Carrying high currents on PCB – From wire to PCB

How hot would you like it?

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Panasonic INDUSTRY
26 T/M 28 SEPTEMBER '23 JAARBEURS UTRECHT

Agenda

01 High Current Applications

02 High Current on PCBs

03 Temperature Measurements on PCBs

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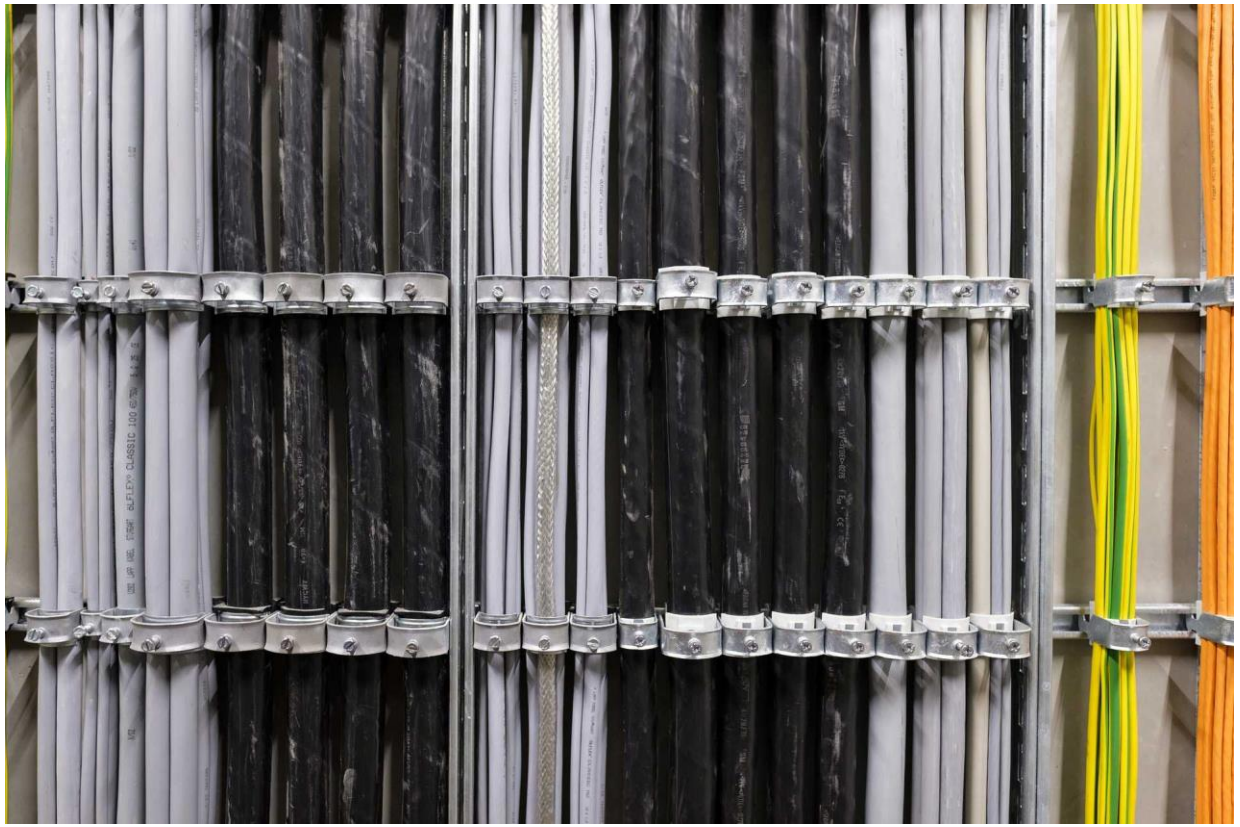
State of the art



This is what we know, and this is what we trust!

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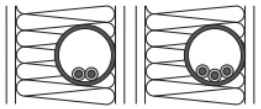
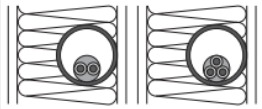
Current Carrying Capability of Cables and Wires DIN VDE 0298-4

Verlegeart	A1	A2	B1
	Verlegung in wärmegedämmten Wänden		Verlegung
	Aderleitungen im Elektroinstallationsrohr in einer wärmegedämmten Wand	mehradriges Kabel oder mehradrige ummantelte Installationsleitung in einem Elektroinstallationsrohr in einer wärmegedämmten Wand	Aderleitung Elektroinst auf einer W
			

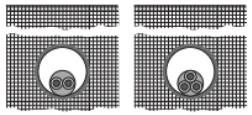
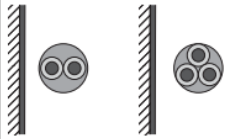
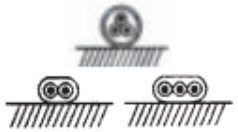
Verlegeart	D	E
	Verlegung in Erde	
	mehradriges Kabel im Elektroinstallationsrohr oder Kabelschacht im Erdboden	mehradriges Kabel mit Abstand von mindestens 0,3 · Durchmesser *D* zur Wand
		

Tabelle 9.1 Referenzverlegearten A1, A2, B1, B2, C, D, E, F und G, für Kabel 70 °C, Umgebungstemperatur 30 °C, nach DIN VDE 0298-4:1998-11 (zurückg

For cables with a nominal voltage of up to 1000 V and for heat-resistant cables at an ambient temperature of + 30 °C.

	Cable category			
	A Single-core cables • Rubber insulation • PVC insulation • TPE insulation • Heat-resistant	B Multi-core cables for domestic/handheld equipment • Rubber insulation • PVC insulation • TPE insulation		C Multi-core cables excl. domestic/handheld equipment • Rubber insulation • PVC insulation • TPE insulation • Heat-resistant
Installation type				
Number of cores under load	1[3]	2	3	2 or 3
Nominal cross-section in mm²	Current rating in A	Current rating in A		Current rating in A
0.08[1]	1.5	-	-	1
0.14[1]	3	-	-	2
0.25[1]	5	-	-	4
0.34[1]	8	-	-	6
0.5	12[2]	3	3	9[2]
0.75	15	6	6	12
1.0	19	10	10	15
1.5	24	16	16	18
2.5	32	25	20	26
4	42	32	25	34
6	54	40	-	44
10	73	63	-	61
16	98	-	-	82
25	129	-	-	108
35	158	-	-	135
50	198	-	-	168
70	245	-	-	207
95	292	-	-	250
120	344	-	-	292
150	391	-	-	335

B1	B2		C	
Verlegung in ktroinstallationsrohren			Verlegung auf einer Wand	
3	2	3	2	3
stbarkeit in A				
15,5	16,5	15,0	19,5	17,5
21	23	20	27	24
28	30	27	36	32
–	–	–	–	33,02
36	38	34	46	41
50	52	46	63	57
–	–	47,17	–	59,43
68	69	62	85	76
89	90	80	112	96
110	111	99	138	119
134	133	118	168	144
171	168	149	213	184
207	201	179	258	223
239	232	206	299	259
262	258	225	344	299
296	294	255	392	341
346	344	297	461	403
394	394	339	530	464

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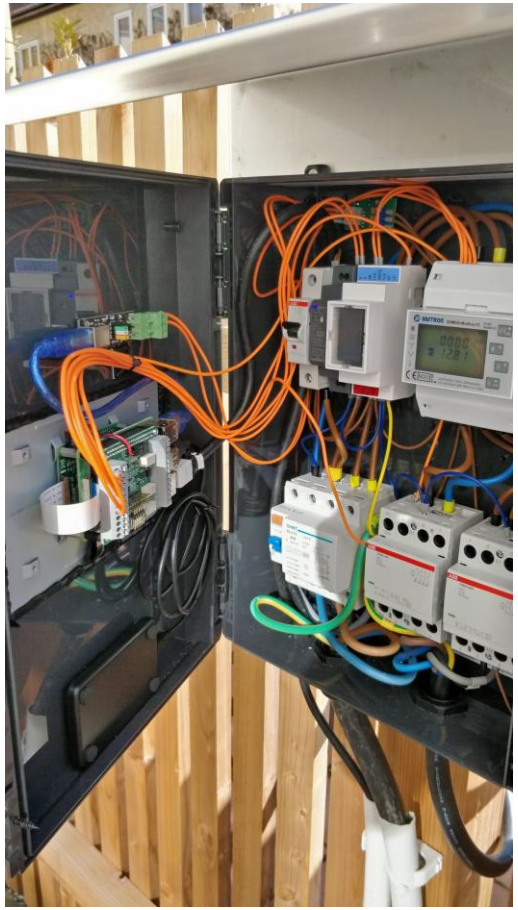
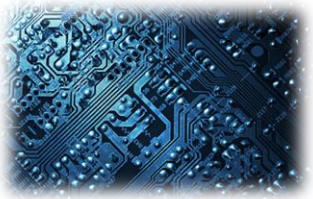
Wires in applications



Open Source Wallbox Project

- Failures in setup and maintenance
- intense maintenances effort



+ Easier to replace
+ Less failures
+ Less maintenances

High Power Applications on PCBs reduce installation and maintenance time

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Applications for high-current AC-relays

PV Inverter

UPS

Industrial Inverter

EV-Charging

Trend to use high currents on pc-board!

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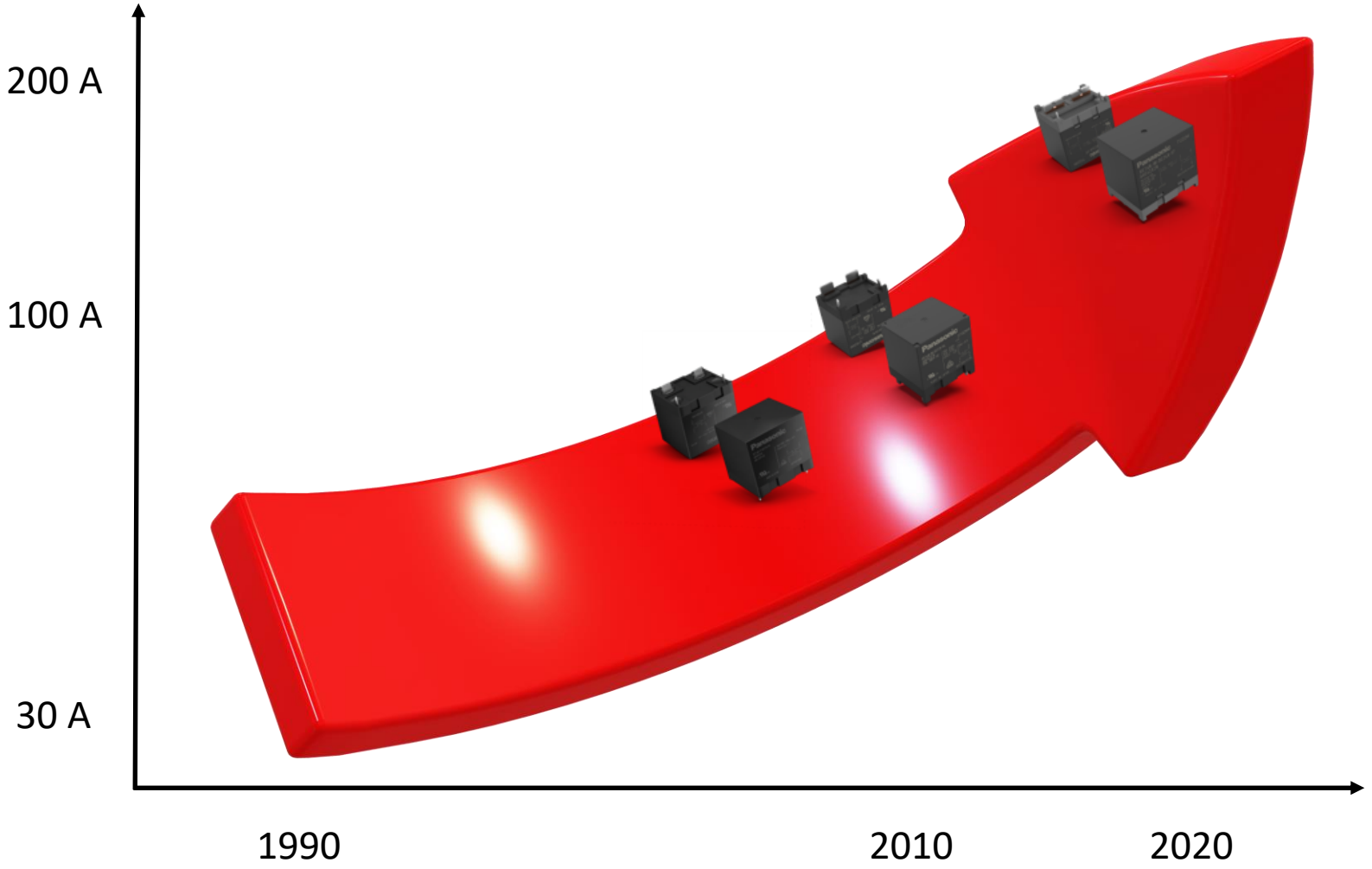
High Power Relais development



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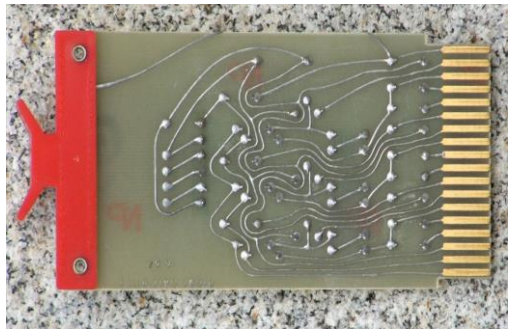
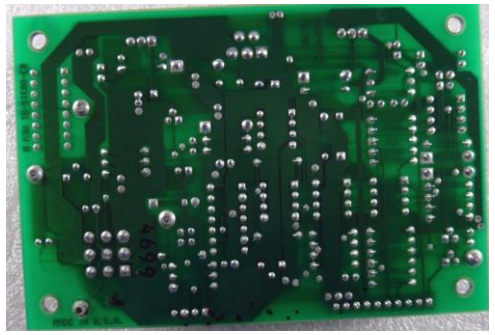
PCB development over the years



Board designed in 1967



…in 1995

…and today

https://www.ksg-pcb.com/leiterplatten-technologien/hsmtec

- Multilayers up to 560 µm thickness
- Selective Copper: normal copper layers + copper profiles (only as much copper as needed)

\+ Best for High Current applications

− expensive manufacturing

− Simulation necessary

What do I do starting out of the blue?

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High Currents on PCB

Calculation for Current Carrying Capability

IPC-2221 Thermal Standards

The thermal standards in IPC-2221 were developed using thermal data from test boards, where traces were supplied with a known current and the temperature change in the trace was measured. The results were gathered for standard thickness boards and summarized into a formula relating copper area (in square mils), temperature rise (in °C), and current (in Amperes):

$$I = k\Delta T^{0.44} A^{0.725}$$

Load curves from the 1960
→ wrong and not in relation to standard technologies

IPC-2152 Thermal Standard

- Only two conductor geometries are analyzed
- Gives a good overall understanding about current carrying capability
- Only qualitative, not quantitative!

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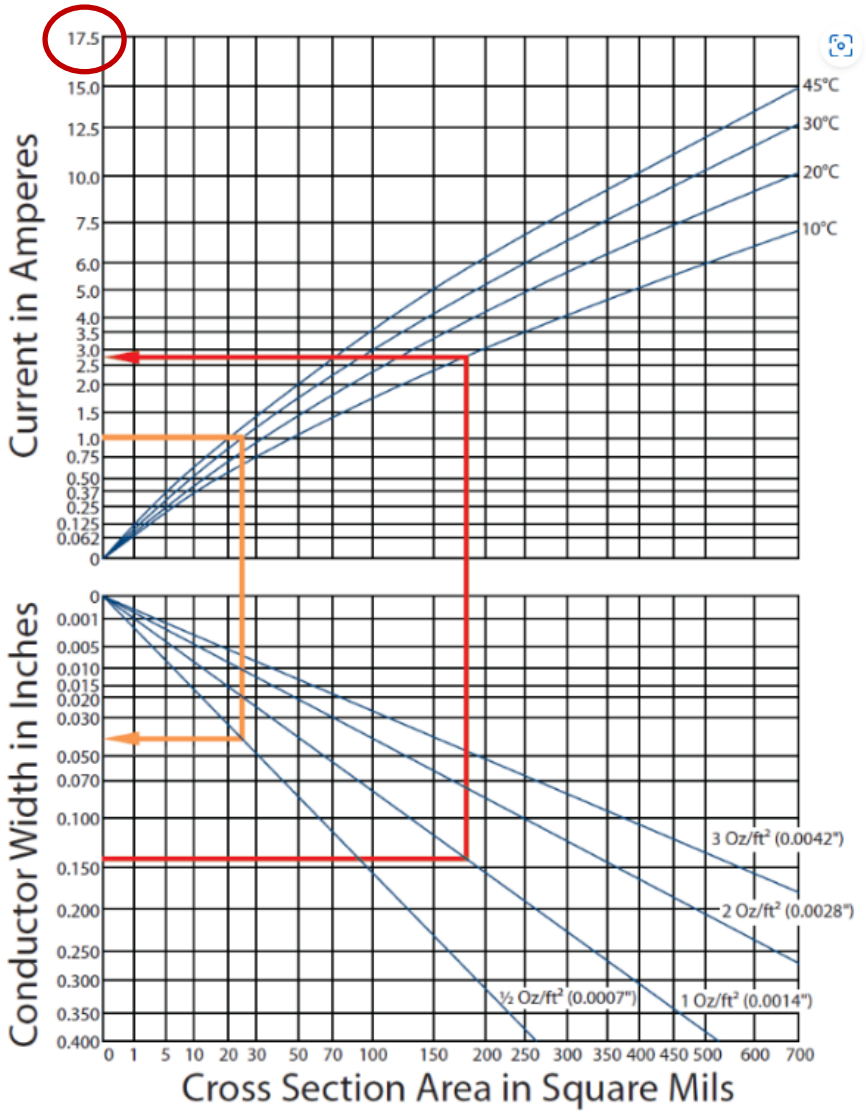

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Physics to consider

- Joules Law and heat generation

Joule‘s law:

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

El. Resistance:

$$R = L \cdot \frac{\rho_{20}\left(1 + \alpha_{20}(T - 20)\right)}{w \cdot d} \qquad \rho_{20} = 0.0175\ \Omega \cdot \frac{mm^2}{\mathrm{m}} \text{ at } 20°\mathrm{C} \qquad \alpha_{20} = 0.00395 \frac{1}{K}$$

Thermal Resistance

- Heat conduction: $R_{th} = \frac{d}{\lambda \cdot A}$
- Convection: $R_{th} = \frac{1}{\delta \cdot A}$
- Heat radiation: $R_{th} = \frac{d}{\varphi \cdot A}$

→ Important to consider in the PCB design

→ Important to consider in the PCB design and the application cooling

Symbol	Description	Unit
R_{th}	therm. Resistance	K/W
d	Thickness	µm
A	Area	mm²
λ	Thermal Conductivity	W/mK
δ	Heat transfer coefficient	W/m²K
φ	Heat transfer coefficient	W/m²K

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Physics to consider

Heat conduction: $R_{th} = \frac{d}{\lambda \cdot A}$

Material	Thermal Conductivity λ [W/mK]
Copper	300
FR4	0,25
Air (still)	0,026

> x 1000

x 10

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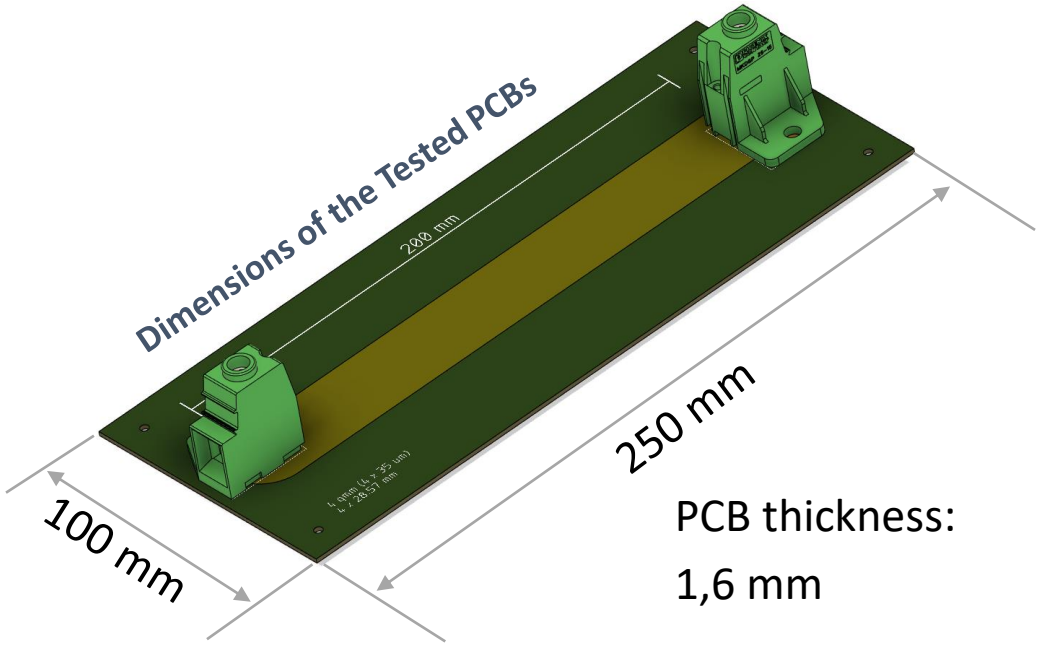
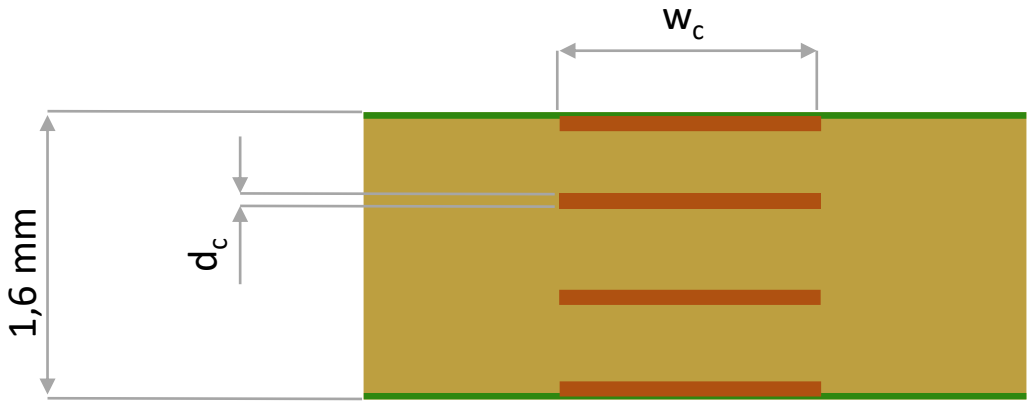
Design variations to properly lead high Currents



PCB thickness:
1,6 mm



- Standard Copper Thickness 35 µm und 70 µm (point of price)
- 4 Layer Stack up
- Measurement ambience: Air (still room), no enclosure
- Conductor track with a length that presumably shows a stable temperature level without influencing the connected exterior

Varying PCB Parameters		
Conductor width w_c [mm]	different	
Conductor depth d_c [µm]	35	70
Cross Section Area [mm²]	3, 4, 6	4, 10, 16
Heat Conduction layer	yes	no
Type of Heat Conduction layer	different	

- Reasonable diameter to carry high currents
- Conductor width vs. Conductor depth
- Importance of heat conductors
- Amount of copper

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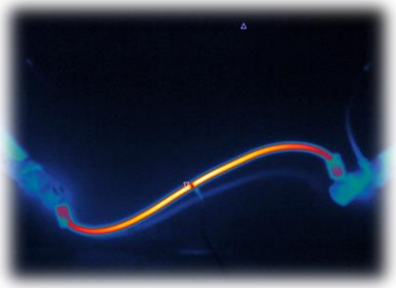
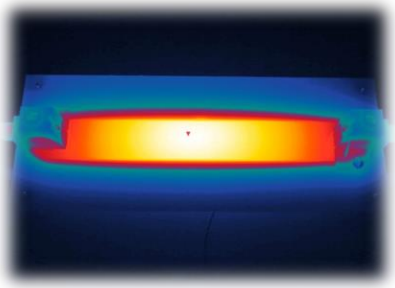
Testing different designs for high current conductors on PCB

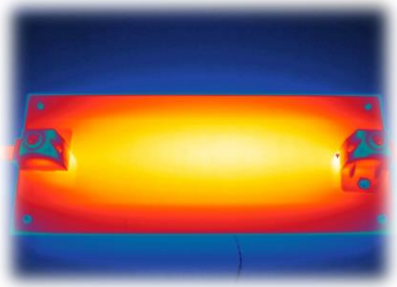
1 Diameter of cable vs.
Diameter of PCB Conductor

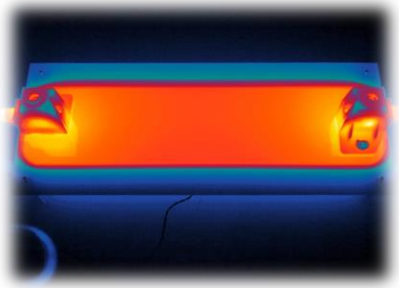


2 PCB with and without heat
Conduction Layers



3 Different Solutions for heat
Conduction Layers
Conductor width vs. Conductor depth





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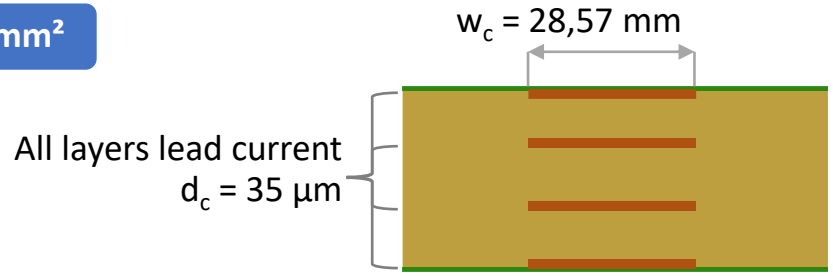
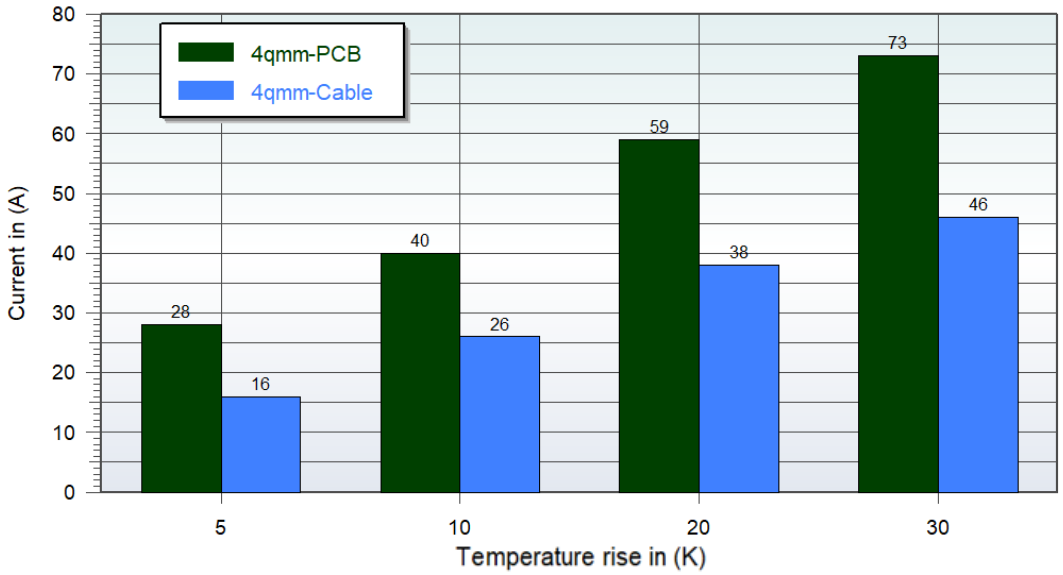
1. Diameter of cable vs. Diameter of PCB Conductor

4 mm²





x = 161 %

Current carrying capacity of PCB Conductor: $x = \frac{PCB}{Cable}$

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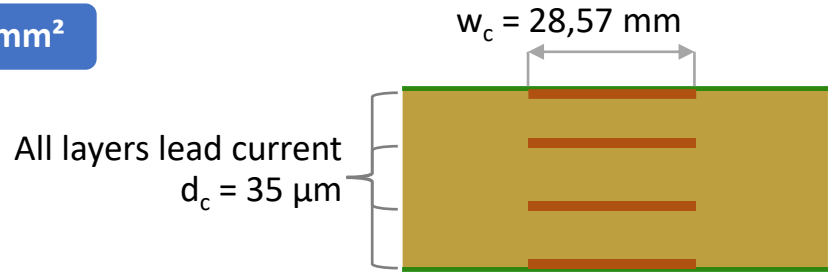
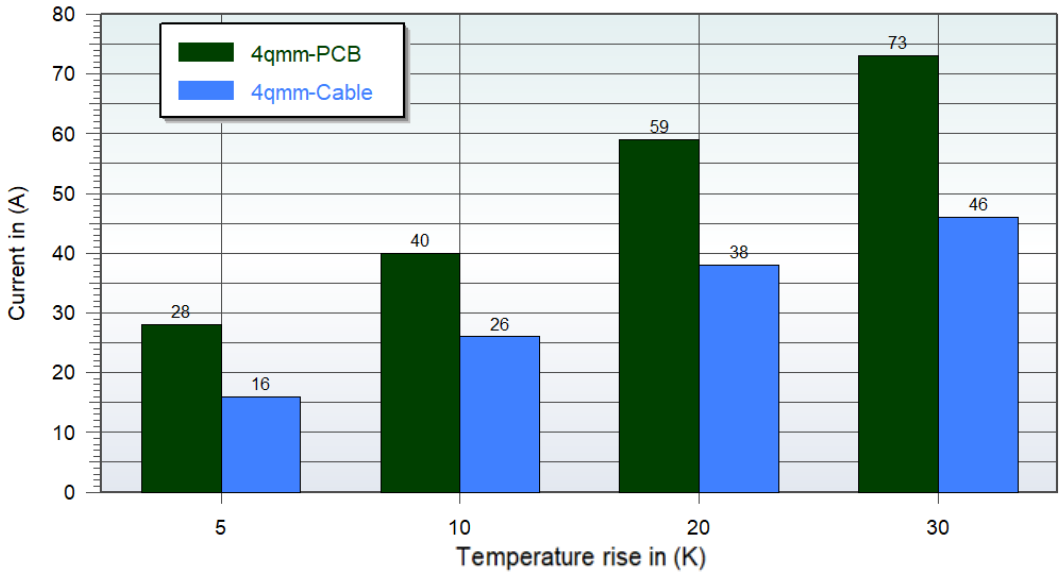
1. Diameter of cable vs. Diameter of PCB Conductor

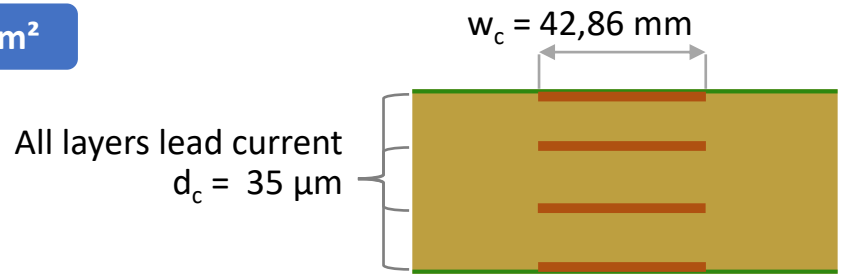
4 mm²

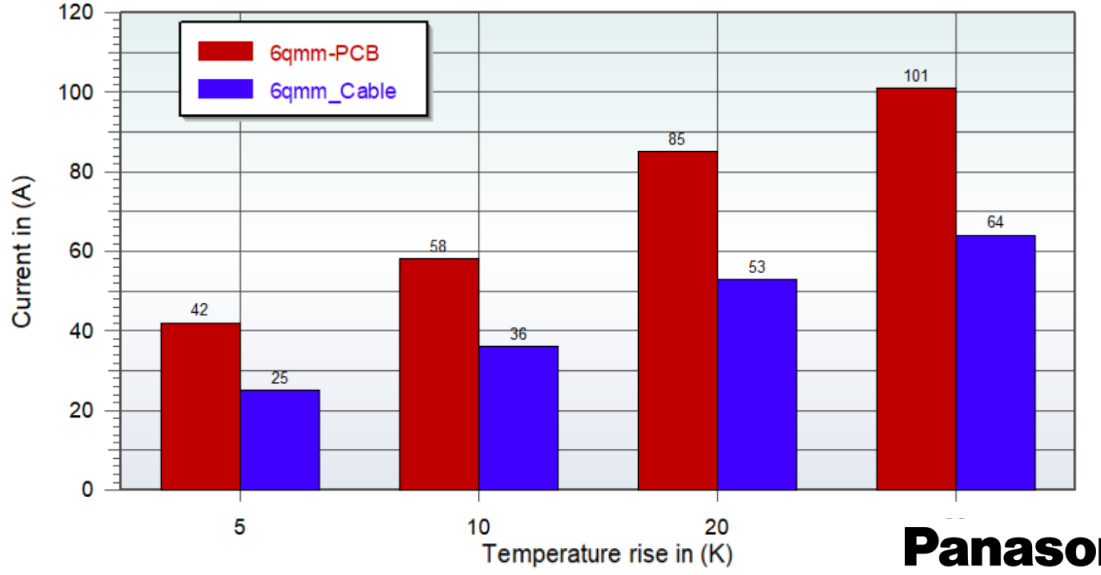




x = 161 %

6 mm²





x = 162 %

Current carrying capacity of PCB Conductor: $x = \frac{PCB}{Cable}$

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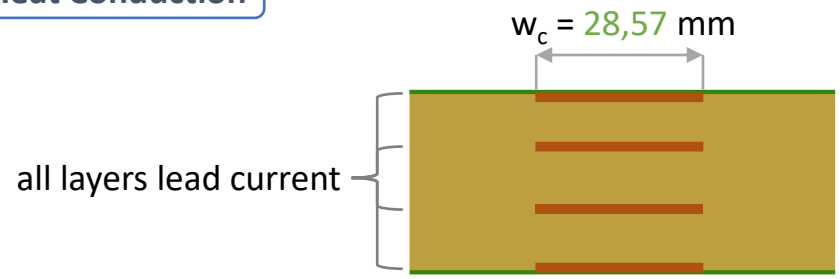
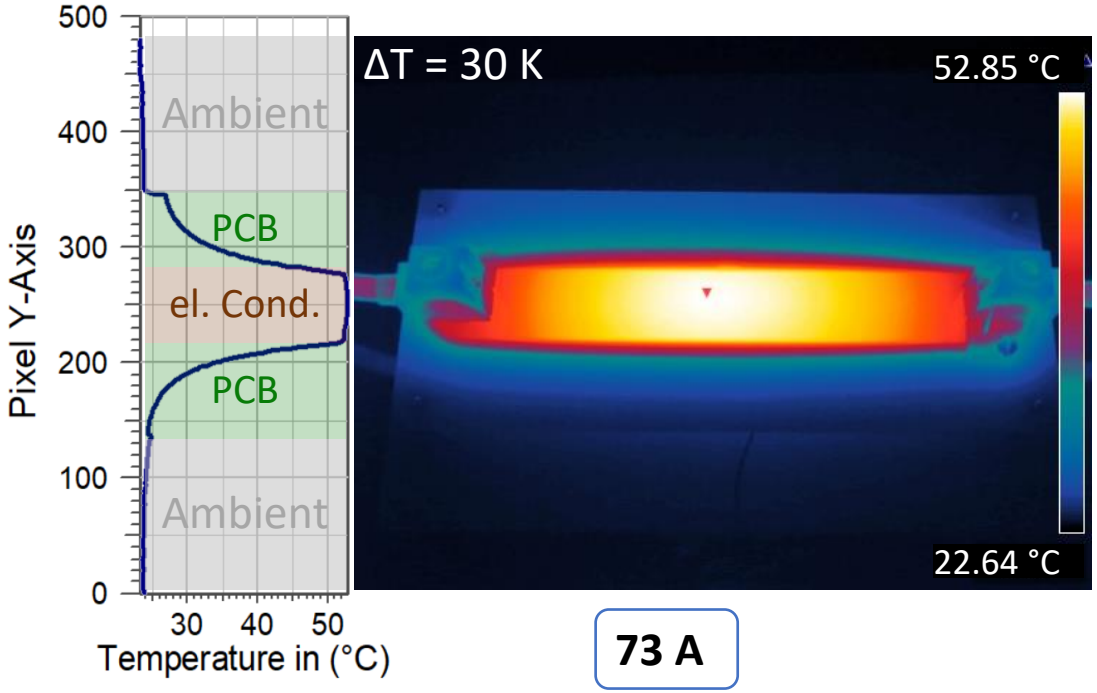
2. PCB with and without heat conduction (same area)

4mm² without Heat Conduction

d_c = 35 µm

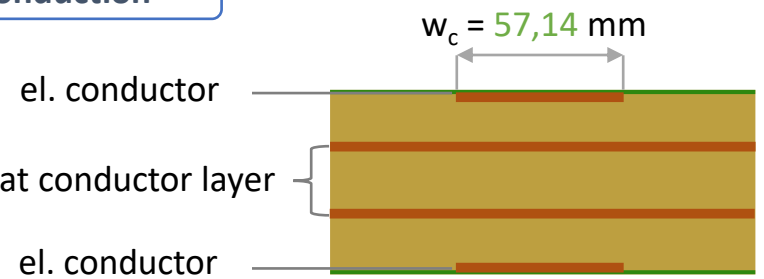


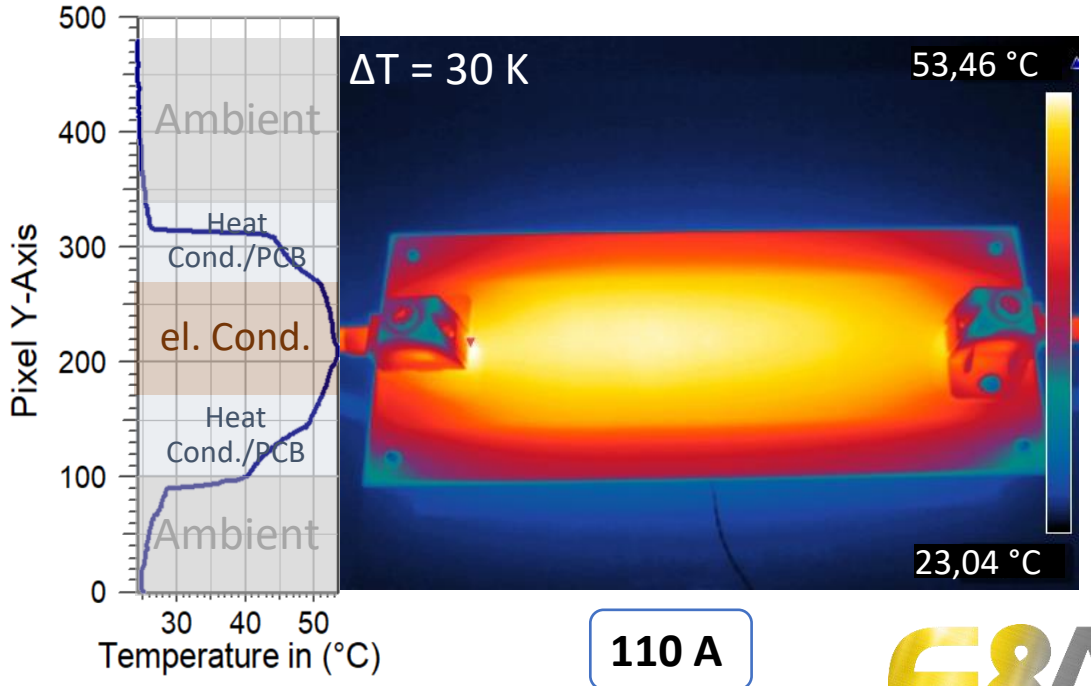


73 A

4mm² with Heat Conduction

d_c = 35 µm





110 A

+ 50 %

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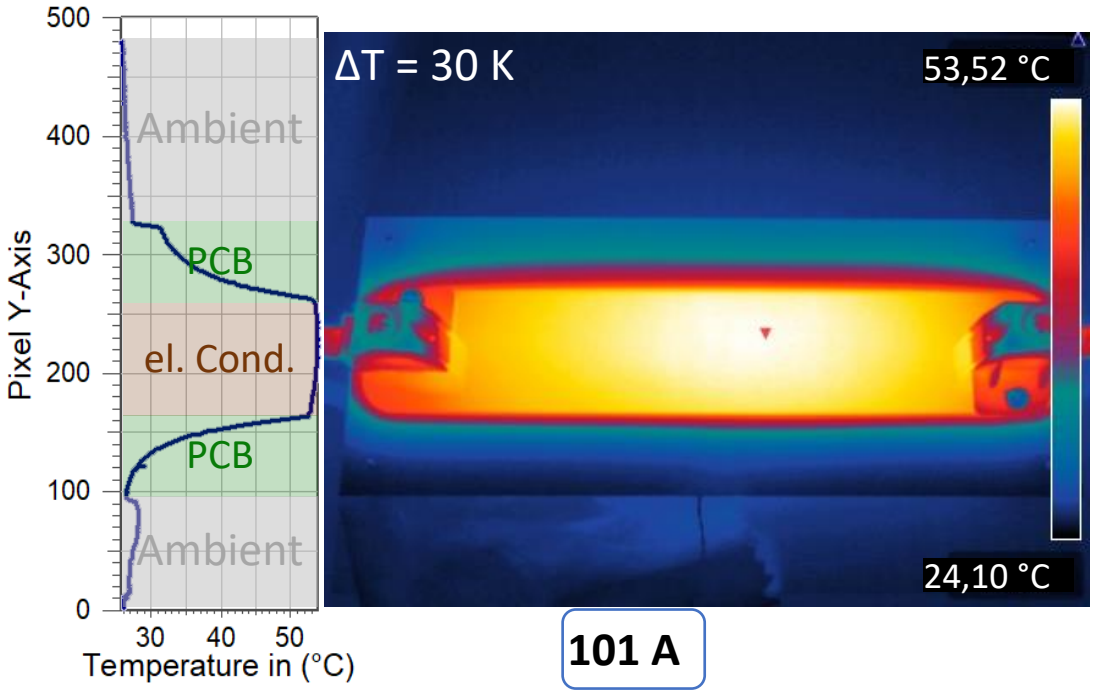
2. PCB with and without heat conduction (different area)

6mm² without Heat Conduction

d_c = 35 µm

w_c = 42,86 mm

all layers lead current



101 A

3mm² with Heat Conduction

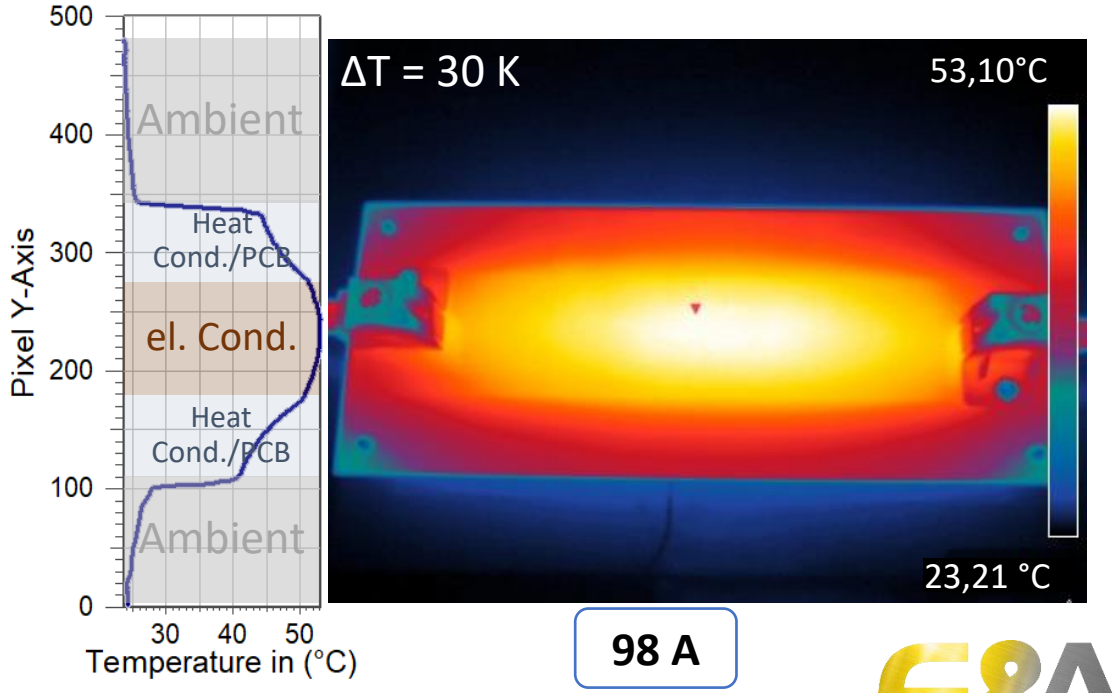
d_c = 35 µm

w_c = 42,86 mm

el. conductor

heat conduction layers

el. conductor



98 A

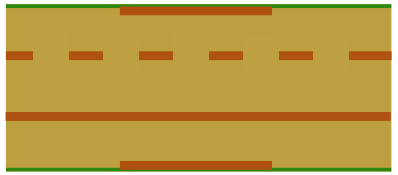
97 % current at 50 % Cable Cross Area

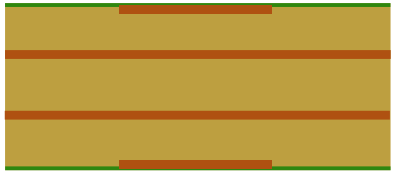
3. Different Solutions for heat conduction / Width vs. Depth

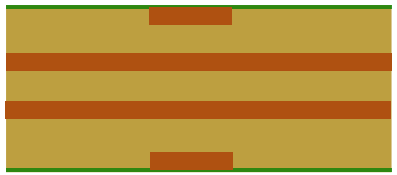
4 mm² with Heat Conduction

	Varying PCB Parameters	
A	Conductor width w_c [mm]	42,86
	Conductor depth d_c [µm]	35
	Type of Heat Conduction	Full + Grid (36%)
B	Conductor width w_c [mm]	42,86
	Conductor depth d_c [µm]	35
	Type of Heat Conduction	Full + Full
C	Conductor width w_c [mm]	28,57
	Conductor depth d_c [µm]	70
	Type of Heat Conduction	Full + Full

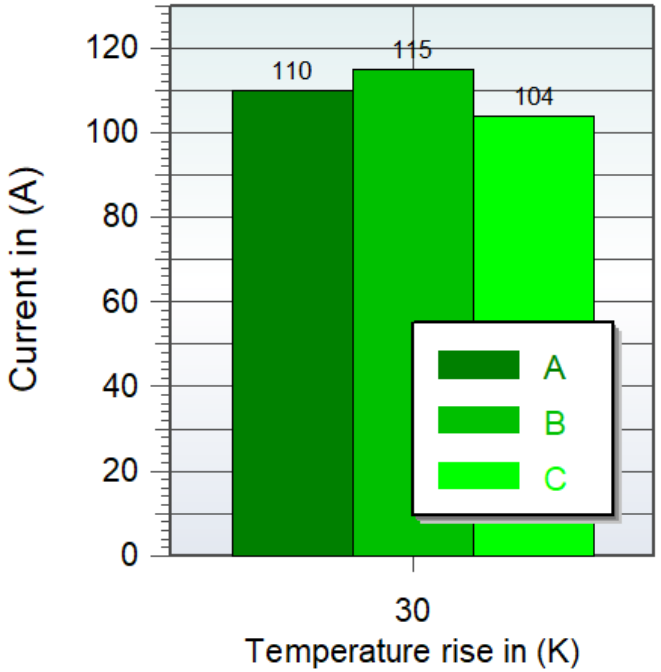
Stack Up







Current Carrying Capability



68 % Heat Conduction Mass leads to 96 % current carrying capability

At same cross section: conductor width is more important than depth!

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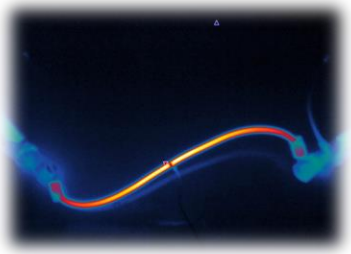
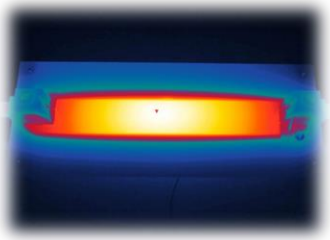
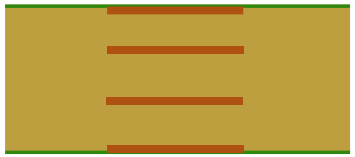
Summary



vs.



PCB showed a 160% better performance % vs. a cable with the same area



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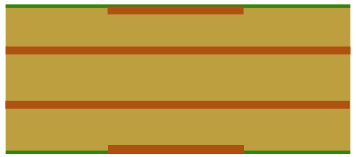
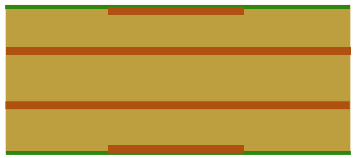
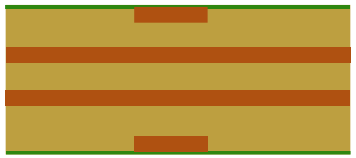


Adding a heat conduction layer improved performance to 150%

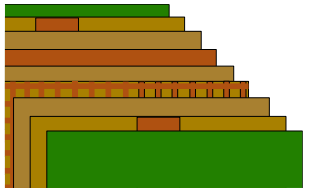
Almost same performance with half conduction area and heat conduction layer



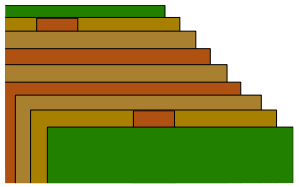
vs.



Width is more important than depth



vs.



Signal layers may not affect the heat conduction much

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