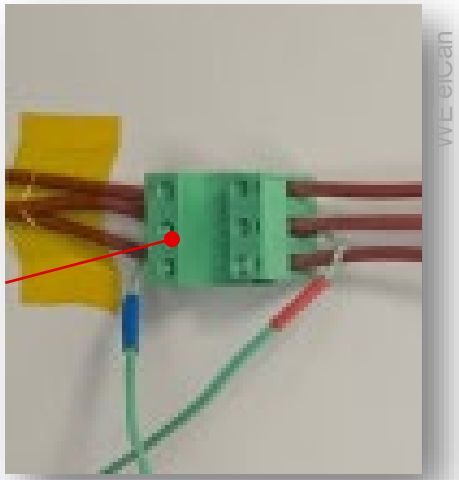
$$\Delta T = k \cdot R \cdot I^2$$

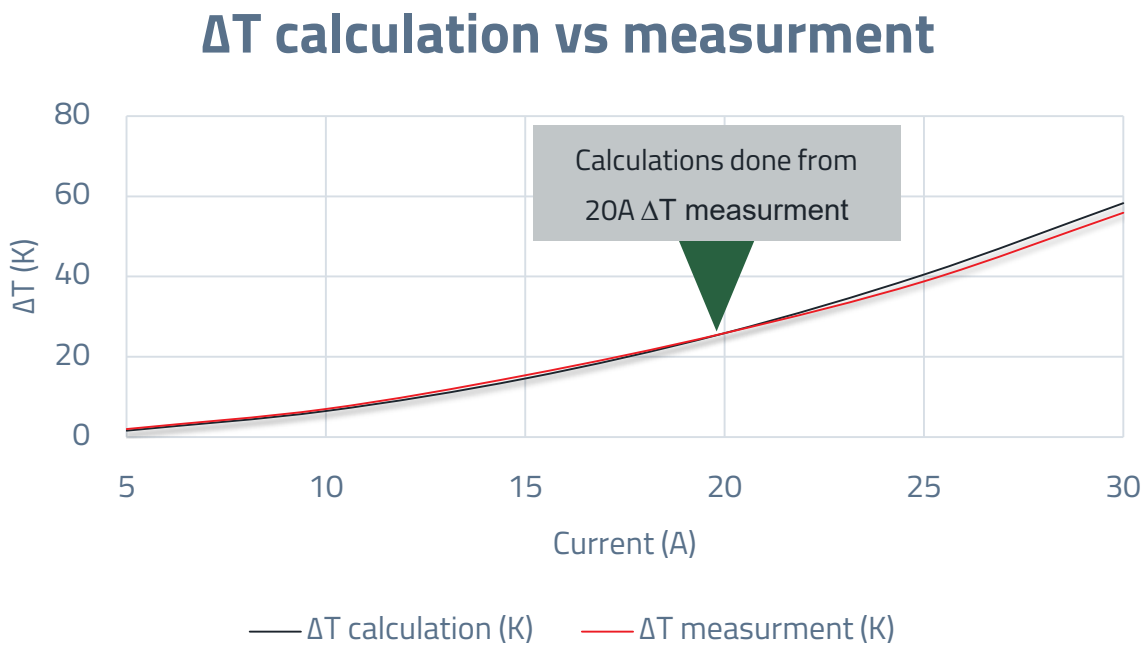
- At I_2=30A → $\Delta T2 \approx \frac{30^2}{15^2} \cdot 15 \approx \boldsymbol{60K}$



Theorical calculation: is it really true ?

Temperature rise test done at 20A



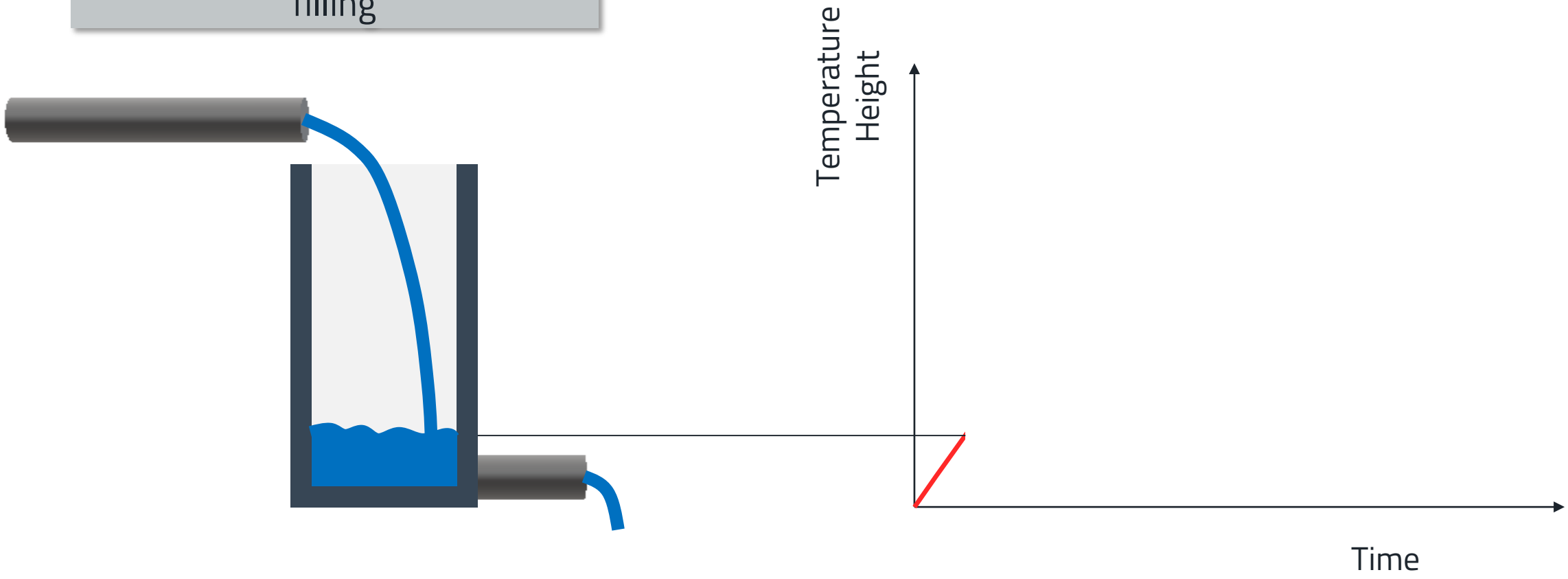


Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

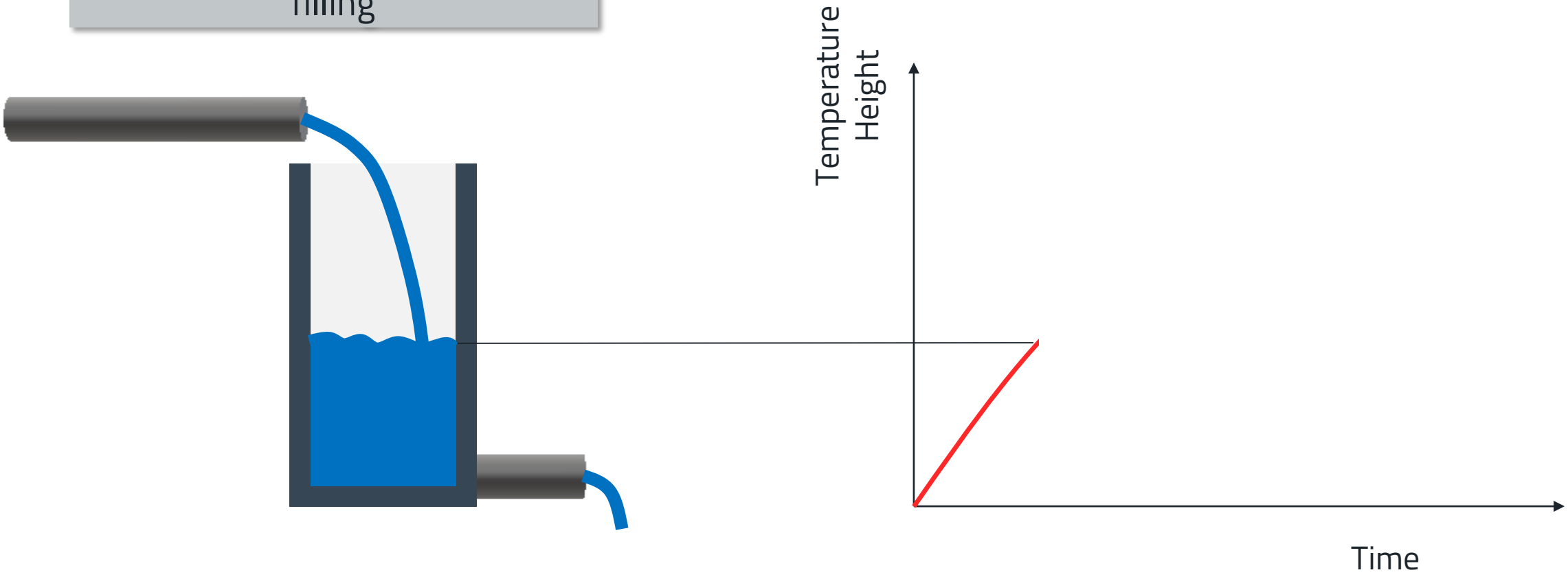
How ΔT is dissipated

Temperature rise analogy tank filling



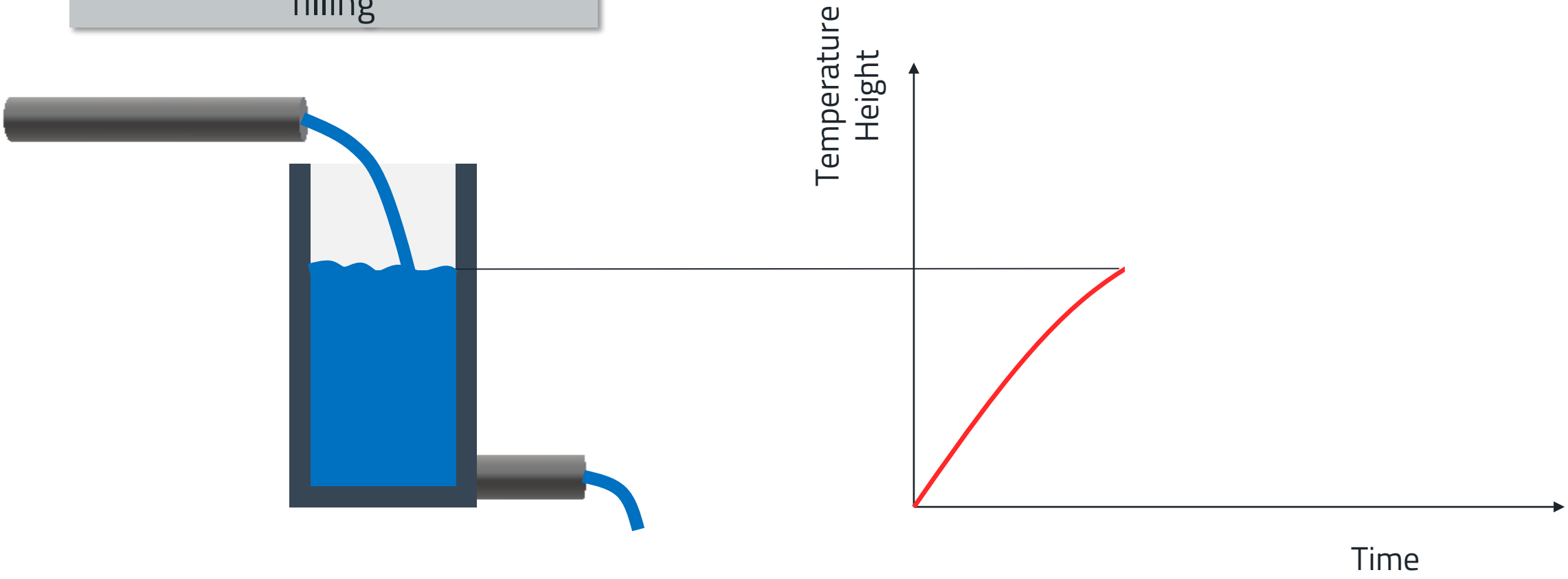
How ΔT is dissipated

Temperature rise analogy tank filling



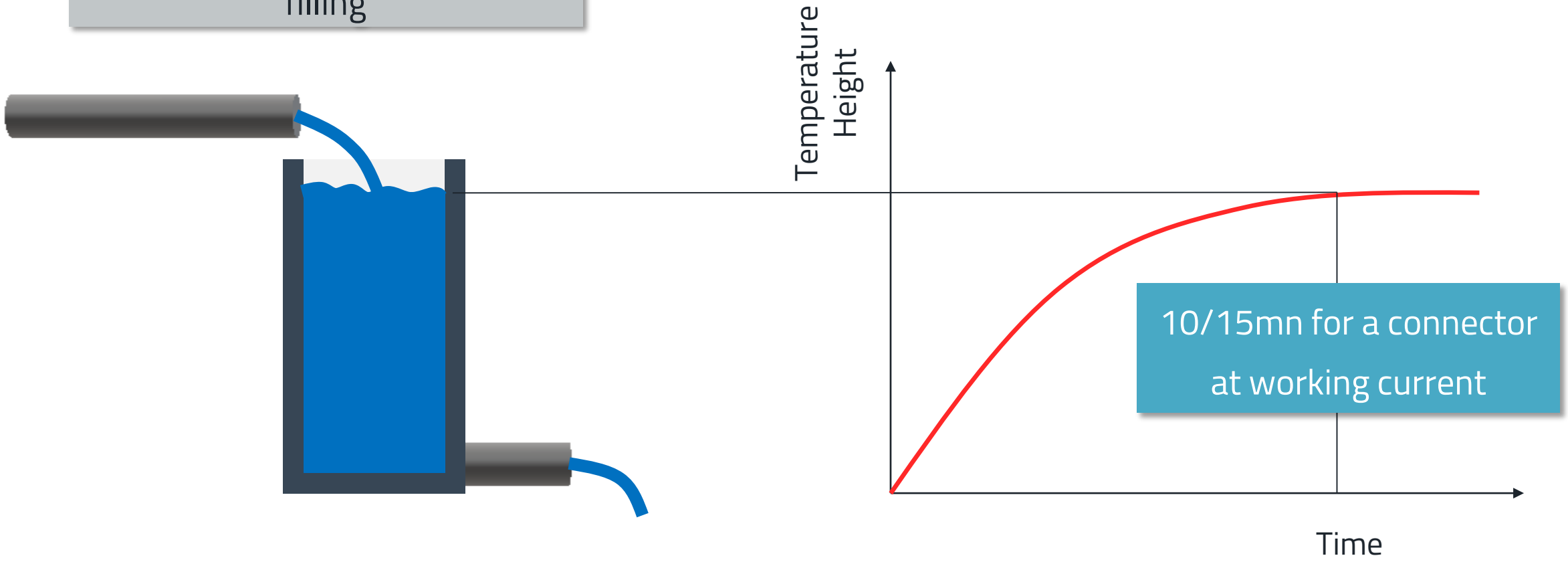
How ΔT is dissipated

Temperature rise analogy tank filling



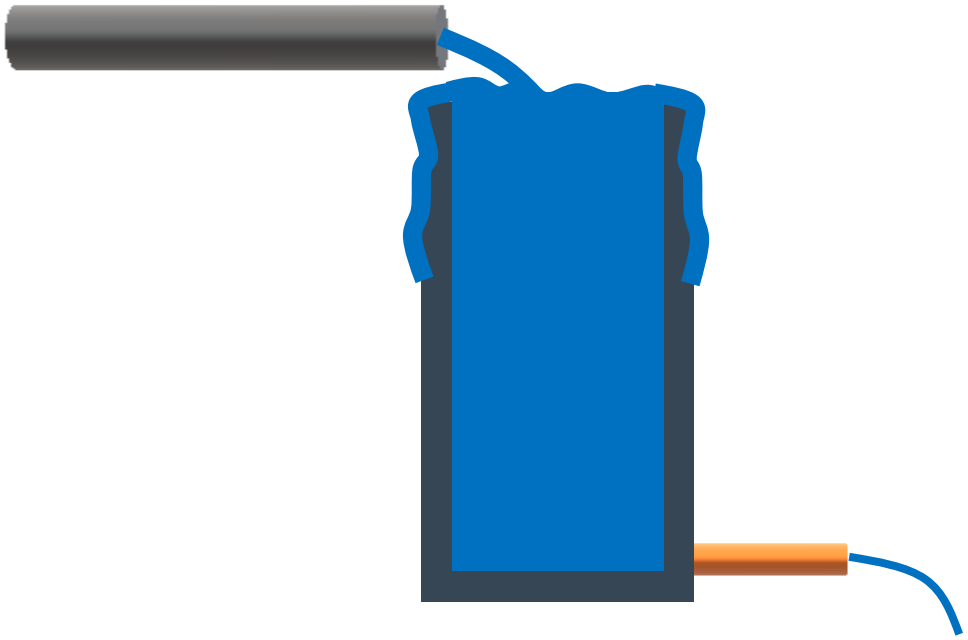
How ΔT is dissipated

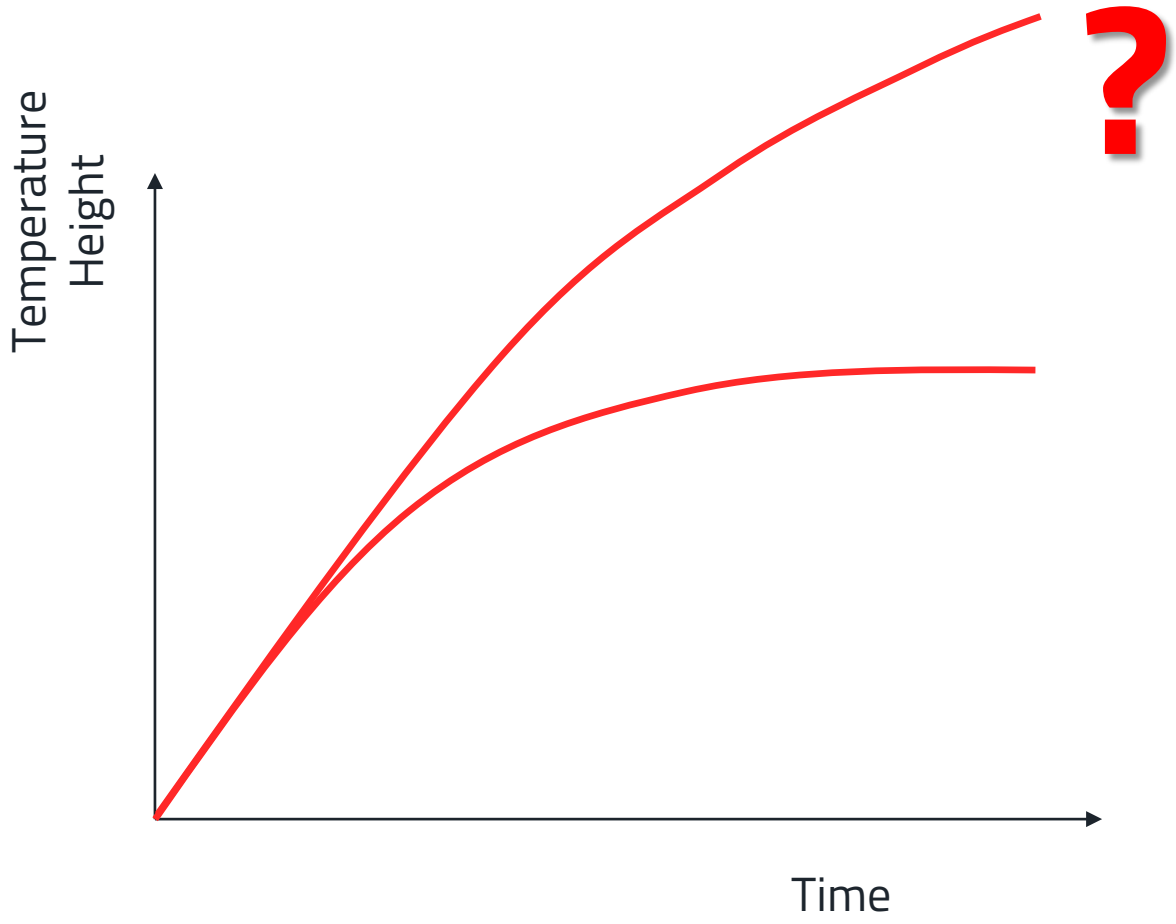
Temperature rise analogy tank filling



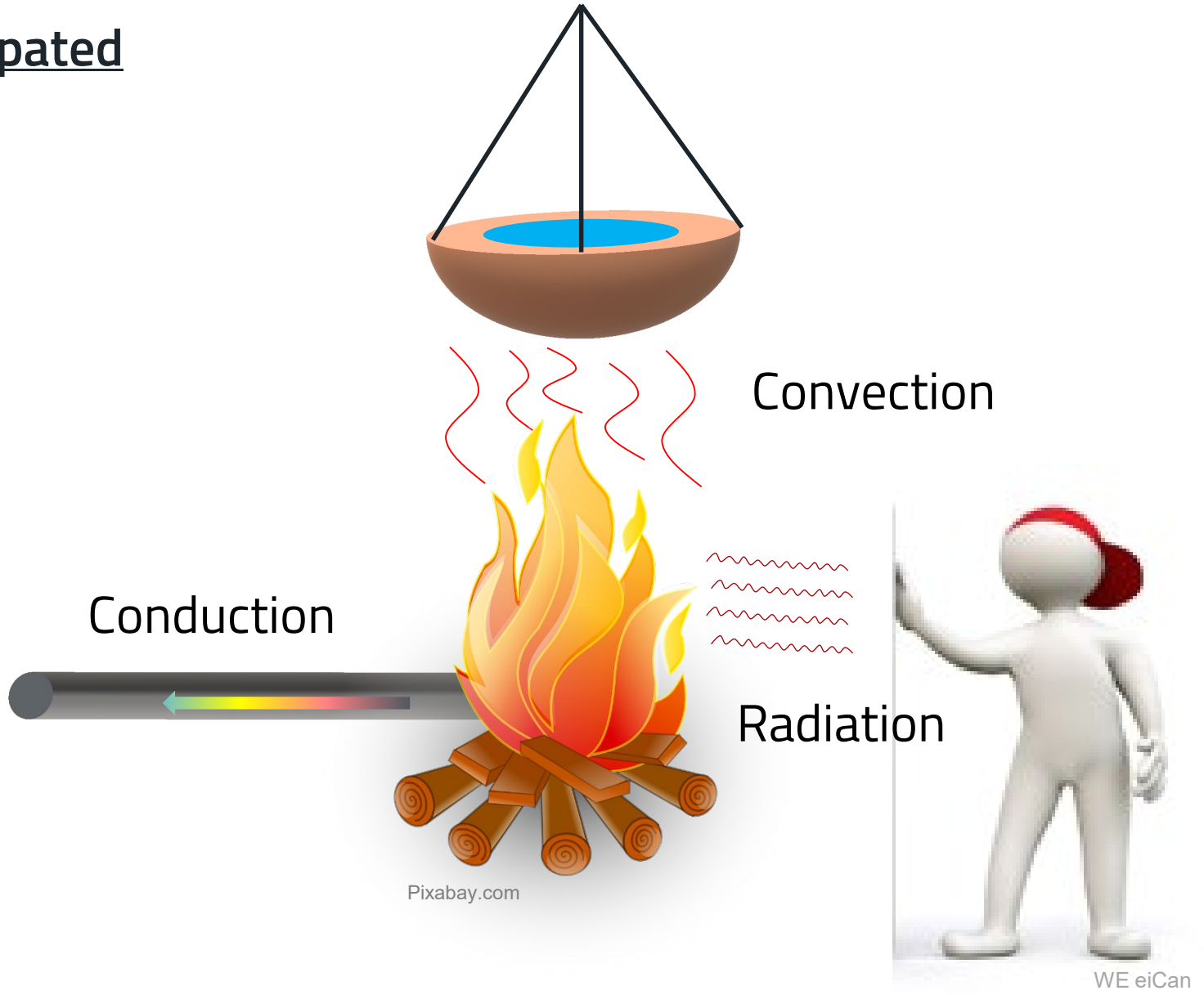
How ΔT is dissipated

Temperature rise analogy tank filling

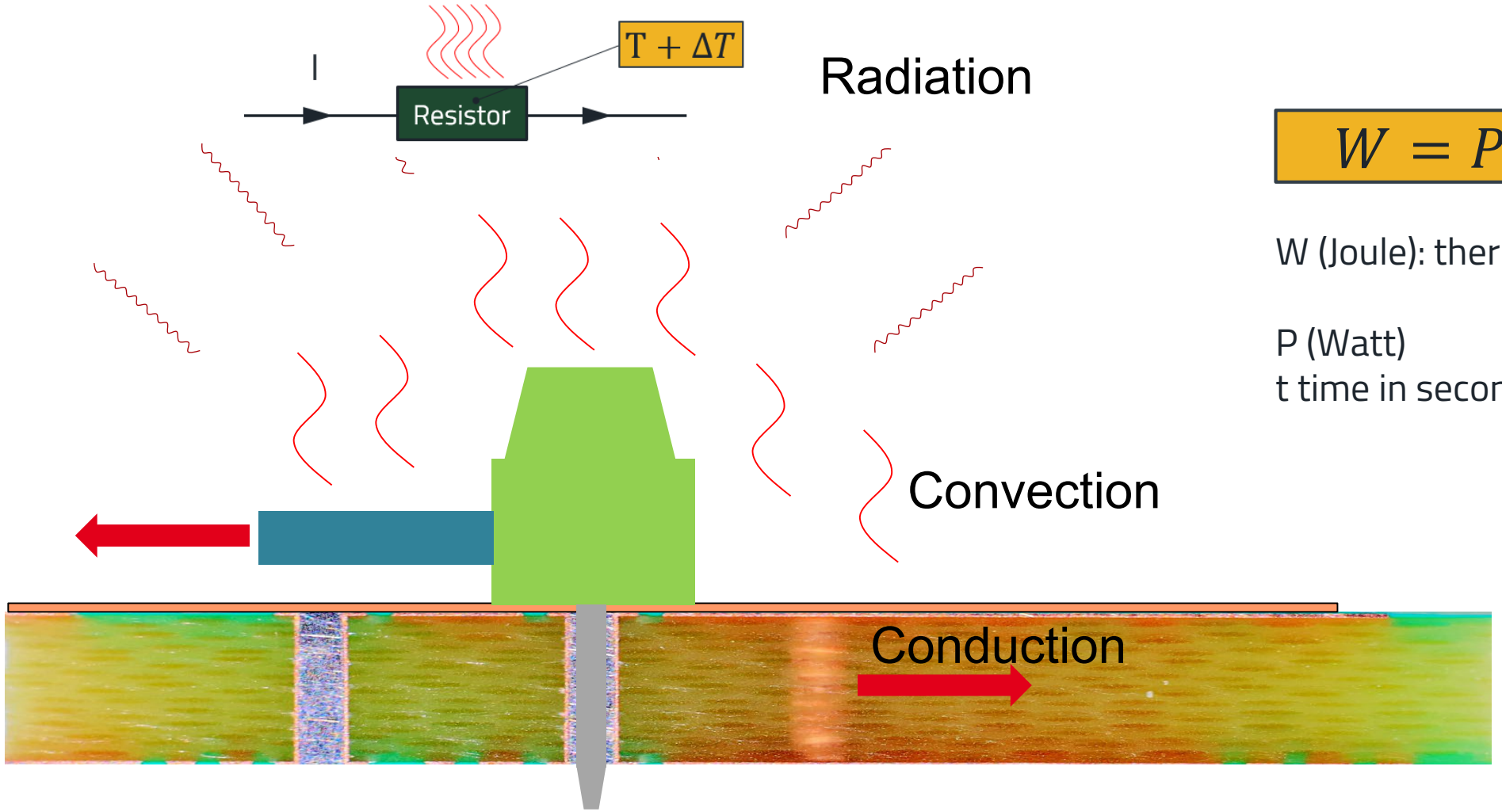




How ΔT is dissipated



How ΔT is dissipated

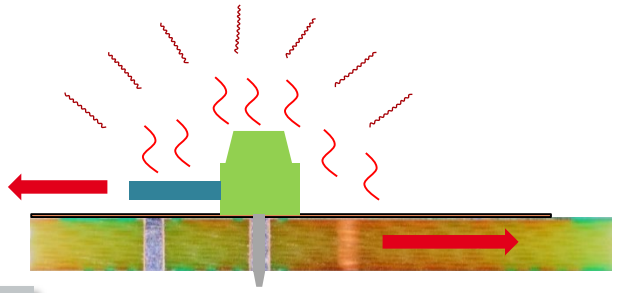


$$W = P \cdot t$$

W (Joule): thermal energy

P (Watt)
t time in second

What to remember ?



- An electrical system **must** have thermal exchanges
- Under current, temperature should stabilized after 10/15mn

- Radiation:
  - Plastic is better than metal
  - Rough metal surface is better than polished

- Convection: increase surface in contact with air

- Conduction:
  - Copper is the best metal for conduction dissipation
  - Increase section optimize exchange

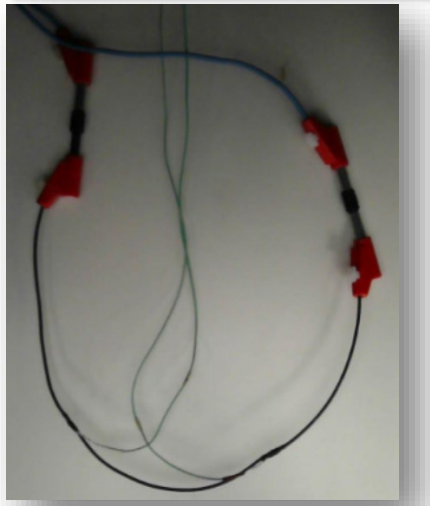
Agenda

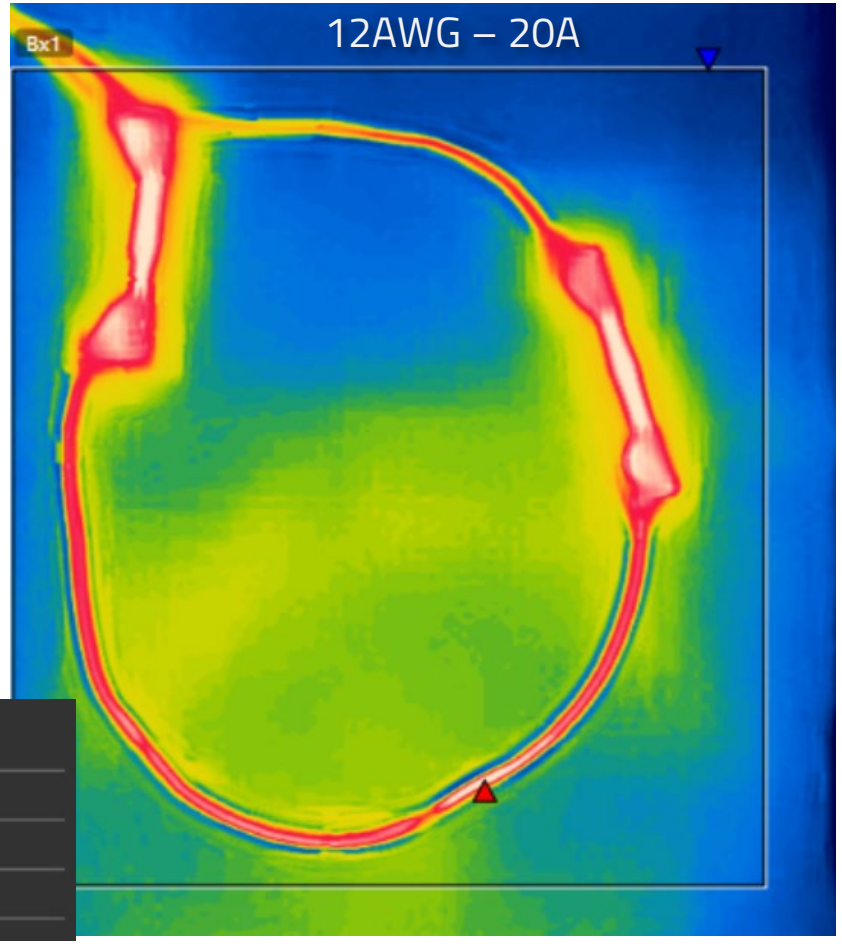
- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

What is the temperature rise with wires ?

Test: **AWG**

- ΔT of 50cm wire
- 2 thermocouples sticked on the copper conductor





Mesures		
Bx1	Max	34,7 °C
	Min	23,5 °C
	Average	25,2 °C

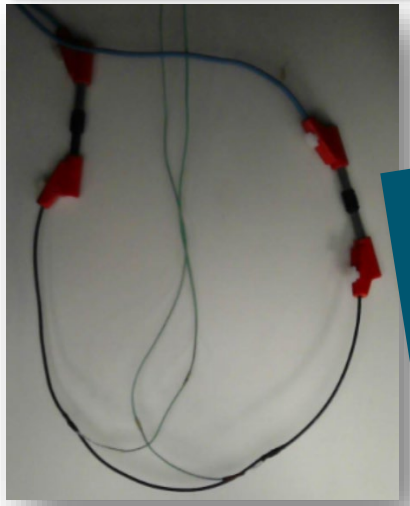
Wire size (AWG)	Current (A)	ΔT (K)
20	5	**5**
18	7	**6**
16	10	**7**
14	15	**10**
12	20	**11**
10	30	**16**
8	50	**20**
6	65	**20**

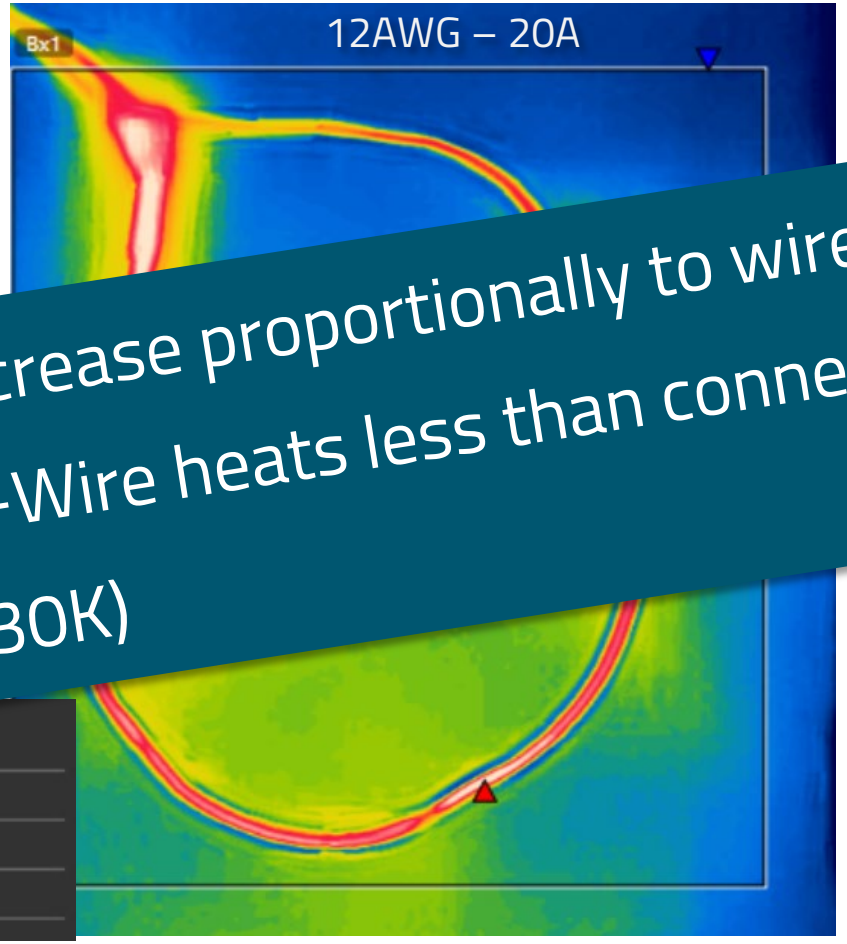
All pictures: WE eiCan

What is the temperature rise with wires ?

Test: **AWG**

- ΔT of 50cm wire
- 2 thermocouples sticked on the copper conductor





1. ΔT decrease proportionally to wire size
2. AWG-Wire heats less than connector (ΔT<30K)

Mesures		
Bx1	Max	34,7 °C
	Min	23,5 °C
	Average	25,2 °C

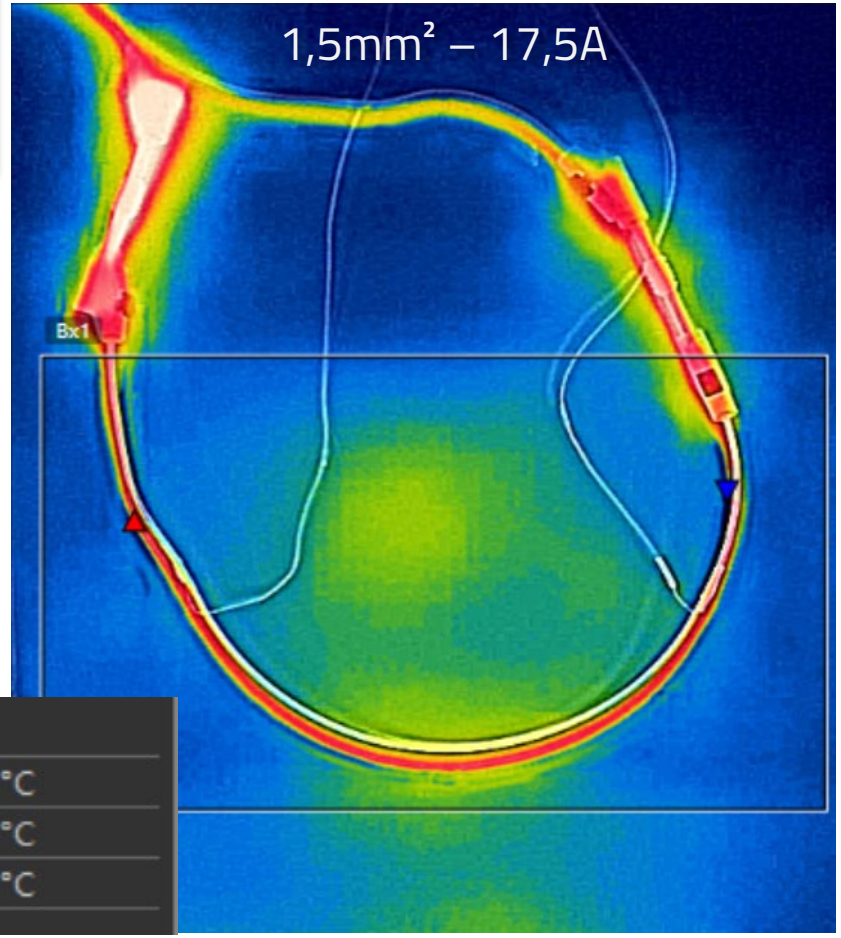
Wire	Current (A)	ΔT (K)
	5	**5**
	7	**6**
	0	**7**
	5	**10**
12	20	**11**
10	30	**16**
8	50	**20**
6	65	**20**

All pictures: WE eiCan

What is the temperature rise with wires ?

Test: mm²

- ΔT of 50cm wire
- 2 thermocouples sticked on the copper conductor



Mesures		
Bx1	Max	32,5 °C
	Min	16,1 °C
	Average	19,8 °C

Wire size (mm²)	Current (A)	ΔT (K)
0,2	4	8
0,5	6	7
0,75	9	10
1	13,5	15
1,5	17,5	17
2,5	24	18
4	32	19
6	41	18
10	57	18
16	76	18

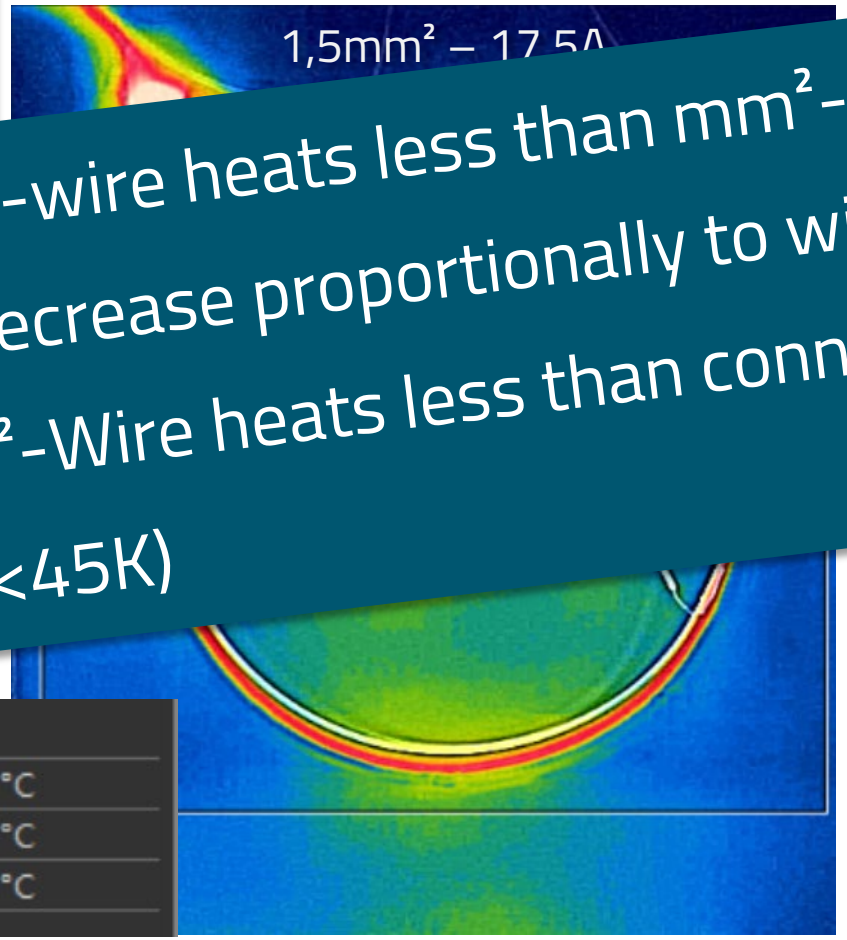
All pictures: WE eiCan

What is the temperature rise with wires ?

Test: mm²

- ΔT of 50cm wire
- 2 thermocouples sticked on the copper conduct

1. AWG-wire heats less than mm²-wire
2. ΔT decrease proportionally to wire size
3. mm²-Wire heats less than connector (ΔT<45K)



Mesures		
Bx1	Max	32,5 °C
	Min	16,1 °C
	Average	19,8 °C

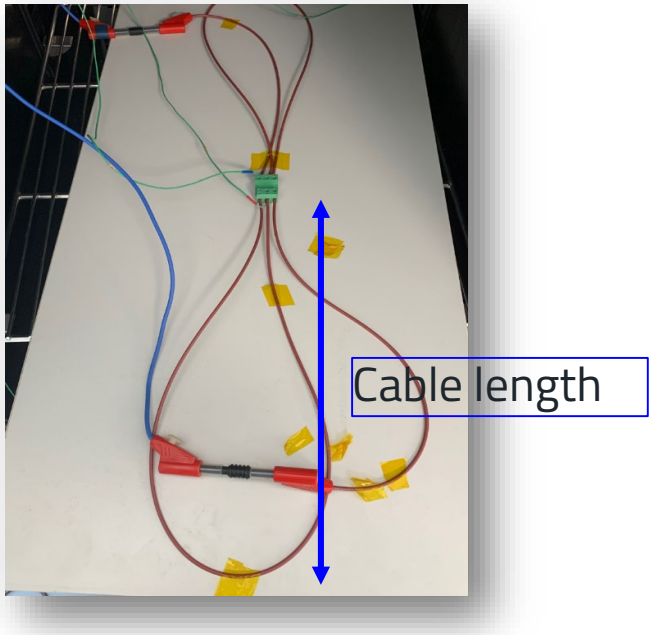
urrent (A)	ΔT (K)
4	8
6	7
9	10
3,5	15
7,5	17
2,5	24
4	32
	19

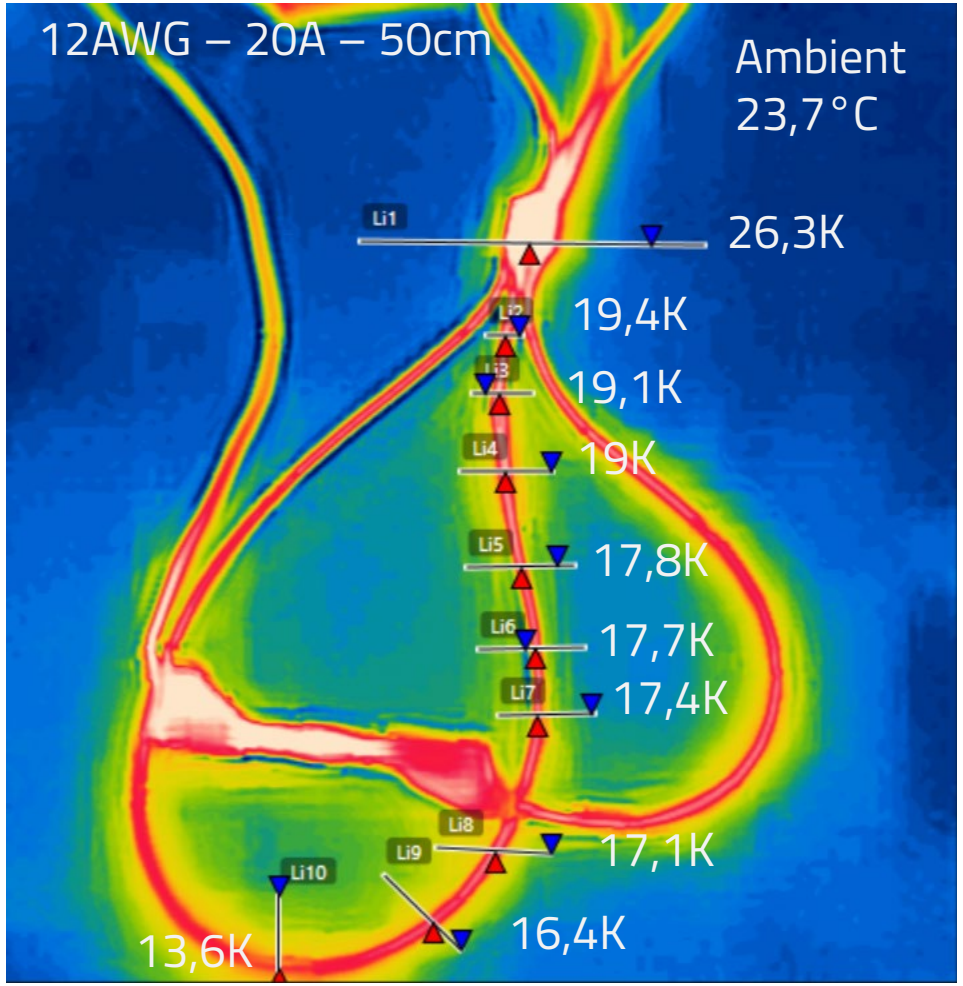
All pictures: WE eiCan

Wire heat dissipation: the right length ?

Test:

- ΔT 12AWG-20A
- TBL plug 3 poles 7,62
- Different wire length
- 2 thermocouples in 2 TBL clamps



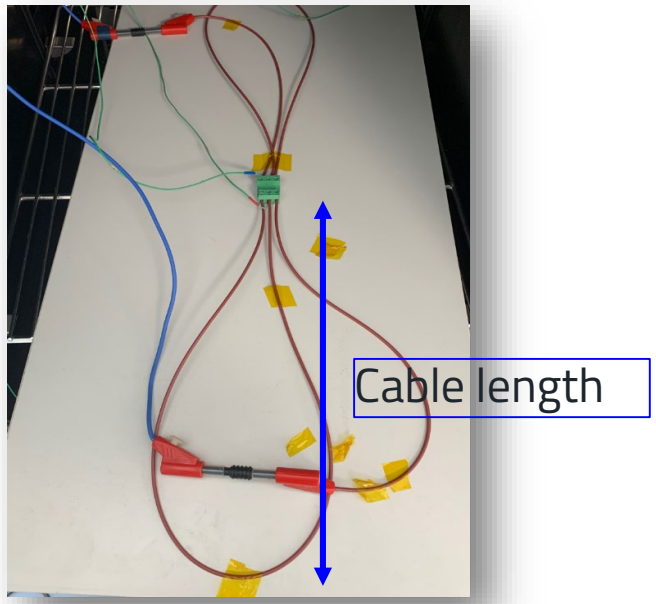


All pictures: WE eiCan

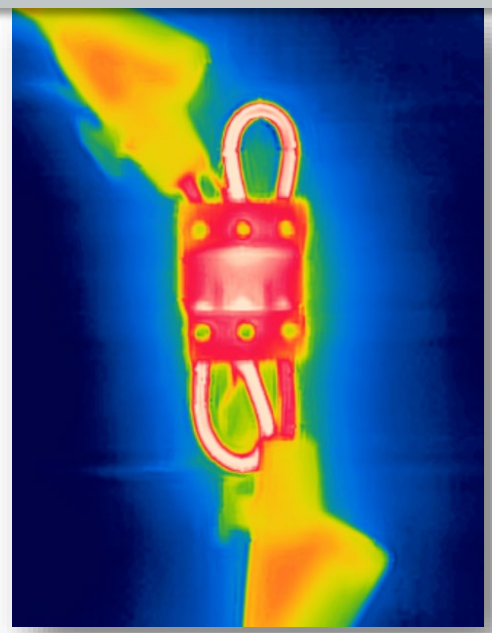
Wire heat dissipation: the right length ?

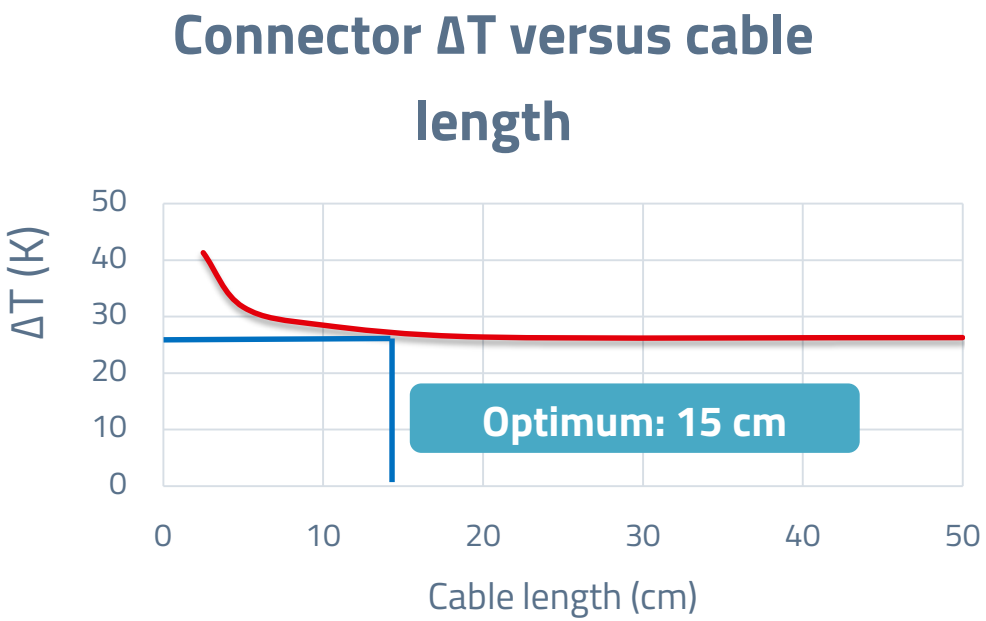
Test:

- ΔT 12AWG-20A
- TBL plug 3 poles 7,62
- Different wire length
- 2 thermocouples in 2 TBL clamps



12AWG – 20A – 2,5cm





All pictures: WE eiCan

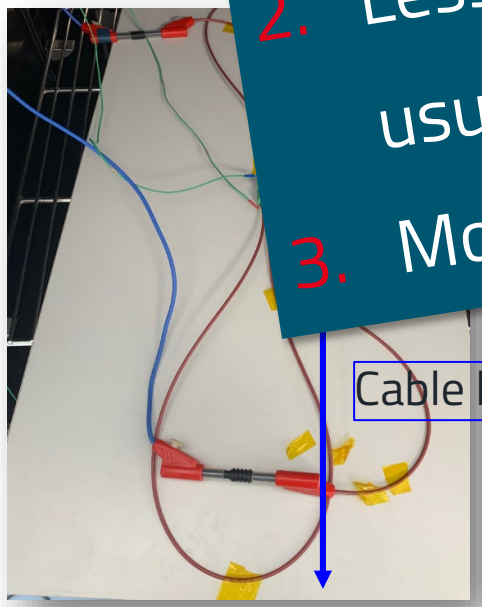
Wire heat dissipation: the right length ?

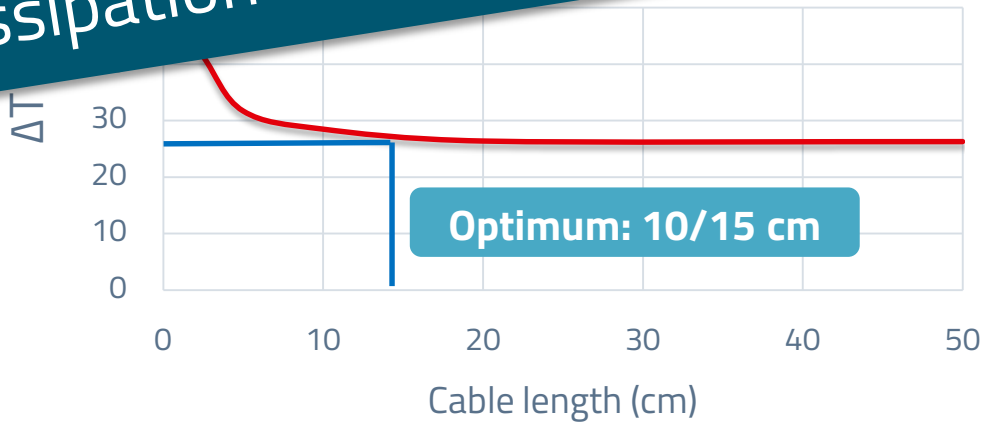
Test:

- ΔT 12AWG-20A
- TBL plug 3 poles 7,62
- Different wire lengths
- 2 thermocouples with clamps

12AWG – 20A – 2,5cm

1. Optimized length for heat dissipation: 10/15cm
2. Less will increase internal connector temperature above usual 30K
3. More is useless for thermal dissipation





All pictures: WE eiCan

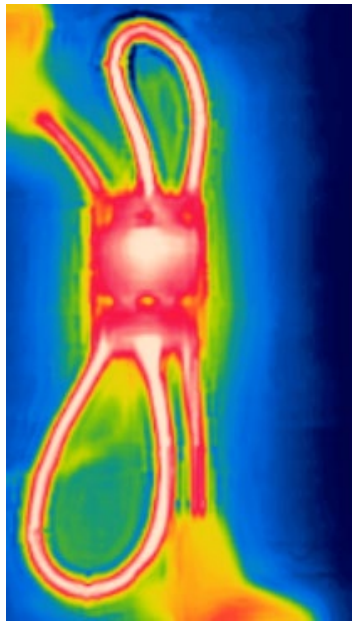
Agenda

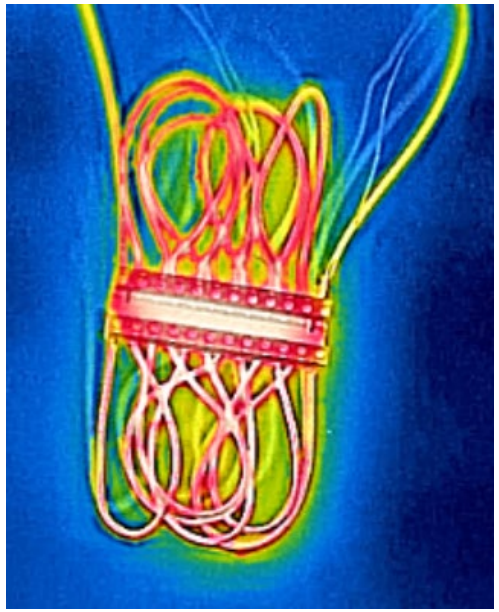
- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

ΔT=30K ok, but only with 3 poles ?

Test:

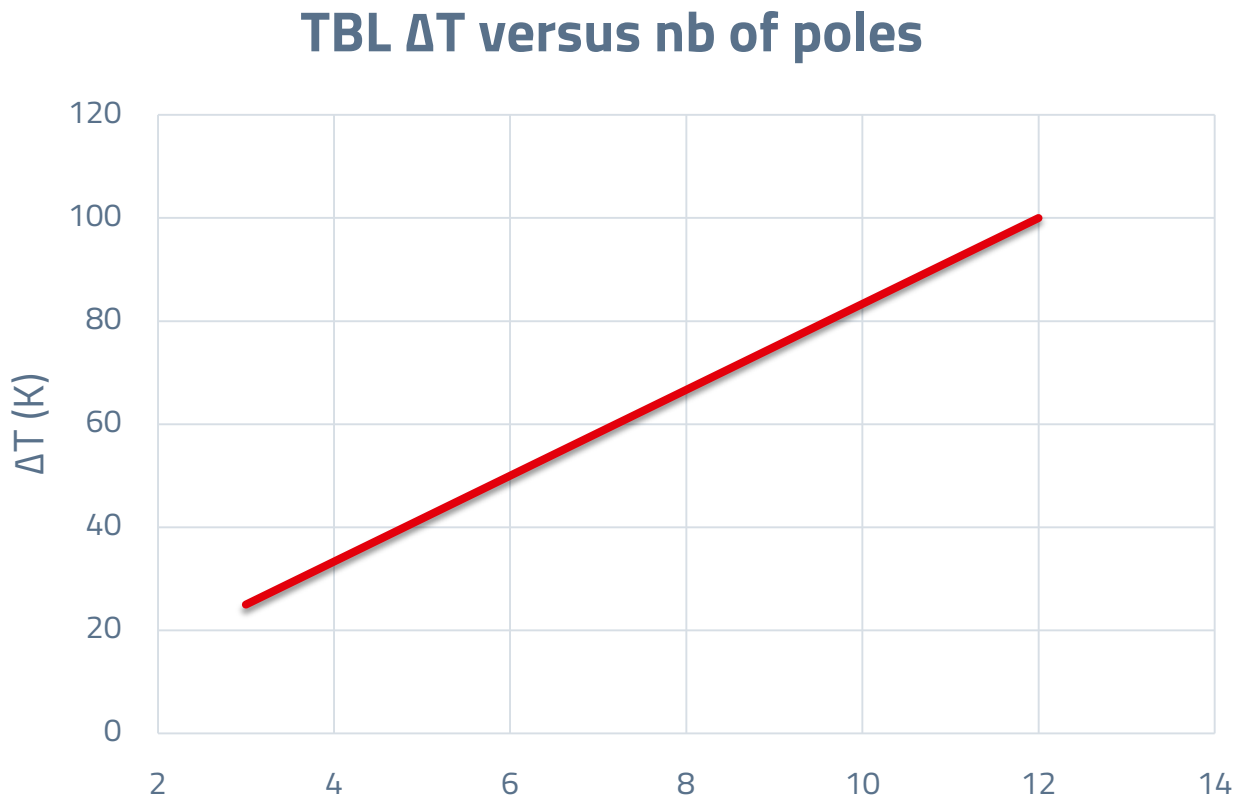
- Working current is tested at 3 poles
- Should we decrease current with more ?





12AWG – 20A – 10cm

This is what you expect ?

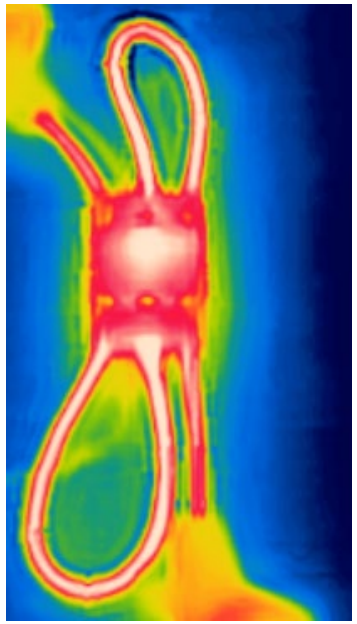


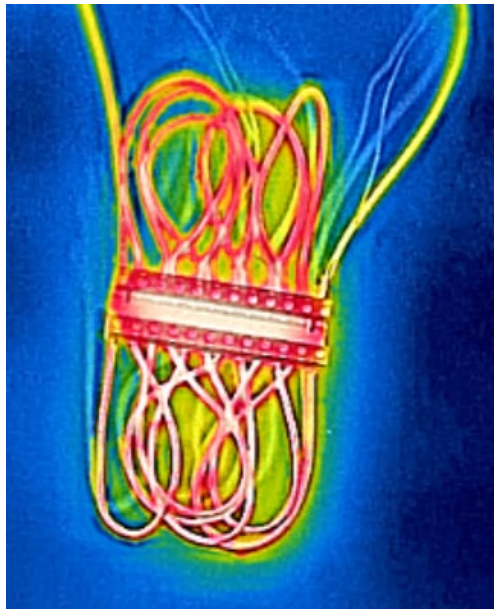
All pictures: WE eiCan

ΔT=30K ok but only with 3 poles ?

Test:

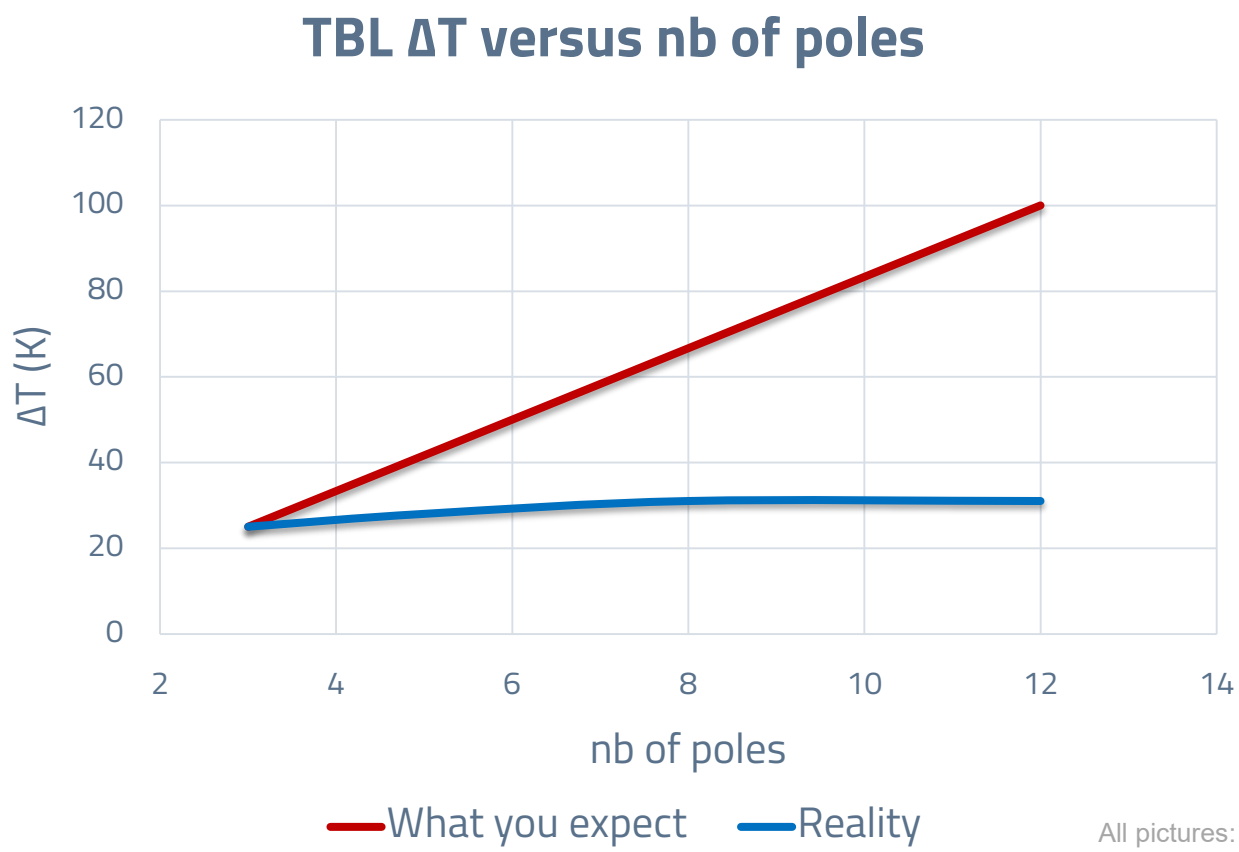
- Working current is tested at 3 poles
- Should we decrease current with more ?





12AWG – 20A – 10cm

Expectation vs reality

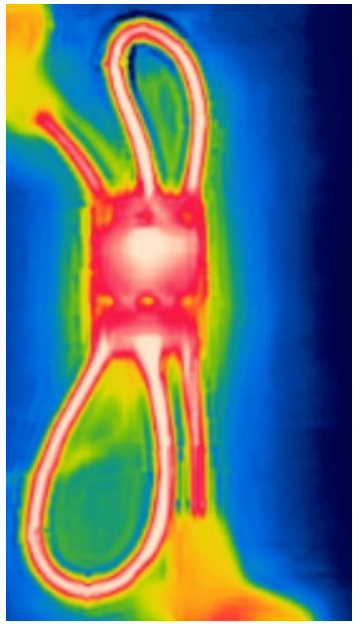


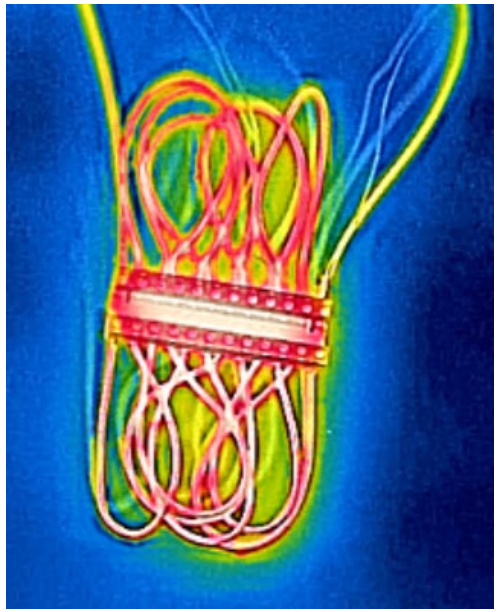
All pictures: WE eiCan

ΔT=30K ok but only with 3 poles ?

Test:

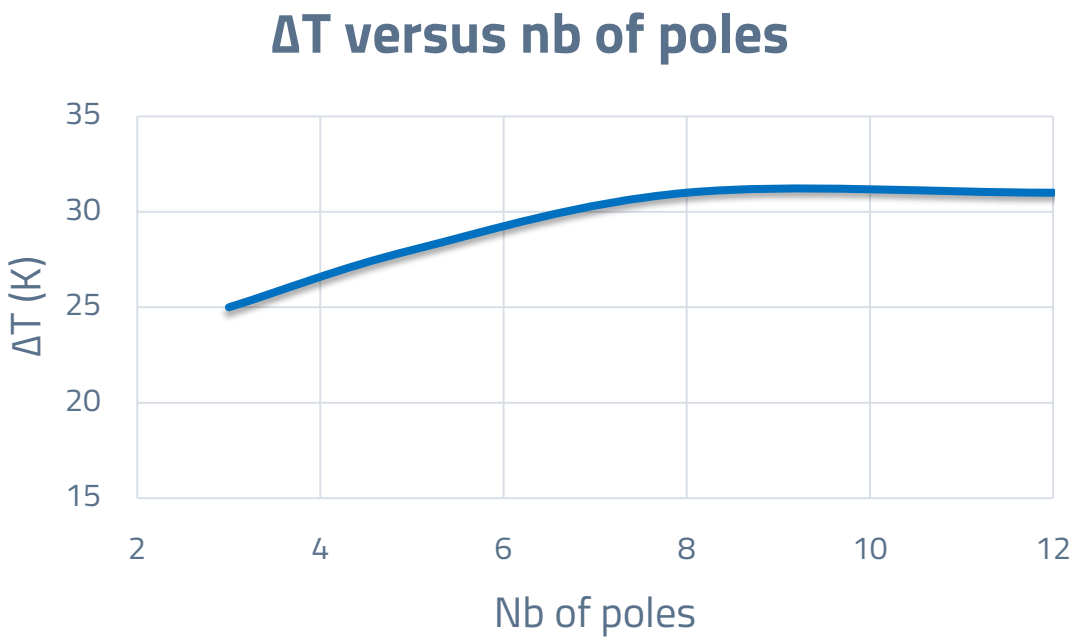
- Working current is tested at 3 poles
- Should we decrease current with more ?





12AWG – 20A – 10cm

Reality



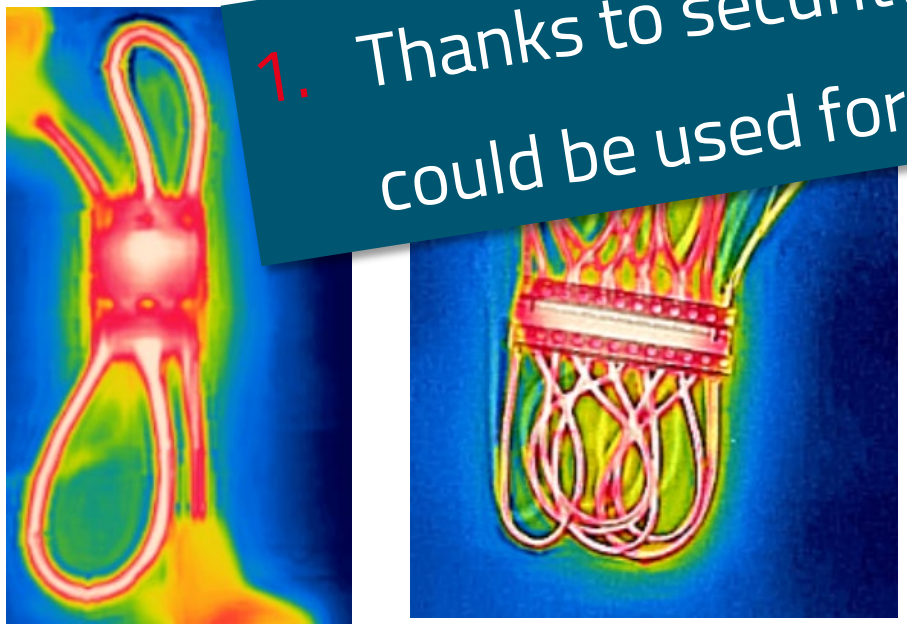
All pictures: WE eiCan

ΔT=30K ok but only with 3 poles ?

Test:

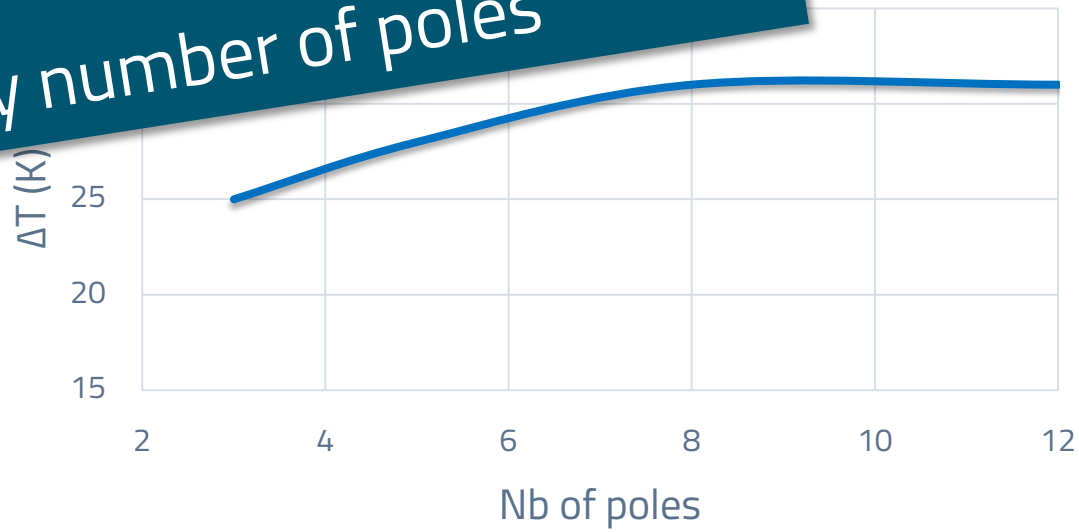
- Working current is tested at 3 poles
- Should we decrease current with more ?

1. Thanks to security margin, working current could be used for any number of poles



12AWG – 20A – 10cm

Reality

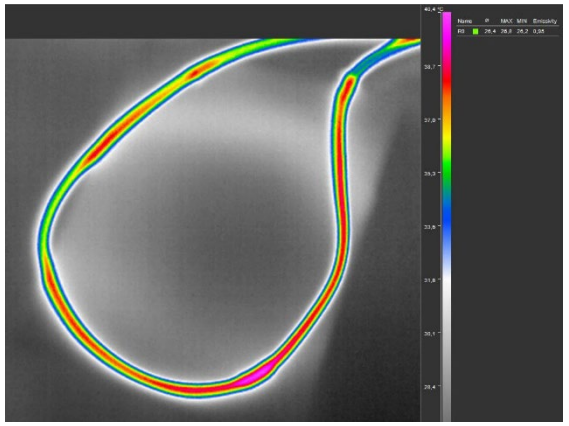


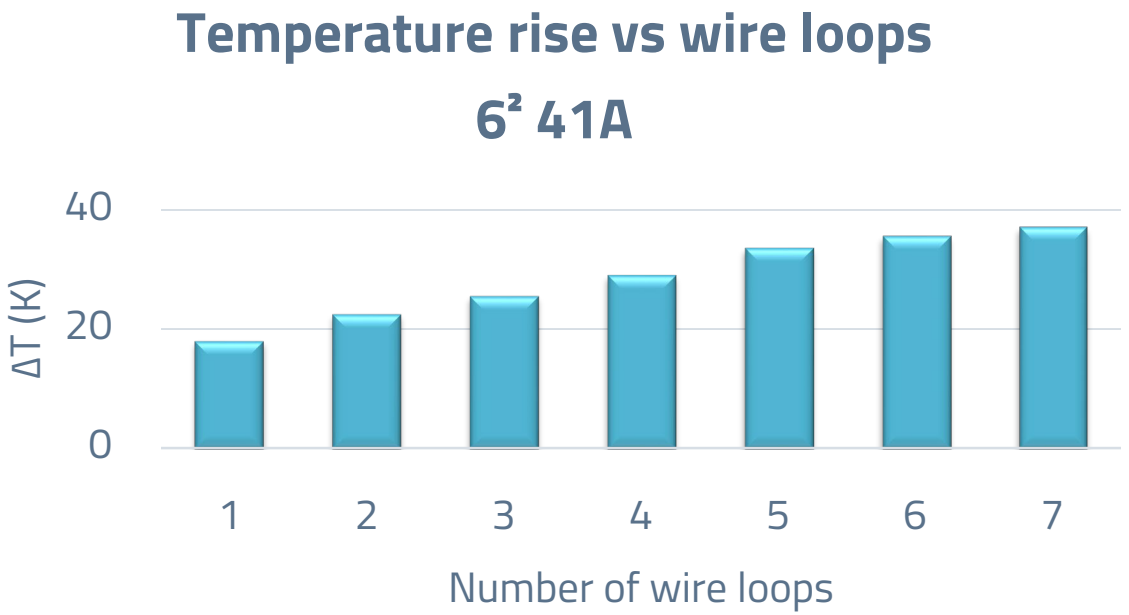
All pictures: WE eiCan

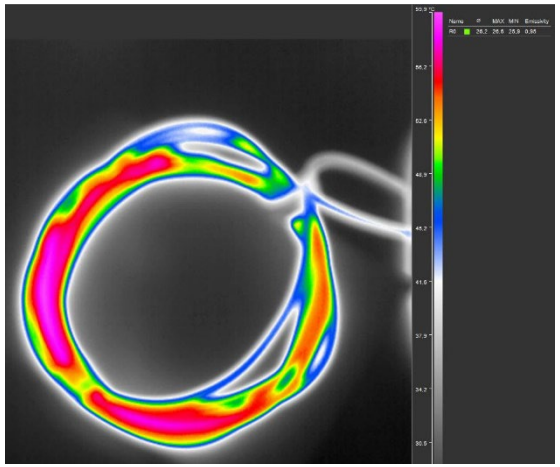
Cable loop – additional heat ?

Test:

- Cable loop influence
- 6^2
- 41A



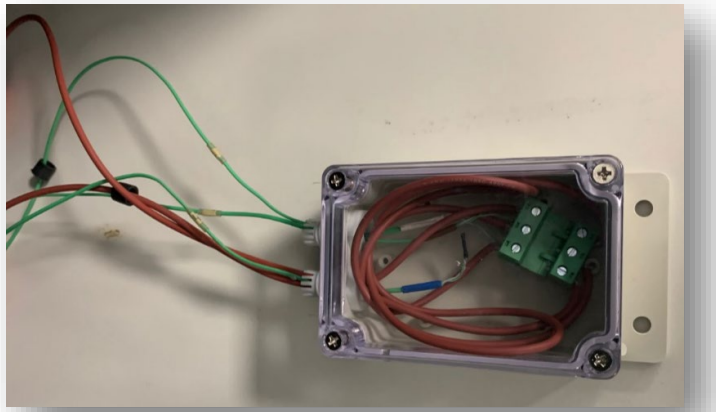


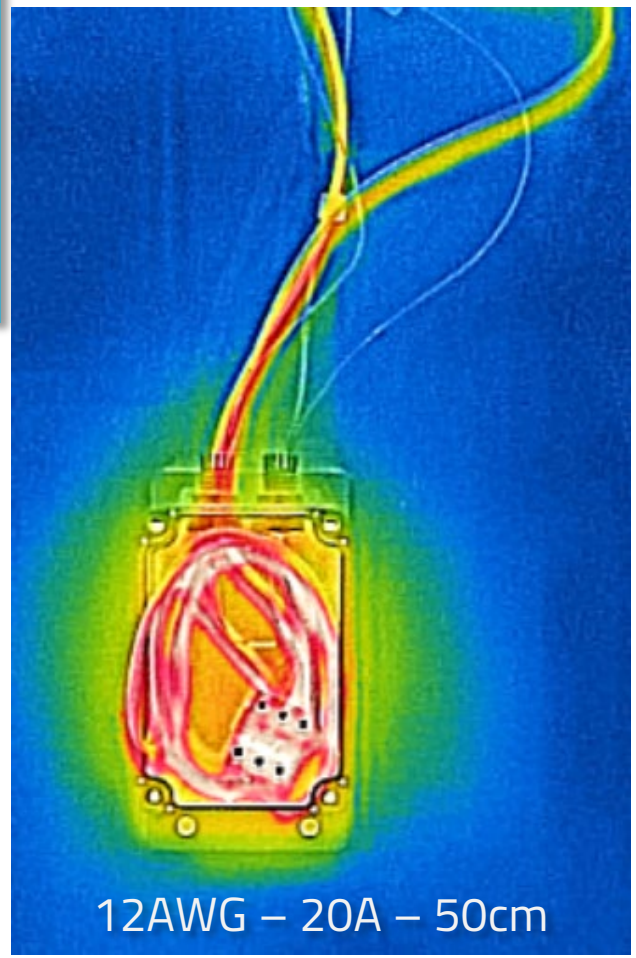


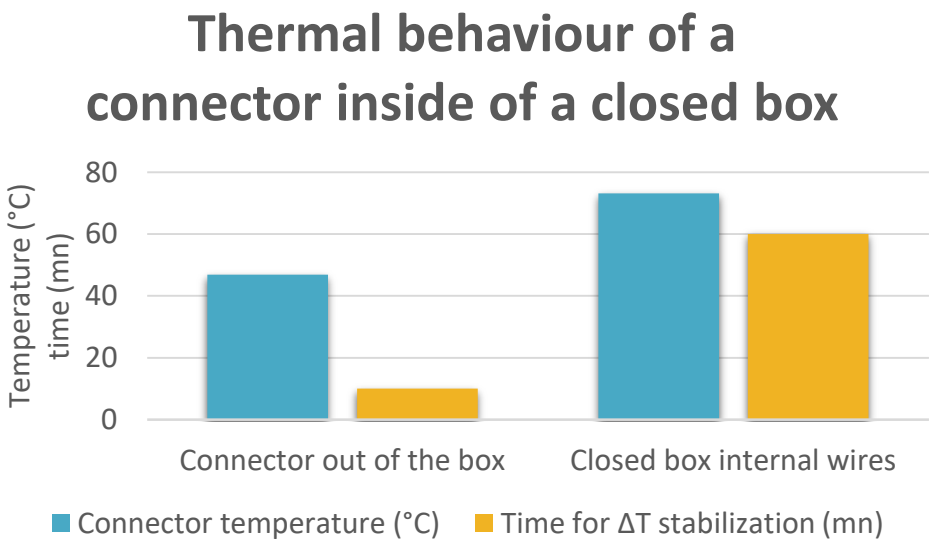
A connector in a closed box

Test:

- TBL plug 3 poles 7,62
- Initial 12AWG - 20A
- 2 thermocouples in 2 TBL clamps + 1 for box ambient air
- Wire length 10cm





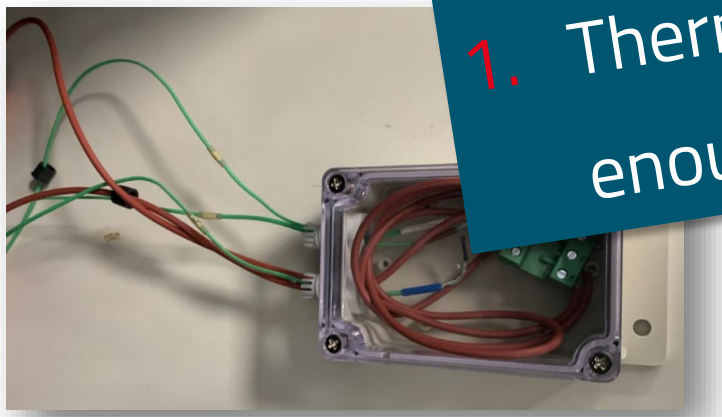


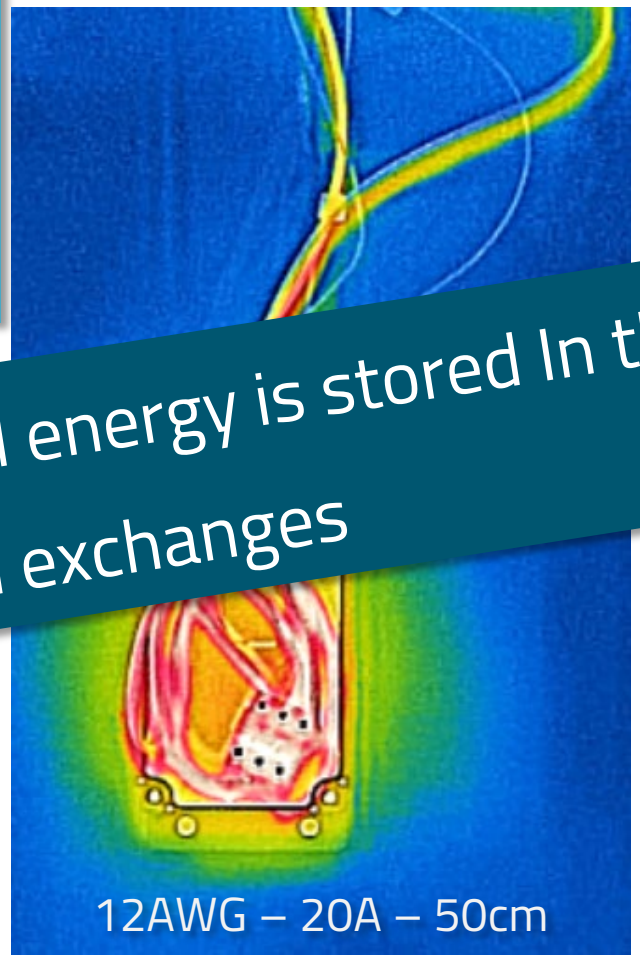
All pictures: WE eiCan

A connector in a closed box

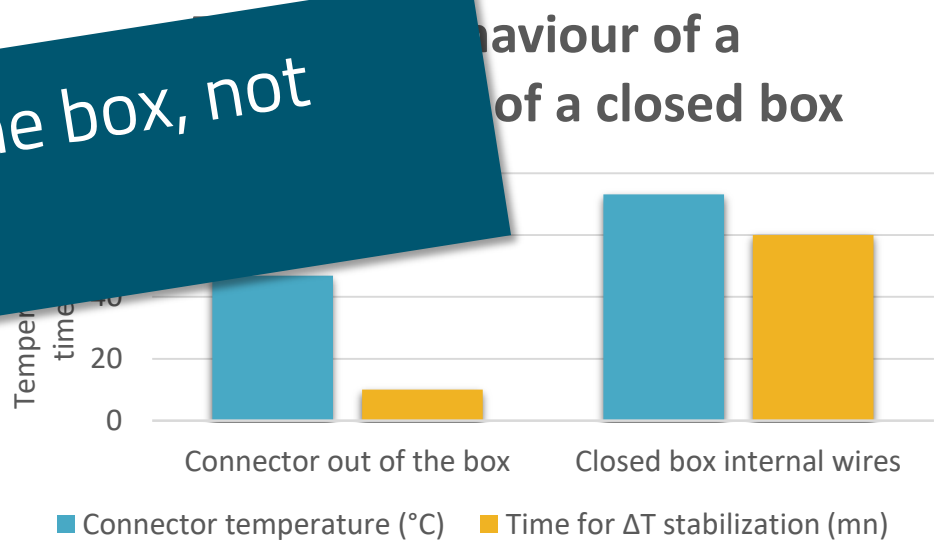
Test:

- TBL plug 3 poles 7,62
- Initial 12AWG - 20A
- 2 thermocouples in 2 TBL clamps + 1 for box ambient air
- Wire length 10cm





1. Thermal energy is stored In the box, not enough exchanges

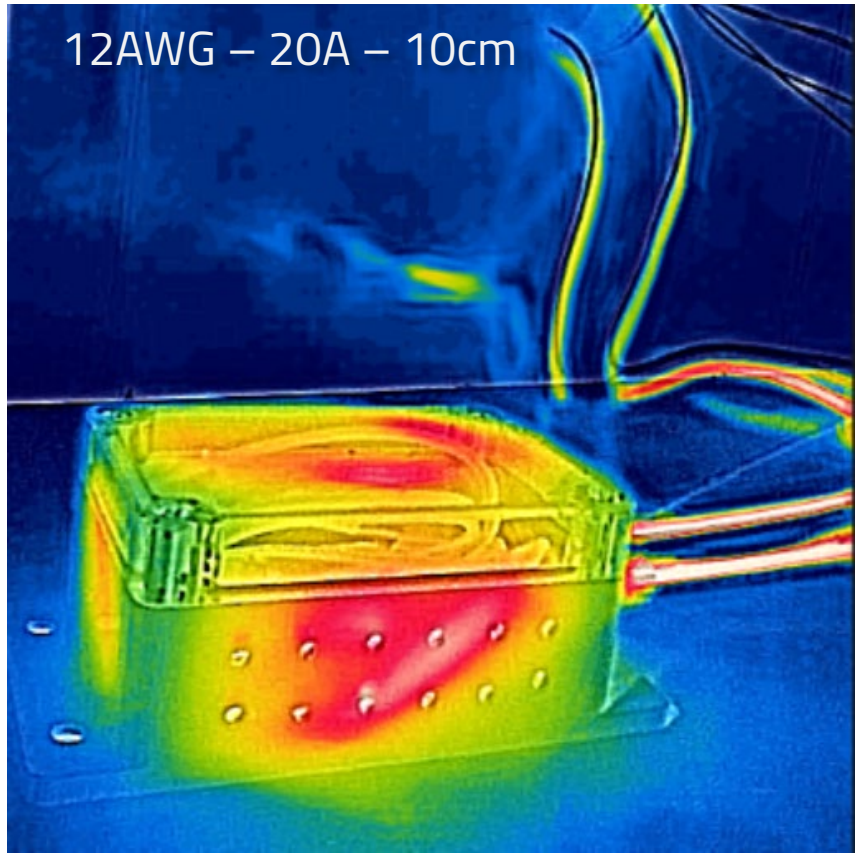


All pictures: WE eiCan

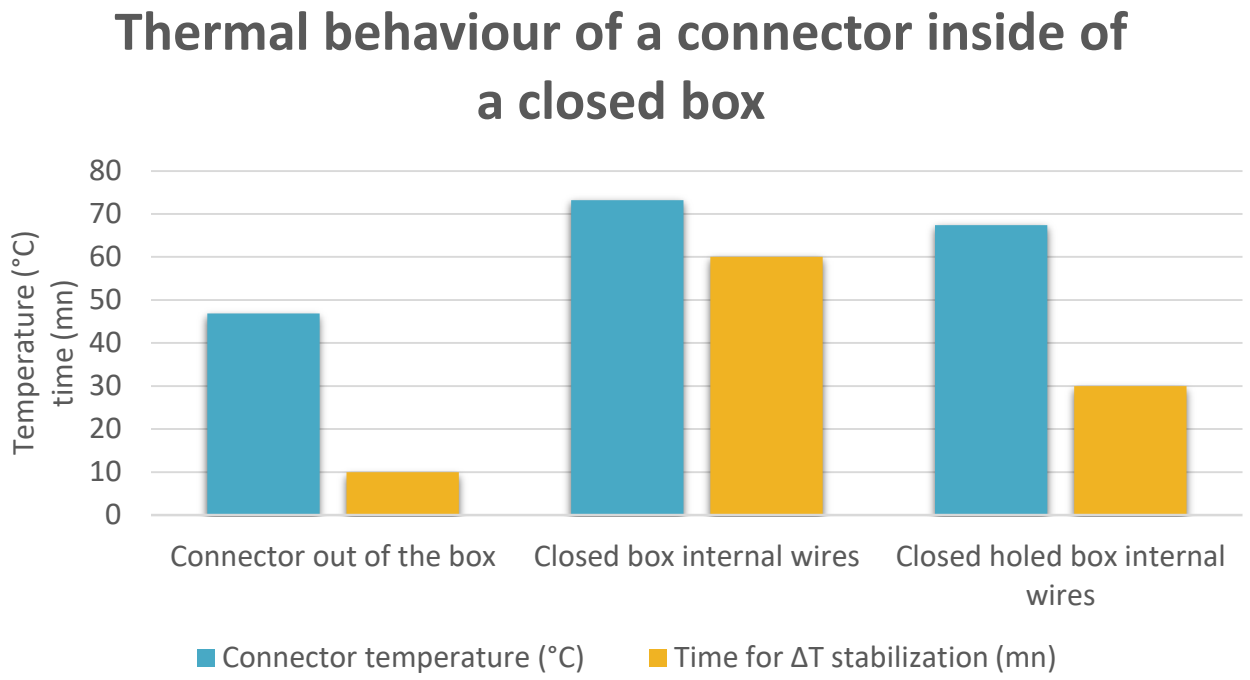
A connector in a closed box

Test:

- Same with closed box with holes



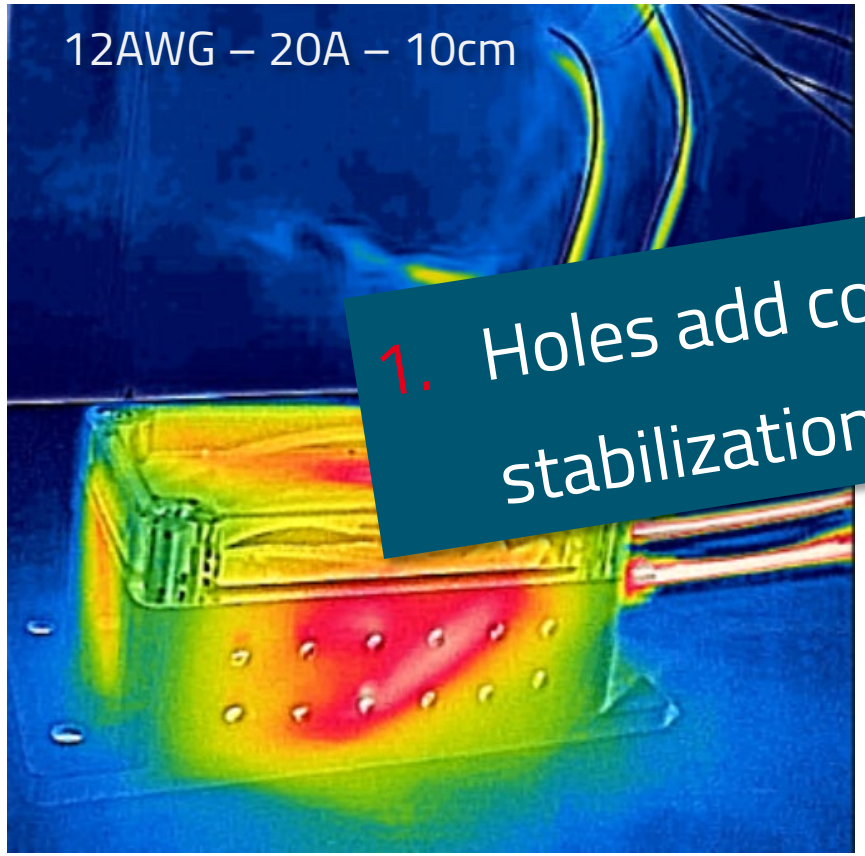
WE eiCan



A connector in a closed box

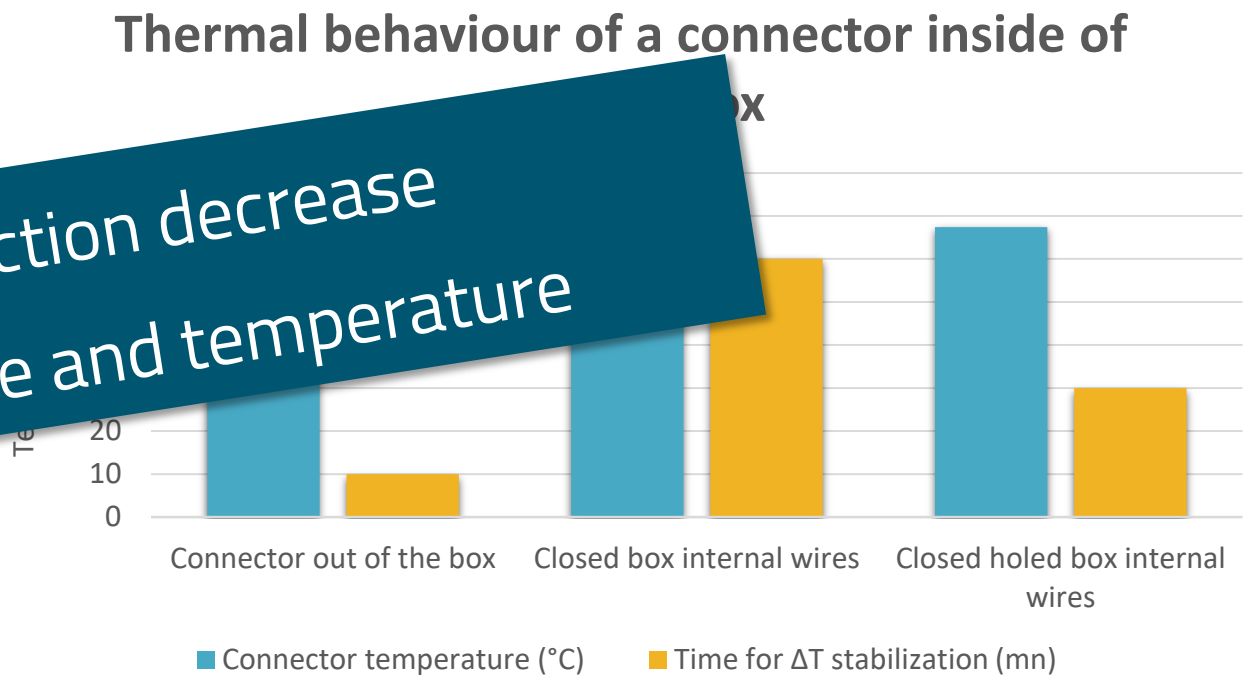
Test:

- Same with closed box with holes



WE eiCan

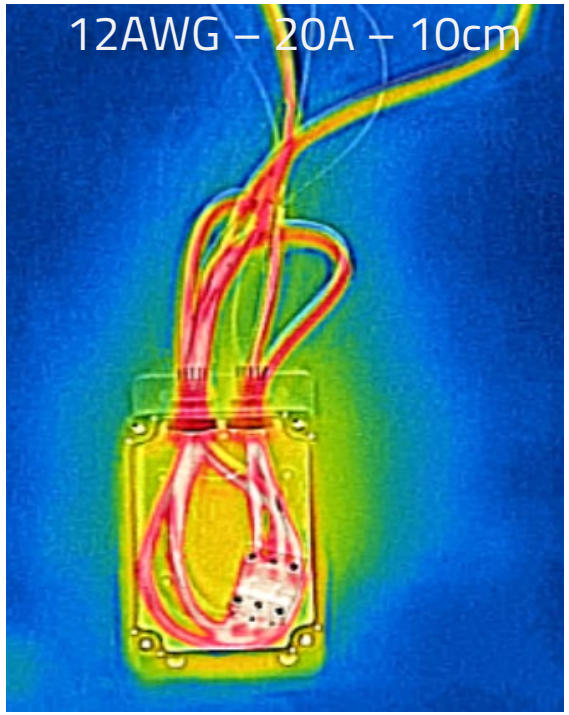
1. Holes add convection decrease stabilization time and temperature



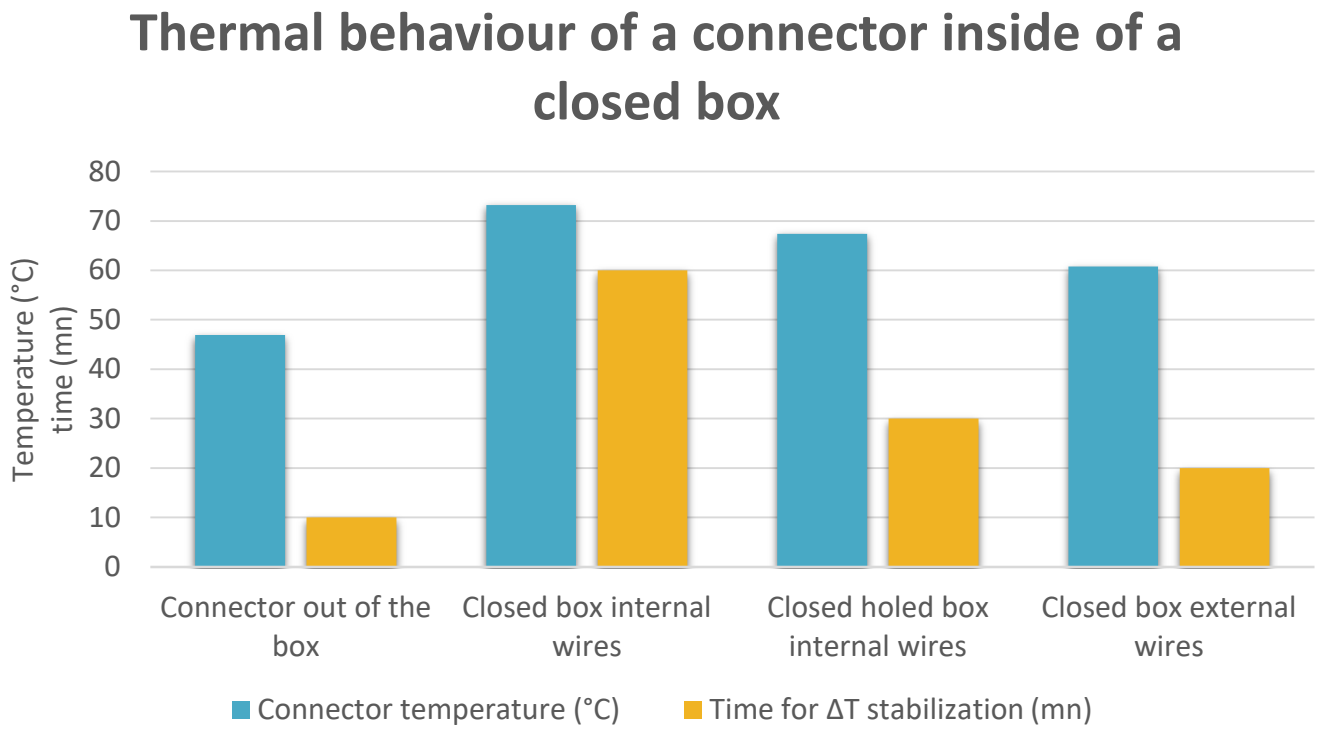
A connector in a closed box

Test:

- Same with closed box with holes and external wires



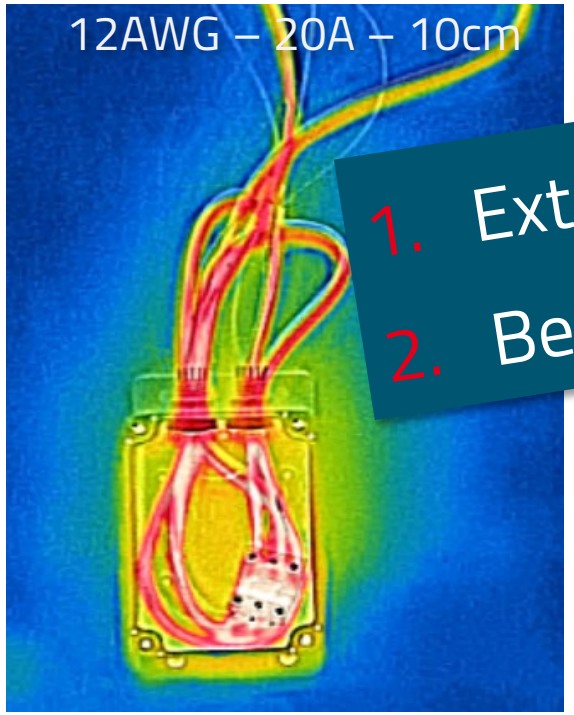
WE eiCan



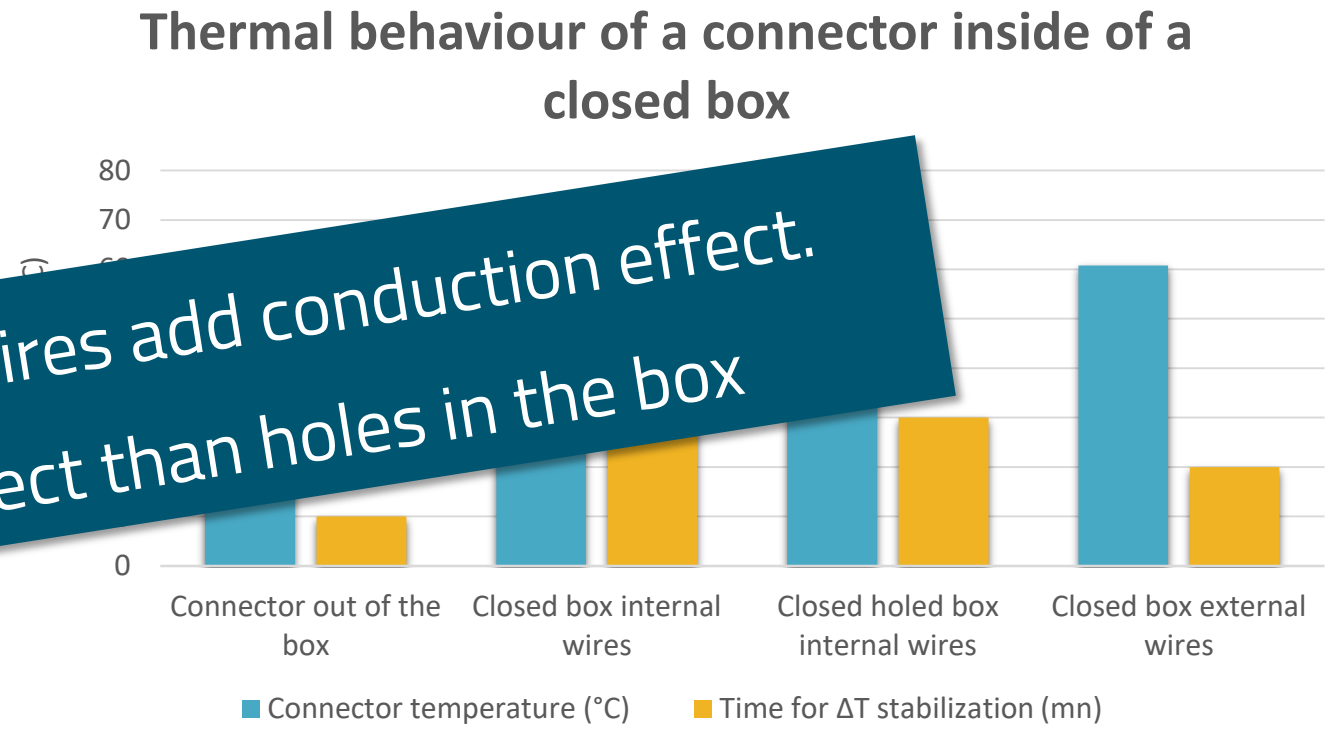
A connector in a closed box

Test:

- Same with closed box with holes and external wires



WE eiCan

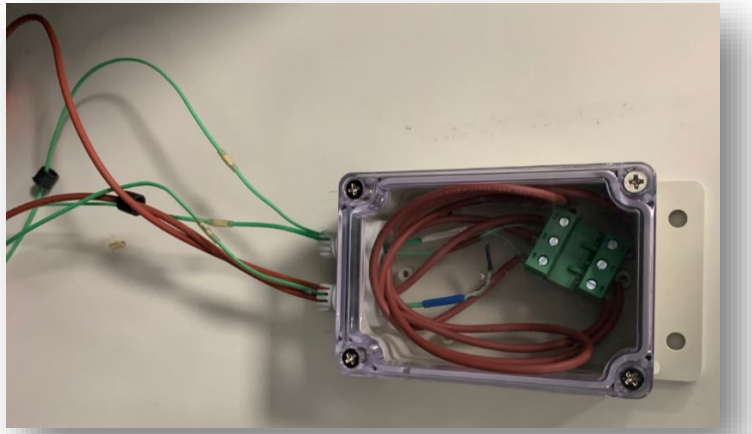


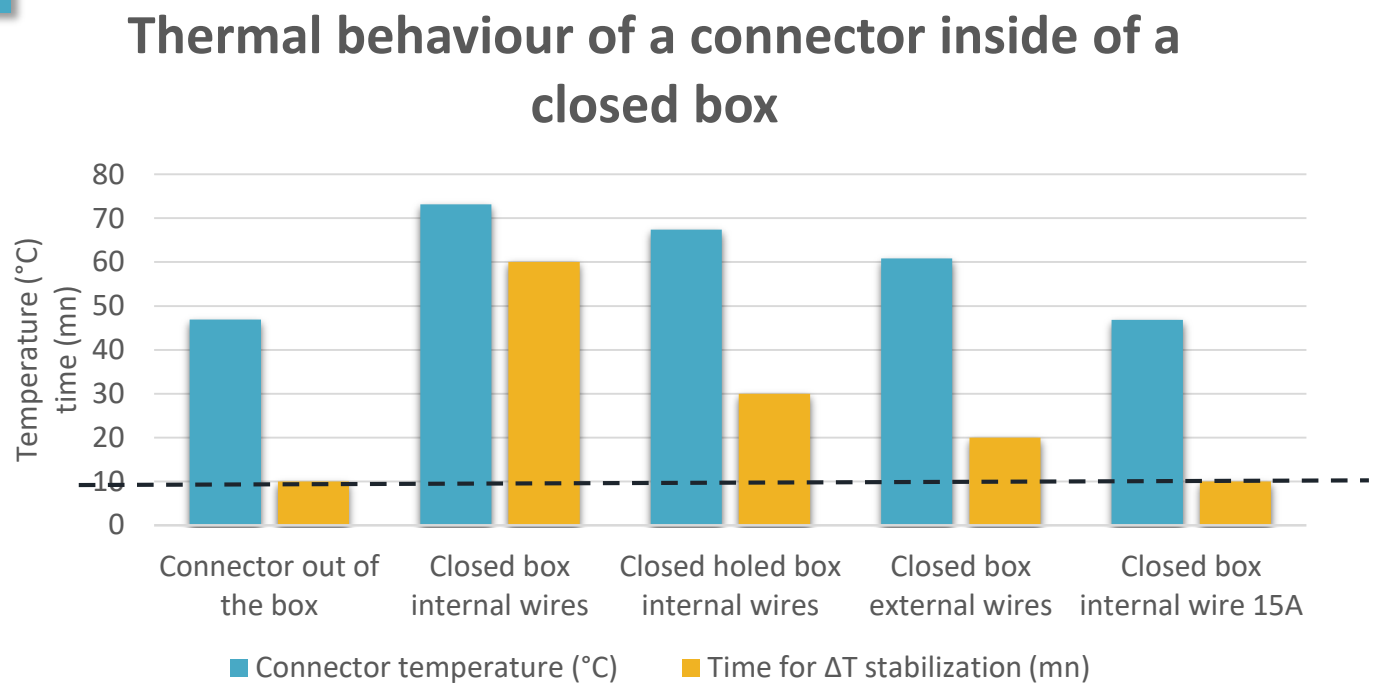
1. External wires add conduction effect.
2. Better effect than holes in the box

A connector in a closed box

Test:

- Closed box
- Internal wires
- No holes
- 15A instead of 20A

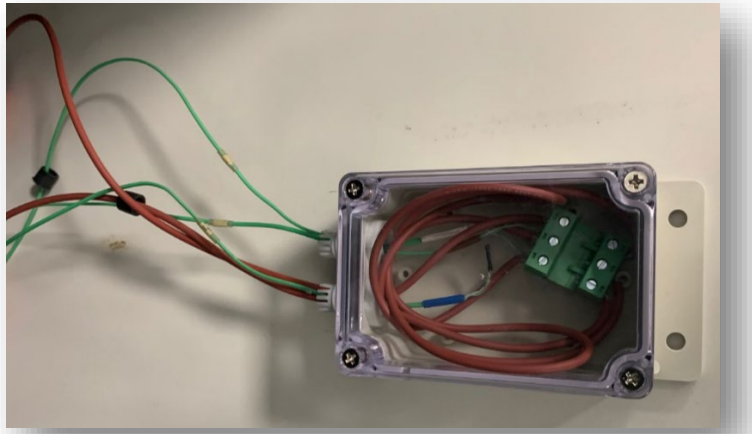




A connector in a closed box

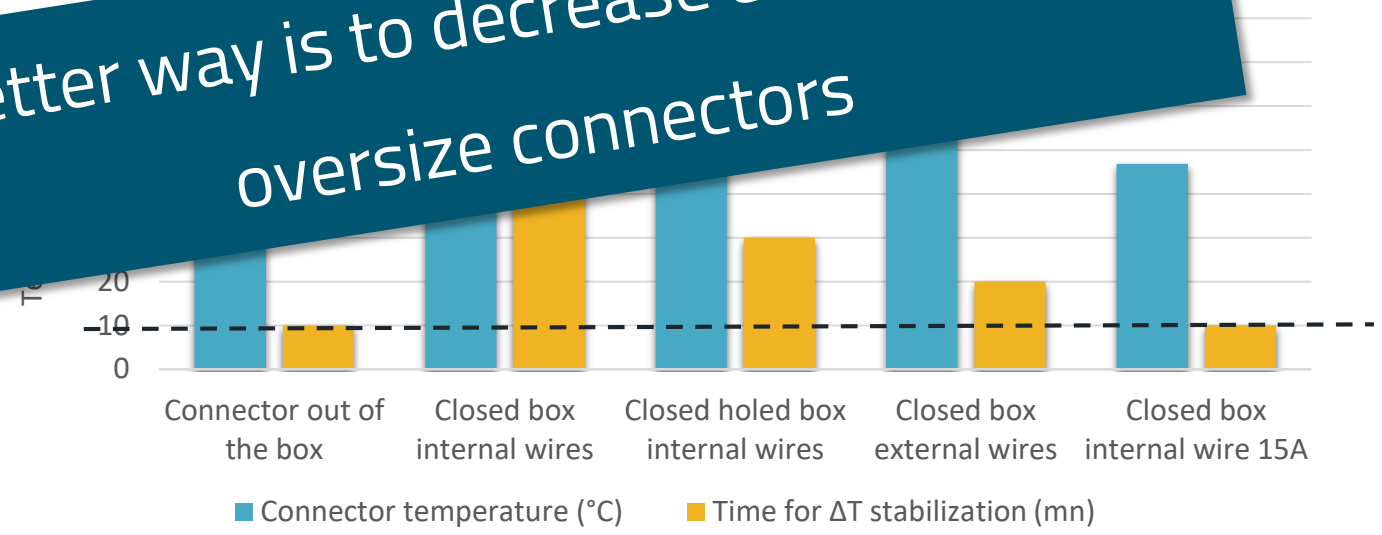
Test:

- Closed box
- Internal wires
- No holes
- 15A instead of 20A



Thermal behaviour of a connect

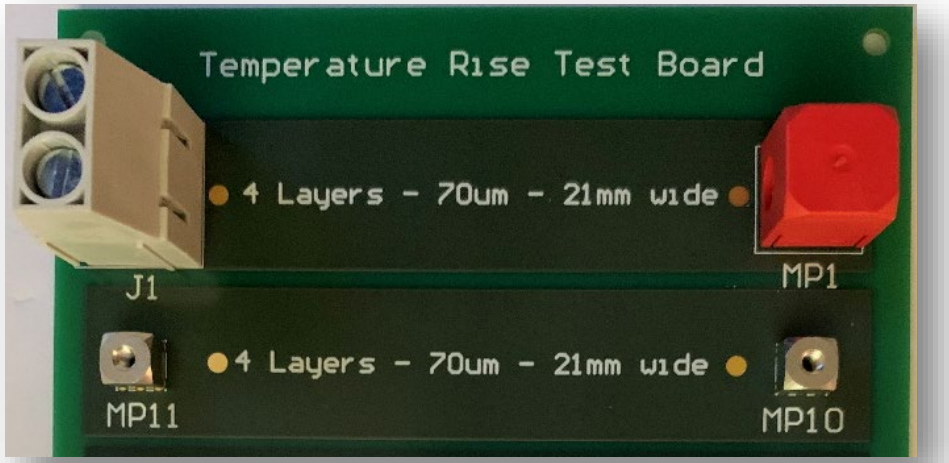
Better way is to decrease current (I^2) or oversize connectors

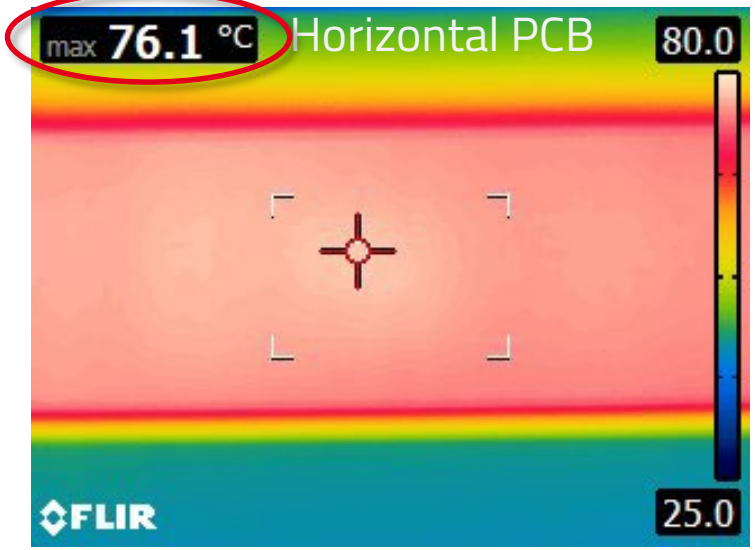


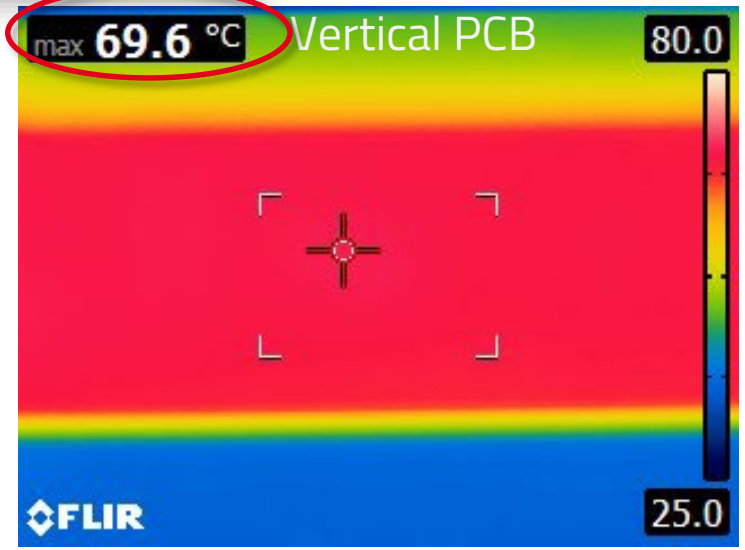
How to naturally cool down a PCB ?

Test:

- PCB redcube
- 100A
- Horizontal and vertical PCB



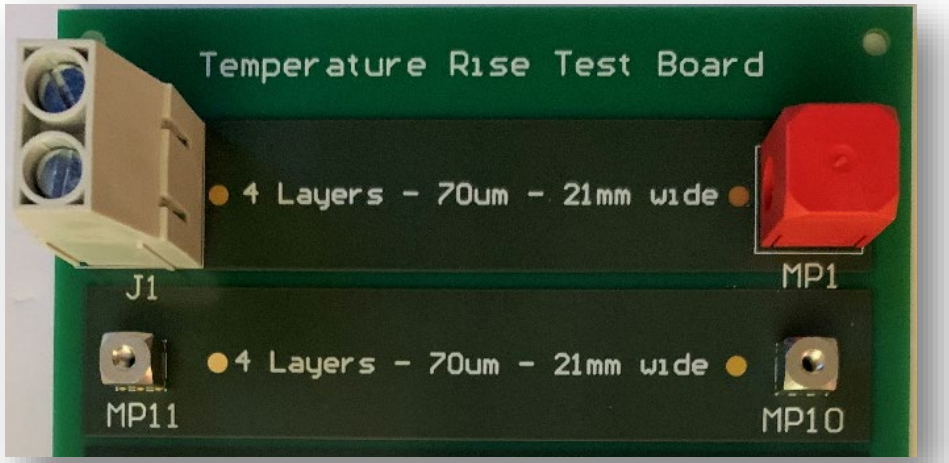


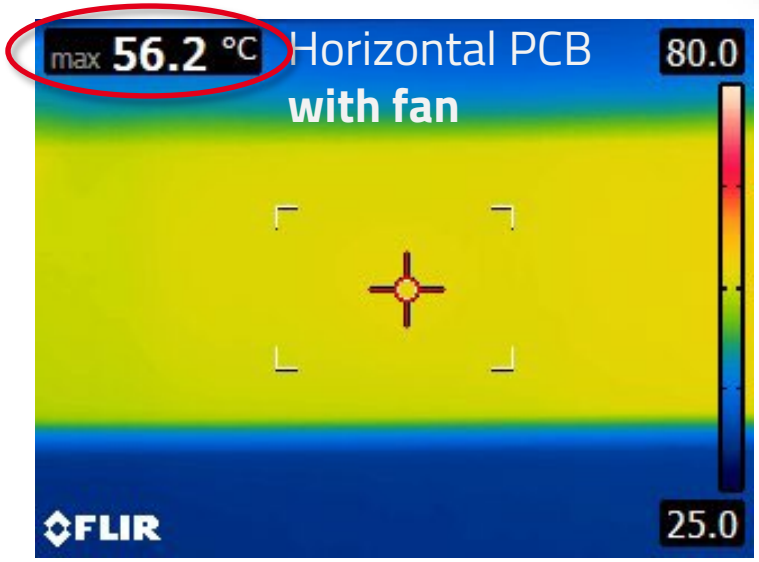


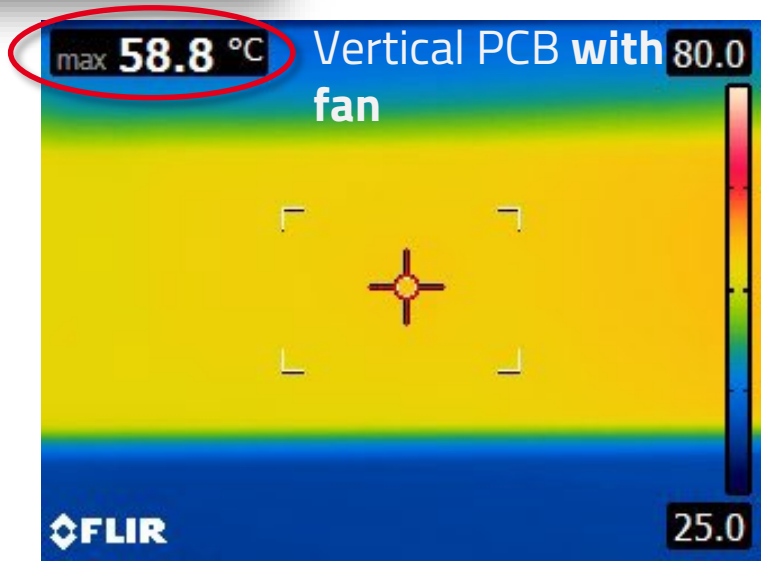
And now with a fan ?

Test:

- PCB redcube
- 100A
- Horizontal and vertical PCB
- With fan





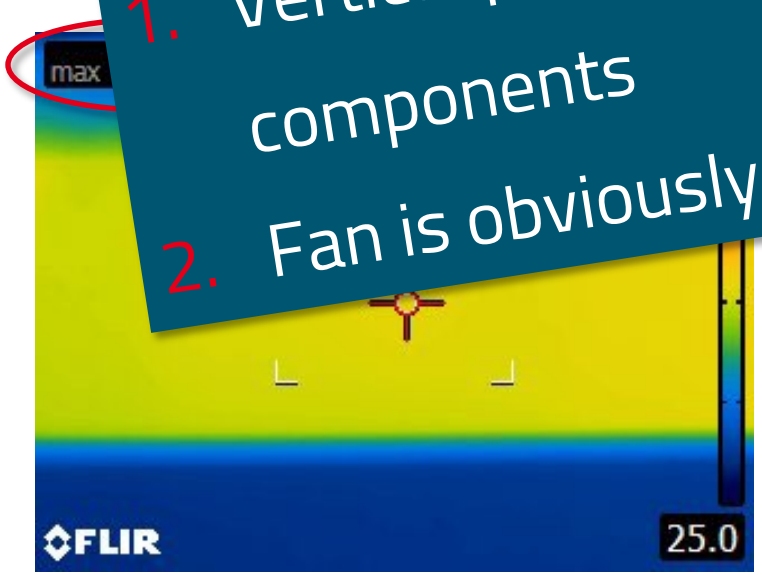


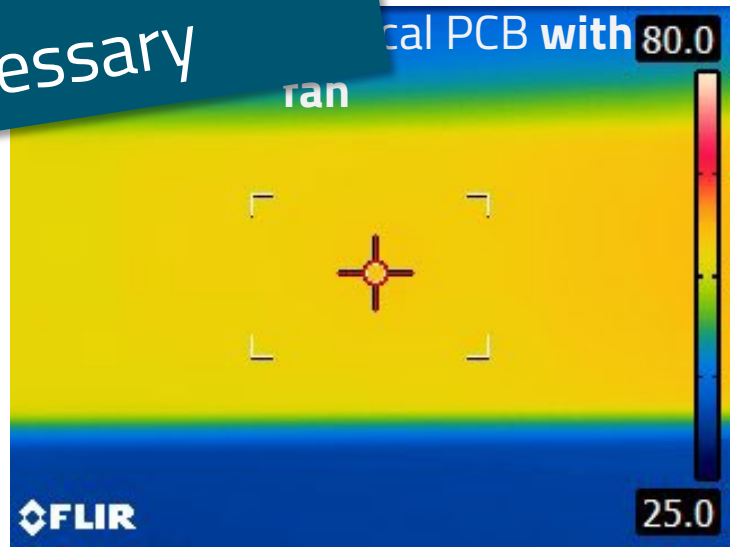
And now with a fan ?

Test:

- PCB redcube
- 100A
- Horizontal and vertical PCB
- With fan

1. Vertical position for a PCB naturally cool down components
2. Fan is obviously a good solution if necessary





Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

Derating curve UL

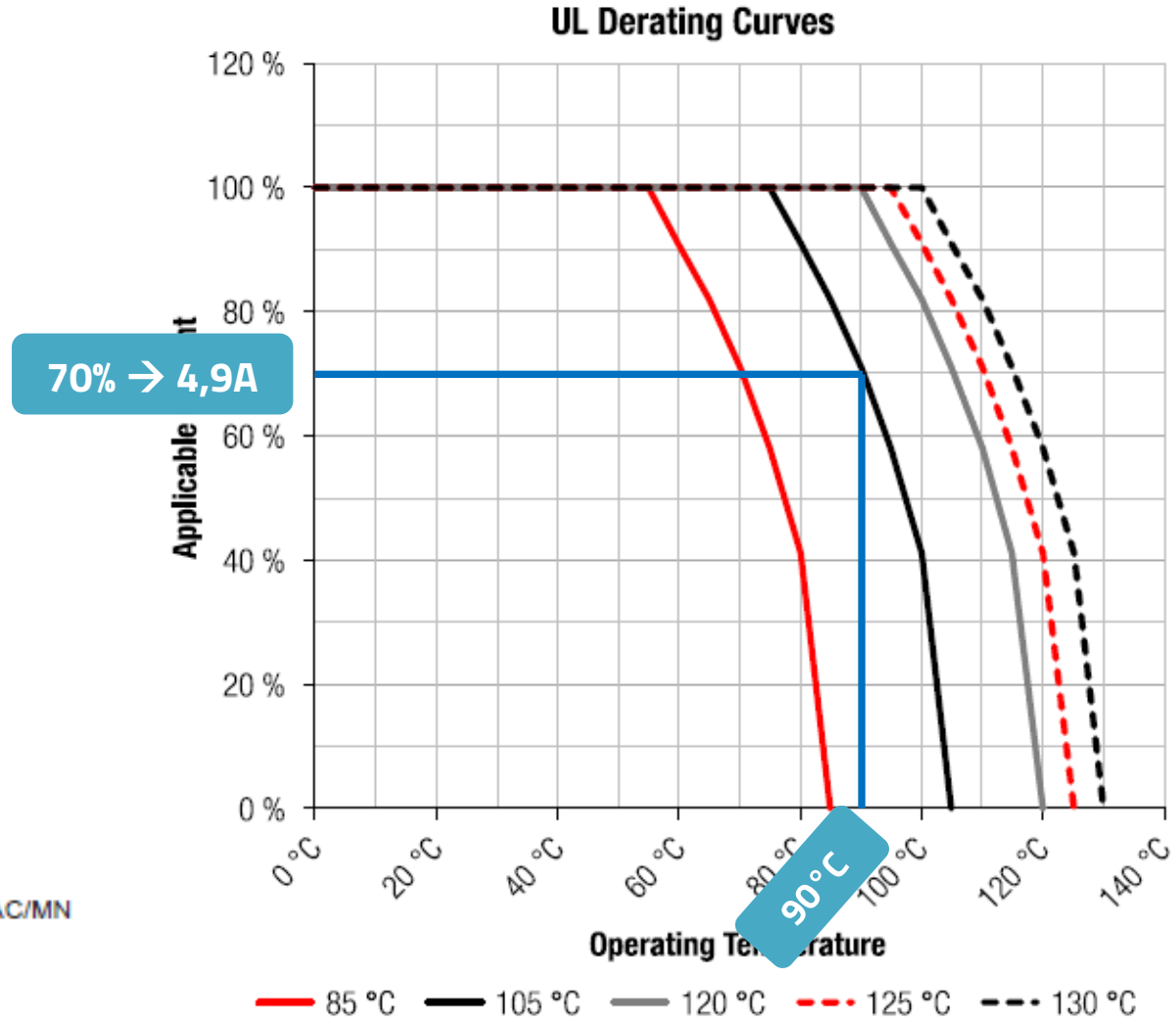
How to decrease current when ambient temperature increase:

- Maximum connector temperature
- **ΔT ≤ 30K**
- ΔT proportional to I²

WE eiCan

ENVIRONMENTAL
OPERATING TEMPERATURE: -40 UP TO 105°C
COMPLIANCE: LEAD FREE AND ROHS

ELECTRICAL
CURRENT RATING: 7 A
WORKING VOLTAGE: 250 VAC
INSULATOR RESISTANCE: >1000 MOHM
DIELECTRIC WITHSTANDING VOLTAGE: 1500 VAC/MN
CONTACT RESISTANCE: 20 mOHM MAX



70% → 4,9A

90 °C

Derating curve VDE

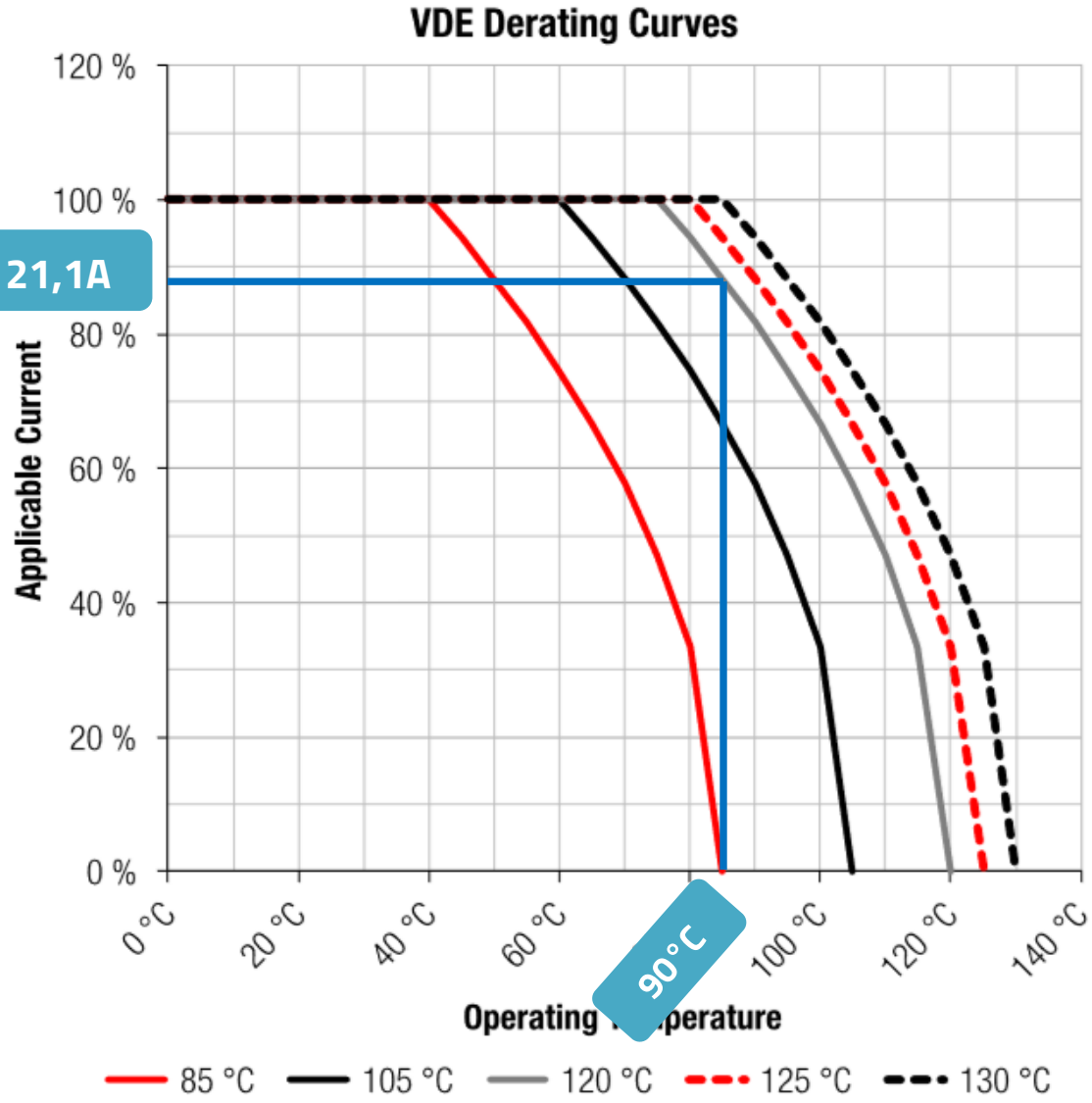
How to decrease current when ambient temperature increase:

- Maximum connector temperature
- **ΔT ≤ 45K**
- ΔT proportional to I²

ENVIRONMENTAL
OPERATING TEMPERATURE: -30°C UP TO +120°C
COMPLIANCE: LEAD FREE AND ROHS

ELECTRICAL	UL	VDE
CURRENT RATING:	16A	24A
WORKING VOLTAGE:	300VAC	750VAC
WITHSTANDING VOLTAGE:	1,6KV	3KV

CONTACT RESISTANCE: 20 mΩ MAX



Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

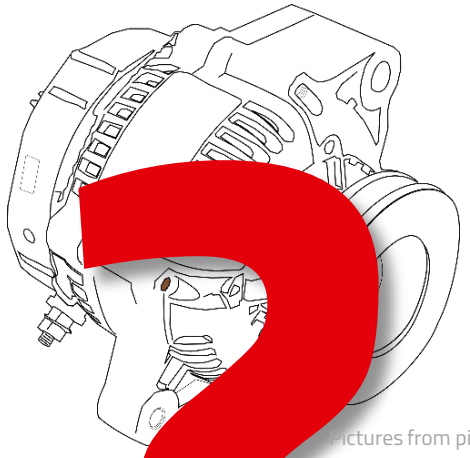
THE GOOD QUESTION

Inrush Current

Pitch 2,54mm

€

ELECTRICAL	cULus
CURRENT RATING:	6 A
WORKING VOLTAGE:	150 VAC
WITHSTANDING VOLTAGE:	1.3 KV
CONTACT RESISTANCE:	20 mOhm MAX



Pictures from pixabay

Current x 6 during short time ?

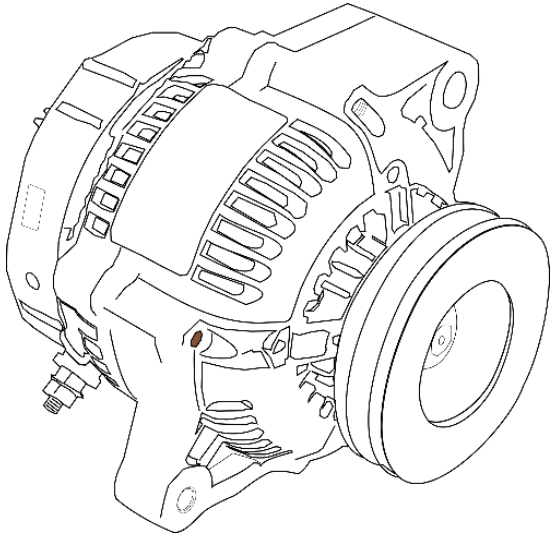
Pitch 10,16mm

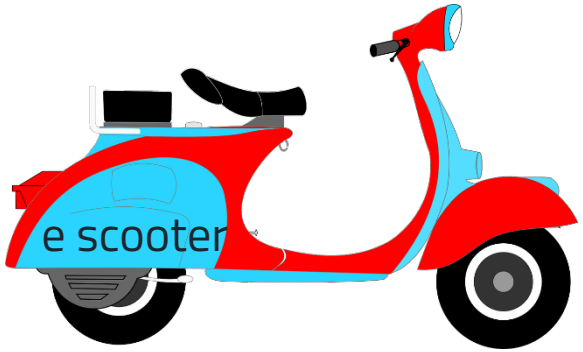
€€€

ELECTRICAL	cULus
CURRENT RATING:	57A
WORKING VOLTAGE:	300VAC
WITHSTANDING VOLTAGE:	1.6KV
CONTACT RESISTANCE:	20 mOhm max

Pictures from WE

APPLICATION ISSUE

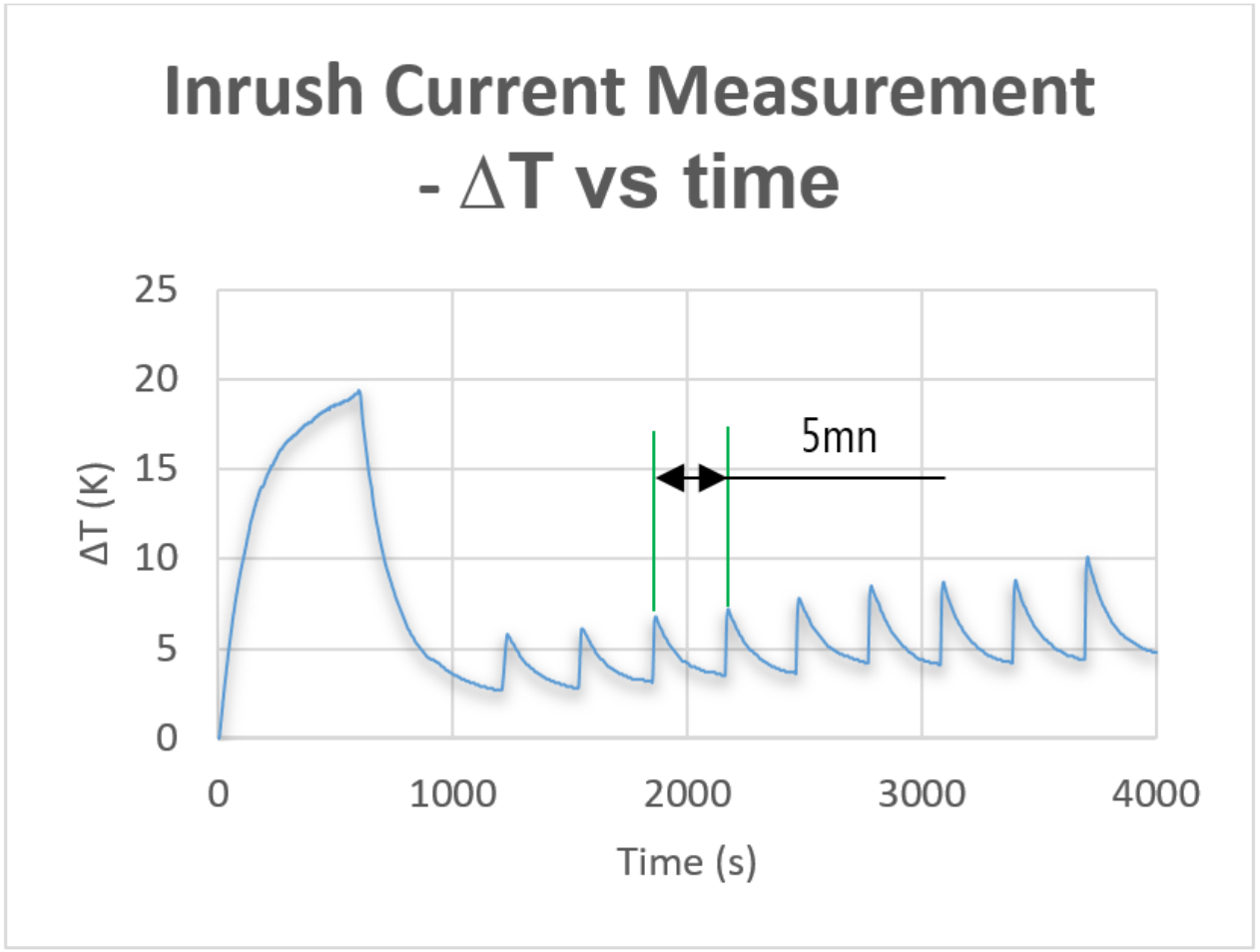




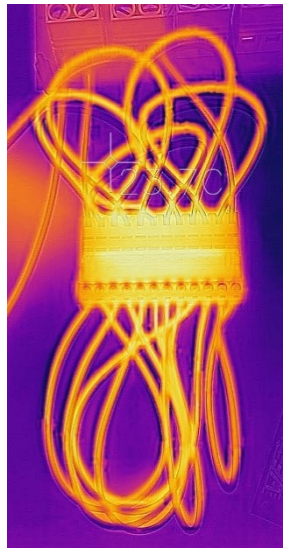
Pictures from pixabay.com

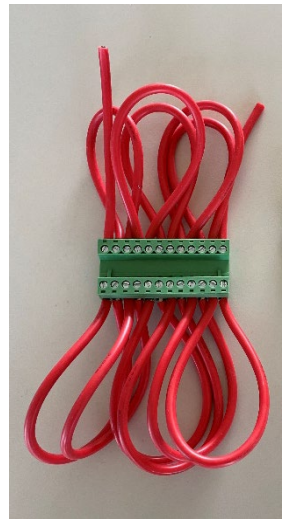
Pictures from WE

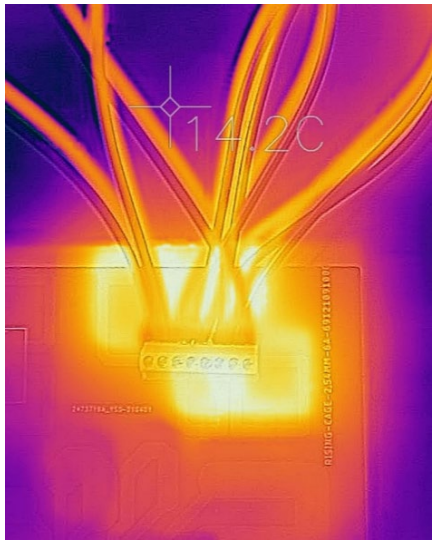
REAL TEST

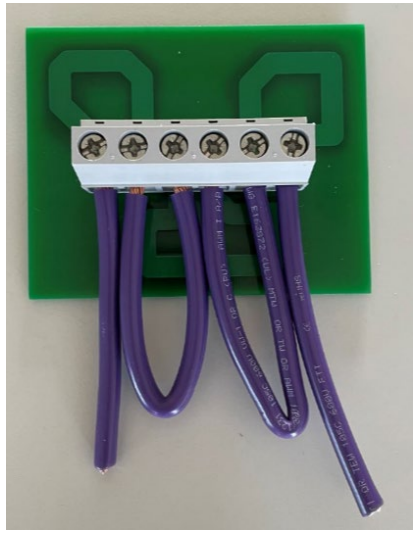


final inrush current test results



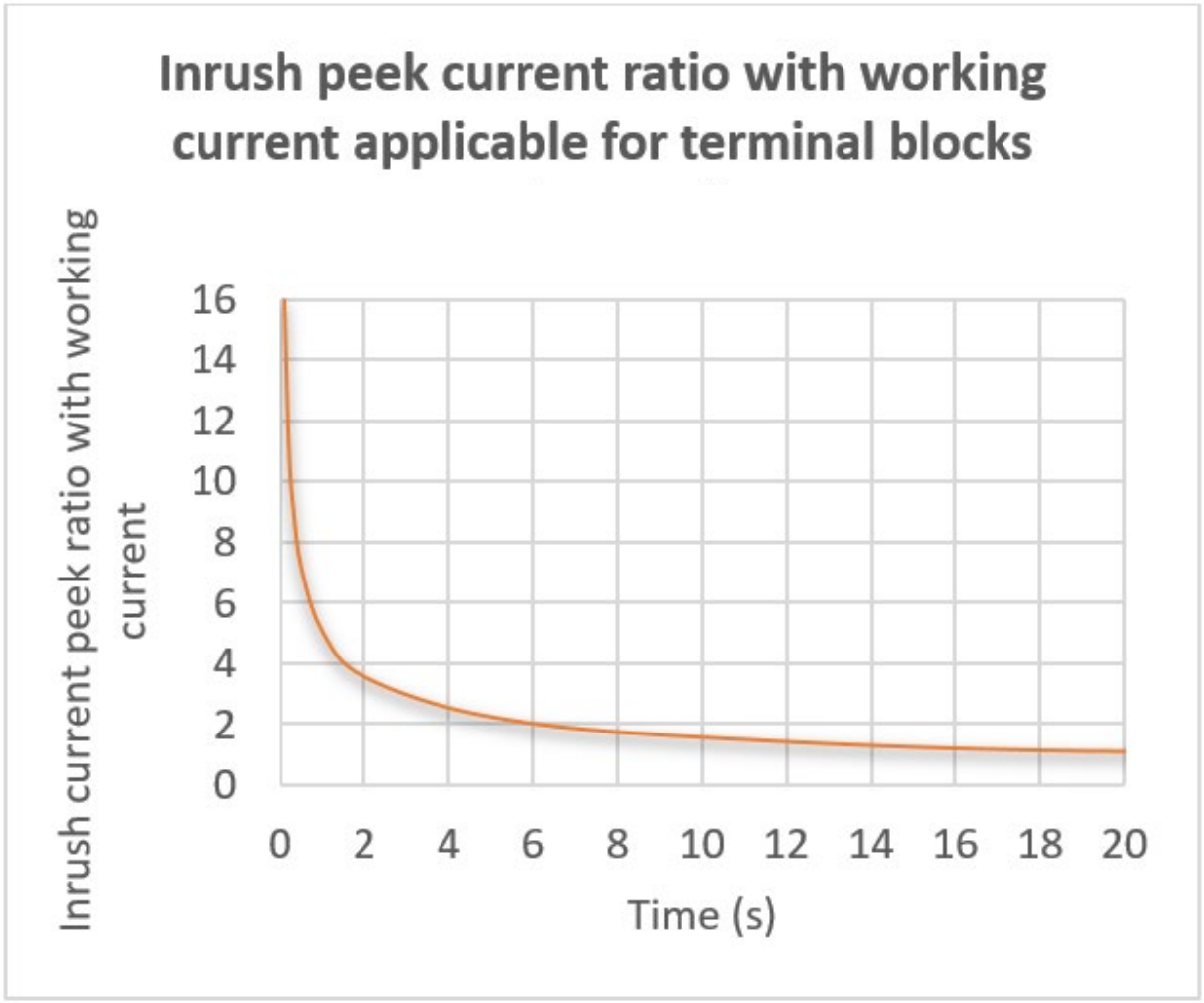


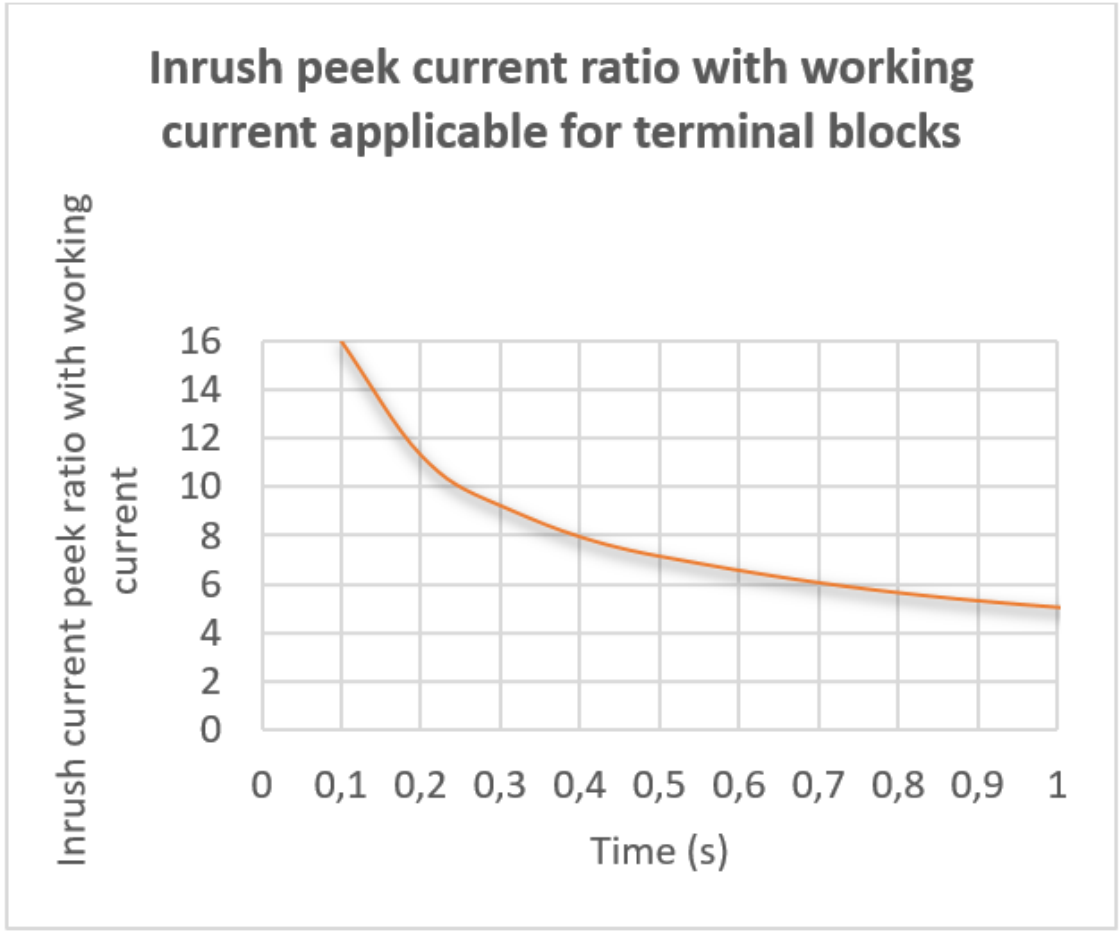




Pictures from WE

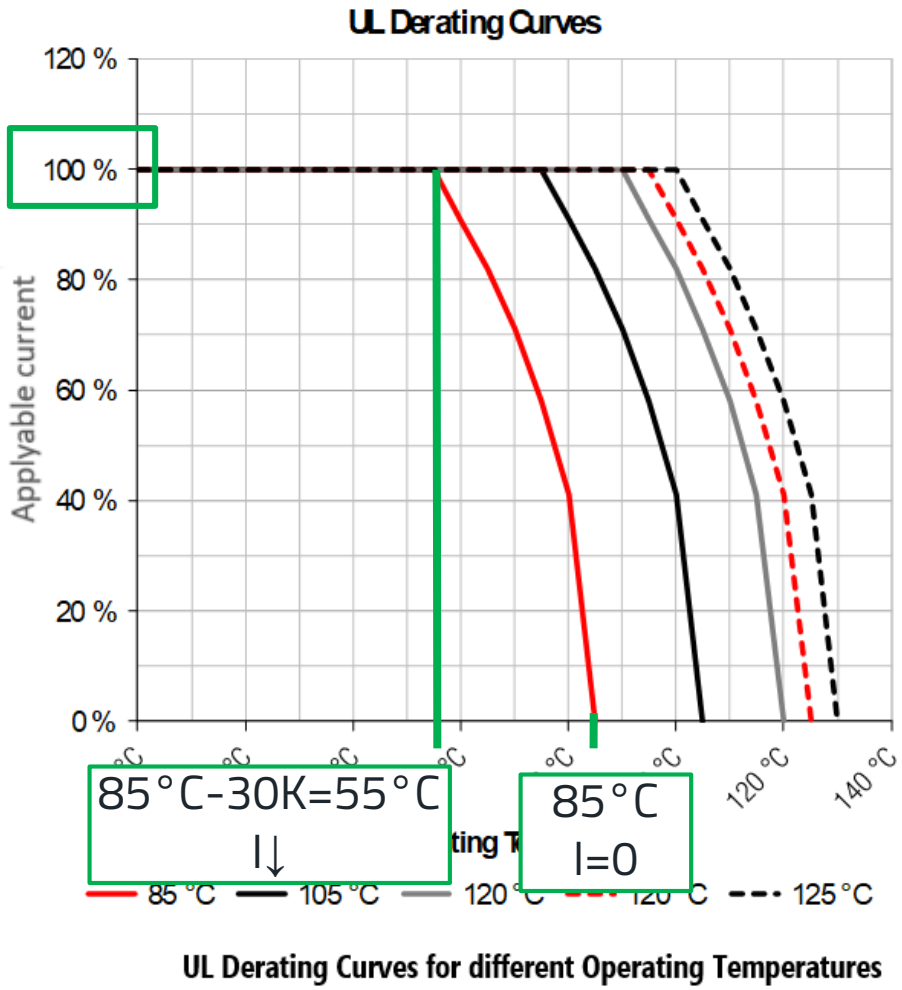
INRUSH CURRENT CURVES





applicable inrush current for eiCan connectors. Different scales

DERATING CURVE WITHOUT INRUSH CURRENT



UL Derating Curves for different Operating Temperatures

Base principle: always **ΔT ≤ 30K**

Connector internal temperature < operating temperature

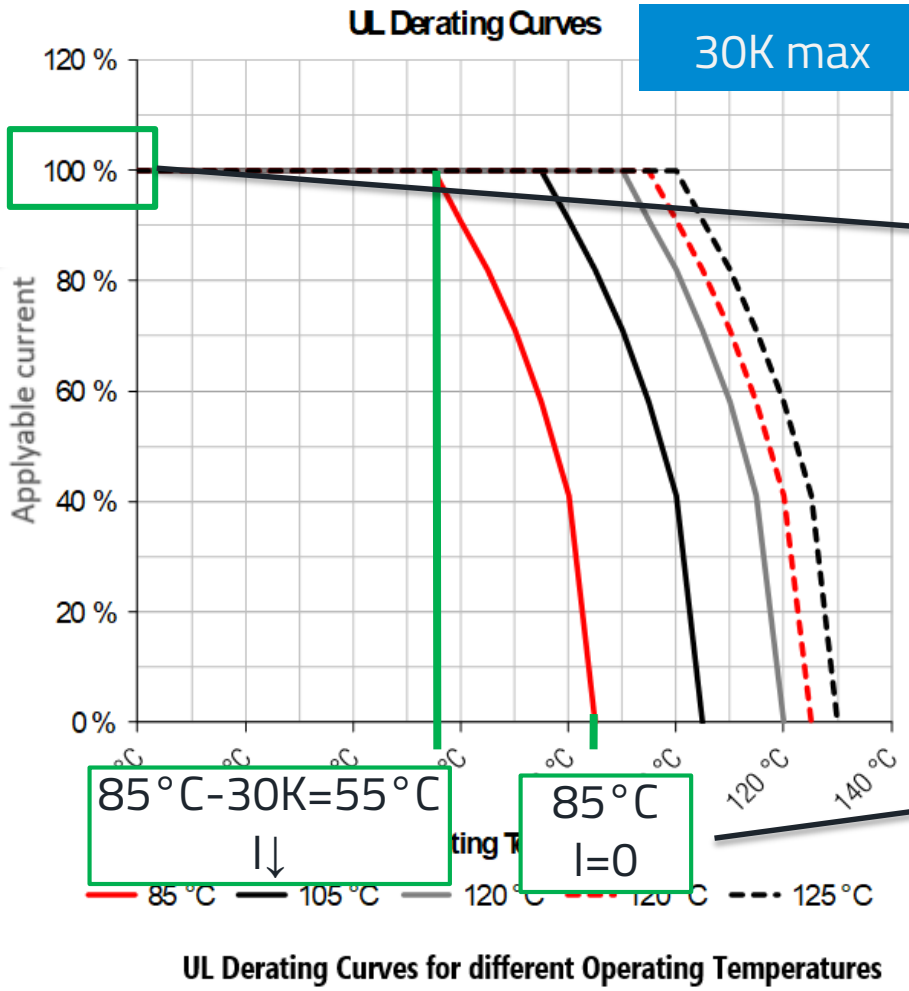
Security margin

Stable current ≤ 15K

and

Inrush current ≤ 15K

DERATING CURVE WITH INRUSH CURRENT



30K max

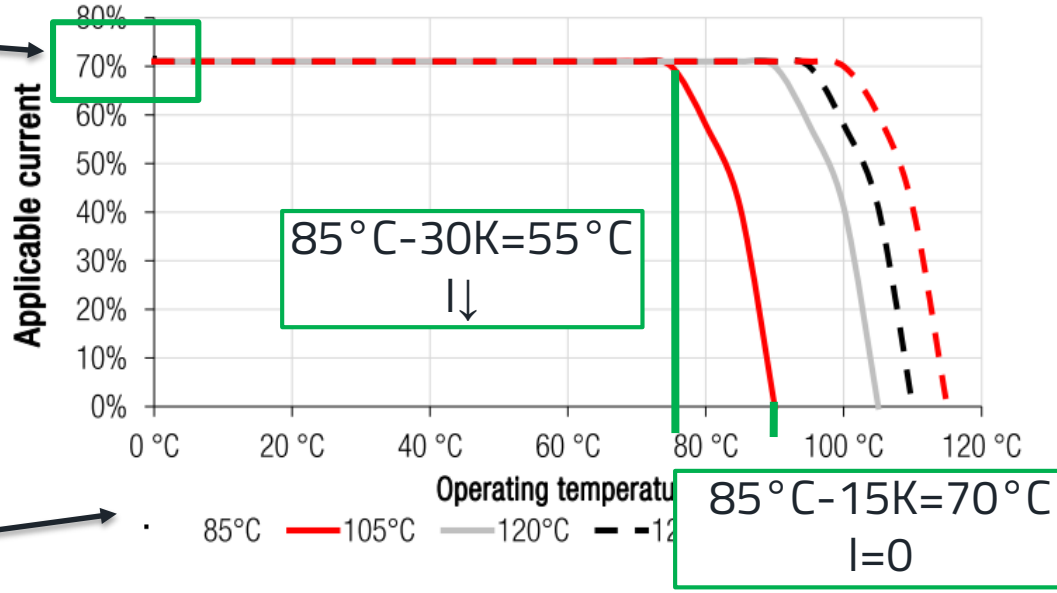
85 °C-30K=55 °C
I↓

85 °C
I=0

Stable current
≤ 15K

15K max

$$I_{max15K} = \sqrt{\frac{15K}{30K}} I_{max30K}$$



85 °C-30K=55 °C
I↓

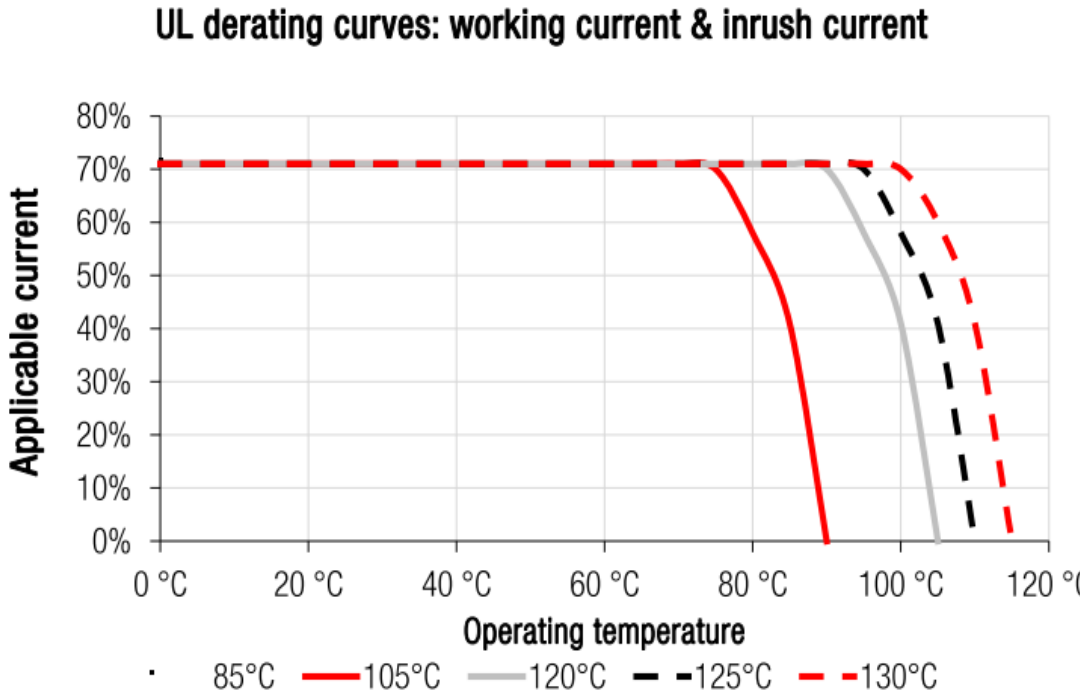
85 °C-15K=70 °C
I=0

UL derating curves for continuous and inrush current at different operating temperatures. For WE terminal blocks only

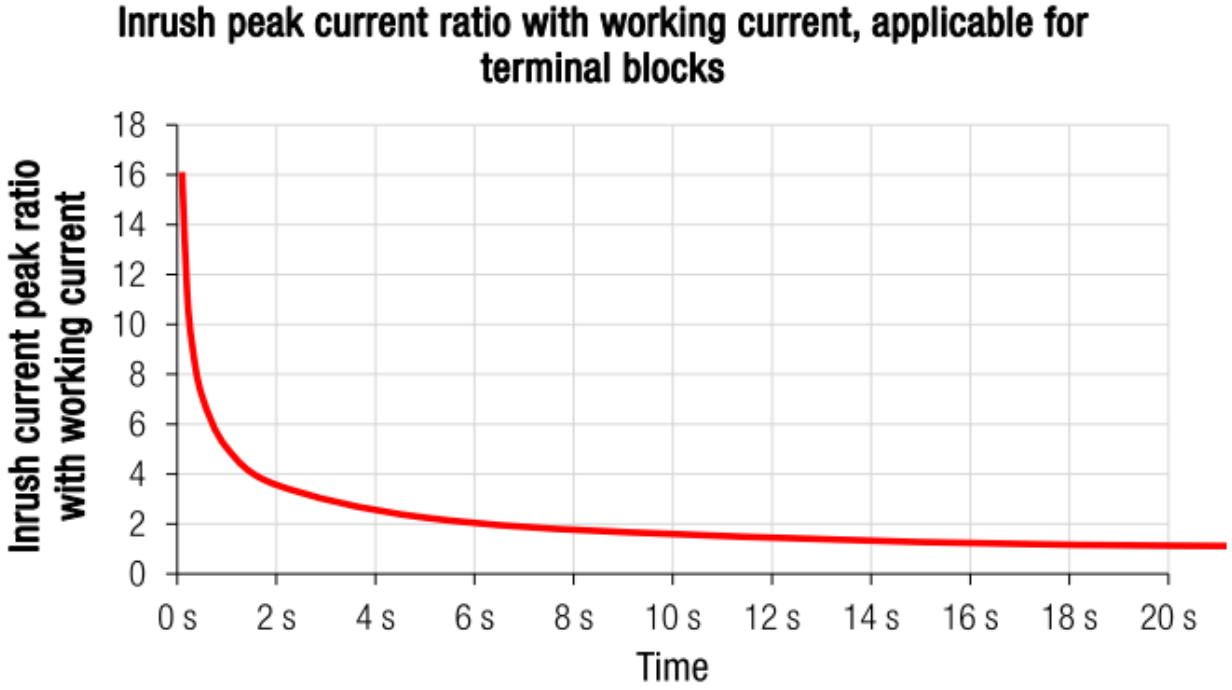
FINAL CURVES

Datasheet is guaranted by WE

Always do a test to check temperature of your system



UL derating curves for continuous and inrush current at different operating temperatures. For WE terminal blocks only



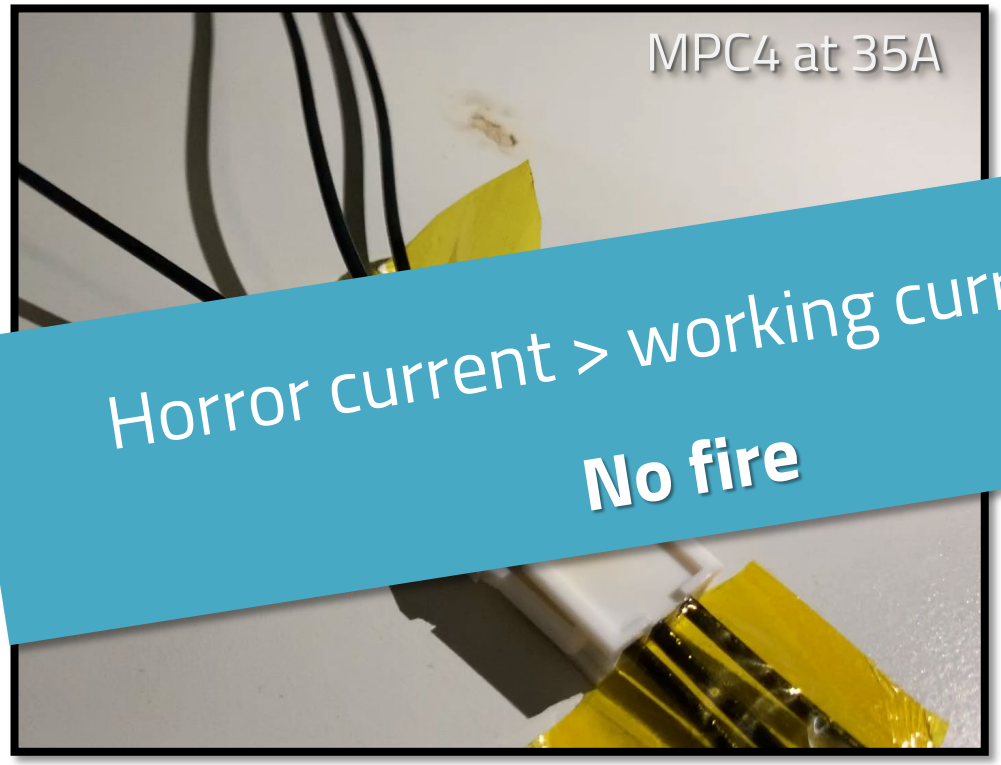
ANE015

Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

Connector horror show

What happens when you increase current ? MPC4:
9A - max +105°C



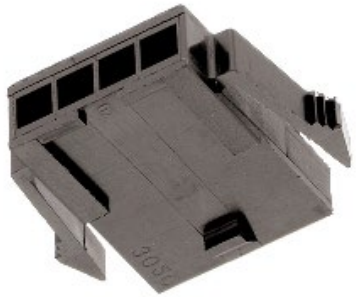
Horror current > working current **x3**

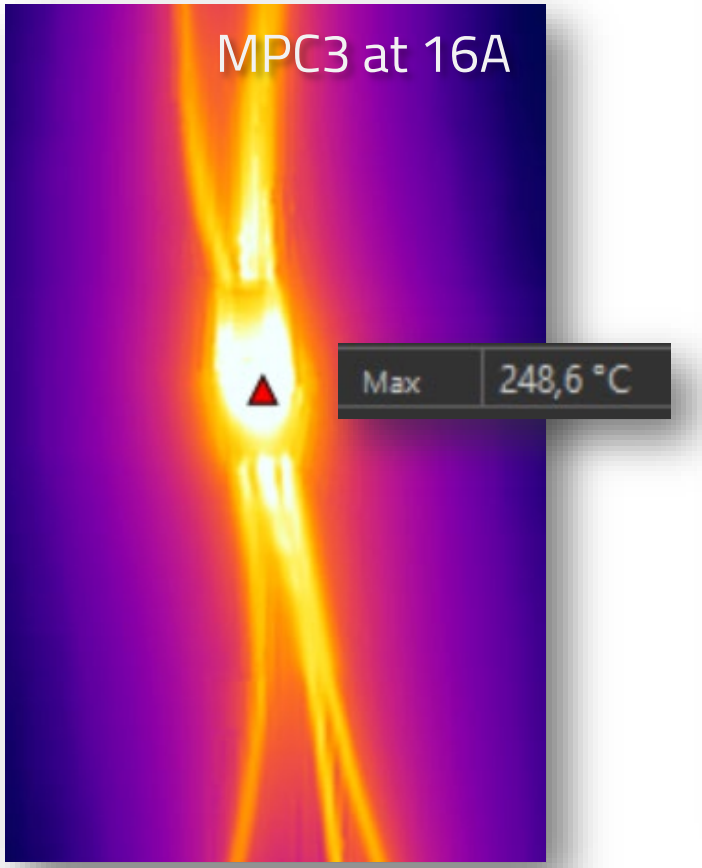
No fire

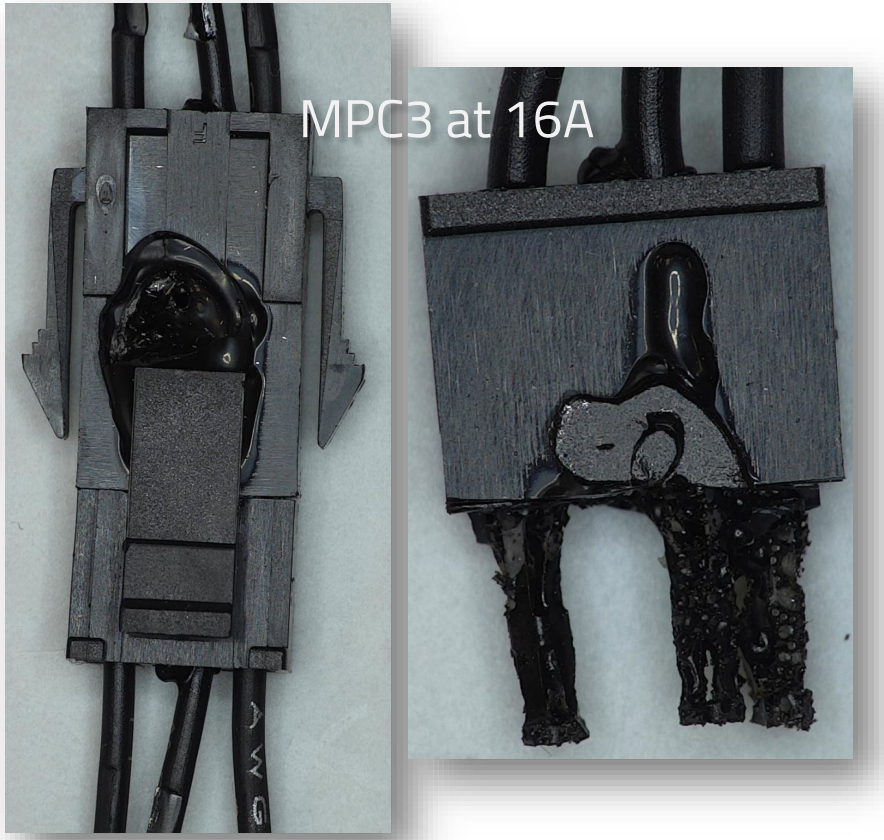
All pictures: WE eiCan

Connector horror show

What happens when you increase current ? MPC3:
5A - max +105°C



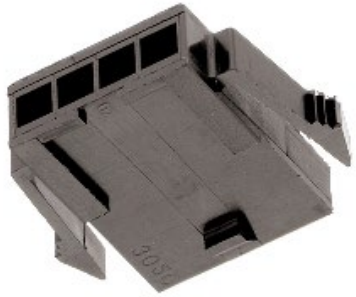




All pictures: WE eiCan

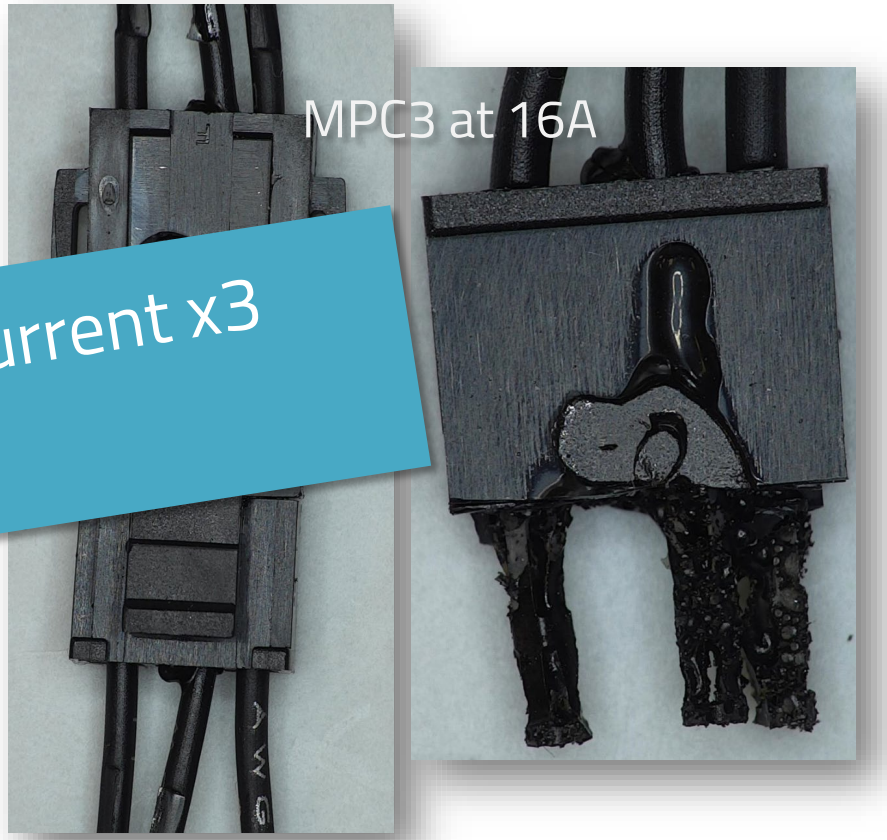
Connector horror show

What happens when you increase current ? MPC3:
5A - max +105°C



Horror current > working current x3

No fire



All pictures: WE eiCan

Agenda

- Current design for connectors
- Consequences of a too high temperature
- Temperature rise rule
- How heat is dissipated
- Heat in a cable
- Some tricks
- Derating curve
- Inrush current
- Connector horror show
- Finally what to remember

WE eiCan