OPENVVVF

DESIGN DOCUMENT

DC Link Thermal Analysis

DC-link capacitor bank standoff heat-path and thermal resistance analysis for Chassis Size 2.

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1. Thermal Analysis - DC Link Module Standoff Heat Path

Heat load at rated ripple was calculated to be 40 W across all capacitors.

1.1. Nomenclature

Symbol	Meaning	Units
	Cross-sectional area (generic)	m²
	Cross-sectional area of one standoff	m²
	Thermal conductivity (generic material)	W/(m·K)
	Thermal conductivity of the aluminium heat-spreader plate	W/(m·K)
	Thermal conductivity of the standoff material	W/(m·K)
	Standoff length (thermal conduction path)	m
	Number of standoffs	-
	Heat flow from capacitor bank ripple current	W
	Effective radius of the aluminium spreading cell around one standoff	m
	Standoff inner (hole) radius	m
	Standoff outer radius	m
	Standoff outer radius (used in spreading model)	m
	Contact resistance across one standoff-to-plate or standoff-to-heatsink interface pair	K/W
	Aluminium heat-spreader plate spreading resistance	K/W
	Standoff conduction thermal resistance	K/W
	Generic thermal resistance	K/W
	Aluminium heat-spreader plate thickness	m
	Temperature rise / difference	K or °C
	Contact resistivity	m²·K/W

1.2. Methodology

All calculations use one-dimensional steady-state thermal resistance:

where

Total system resistance is the sum of three series components:

1. **Standoff conduction**

2. **Contact resistance** (both faces in series)

3. **Aluminium spreading**

1.2.1. Material properties

Material	Thermal conductivity [W/(m·K)]
Aluminium (6063 / generic)	200
Brass (C36000)	120
Copper (C11000)	400
Carbon steel	50
18-8 Stainless steel	16

1.2.2. Contact resistivity values

Condition	Resistivity [m²·K/W]
Dry metal-to-metal	
With thermal paste / thin pad	

1.2.3. Geometry constants

- Heat-spreader plate: 3.18 mm (1/8 in) thick aluminium *(corrected from 4 mm to match the fabricated plate, HW-C2-PLT-CHSP-A; all spreading-resistance values below use 3.18 mm)*
- Standoff length: 55 mm (final design)
- Number of standoffs: 6 (final design)
- Standoff spacing: assumed ~100 mm centre-to-centre (spreading cell radius mm)

1.3. Design Evolution

1.3.1. Initial concepts (for reference)

Configuration	[W/m·K]	Area [mm²]	[K/W]	[°C]	Total (paste) [°C]
8 mm hex brass, hollow M5	120	35.8	2.13	85.4	123
10 mm hex Al, hollow M5	200	67.0	0.684	27.4	53.9
16 mm round Al, hollow M8	200	150.8	0.304	12.2	29.9
16 mm round Al, solid	200	201.1	0.228	9.1	25.8

All at 40 W, 6 standoffs, 55 mm long. Values rounded.

1.3.2. Selected design - 13 mm round aluminium spacers

Final part specification:
- Outer diameter: 13.0 mm
- Inner diameter (M6 clearance): 6.3 mm
(Note: M6 major diameter = 6.0 mm; 6.3 mm ID provides thread engagement or clearance depending on part type)
- Wall thickness: 3.35 mm
- Length: 55 mm
- Material: Aluminium
- Thread: M6 × 1 (male-female or through-hole with bolt)
- Quantity: 6

Cross-sectional area:

1.4. Final Design Calculation

1.4.1. Standoff conduction resistance

1.4.2. Contact resistance (both faces)

With thermal paste:

Dry metal-to-metal:

1.4.3. Aluminium spreading resistance

(Spreading resistance is independent of standoff material; it depends only on plate conductivity, thickness, and cell geometry.)

1.4.4. Total temperature rise

Condition	
With thermal paste	
Dry metal-to-metal	

1.4.5. Absolute temperatures (heatsink base = 40 °C)

Condition	Aluminium plate temperature
With thermal paste	**~80 °C**
Dry metal-to-metal	**~87 °C**

450 V capacitor-only upgrade: The 450 V upgrade is a single part-number swap to 60× Nichicon UCS2W680MHD 68 µF / 450 V capacitors (4.08 mF total). These parts are 5 mm shorter than the 200 V UCS2D331MHD, so the standoff length is reduced by 5 mm (from 55 mm to 50 mm). The same 13 mm OD aluminium standoff thermal path applies, with marginally lower conduction resistance due to the shorter length.

1.5. Sensitivity & Margin

1.5.1. Effect of standoff material

If stainless steel (18-8, W/m·K) were used instead of aluminium:

Total rise would exceed 245 °C. Stainless steel is **not acceptable** for this thermal path.

1.5.2. Effect of quantity

Standoff count	[K/W]	[°C]	Total (paste) [°C]
4	0.677	27.1	52.3
6 (selected)	0.451	18.1	40
8	0.338	13.5	33.9

Six standoffs provides adequate margin; eight would be better but is not required at 40 W.

1.5.3. Effect of length

Length [mm]	[°C]	Total (paste) [°C]
30	9.9	32
55 (selected)	18.1	40
65	21.4	43

1.6. Recommendations

1. **Use aluminium standoffs/spacers only.** Do not substitute stainless or carbon steel.
2. **Apply thermal paste** (or a thin graphite / indium thermal pad) at both the plate-to-standoff and standoff-to-heatsink interfaces. This saves ~6.5 °C and improves long-term thermal stability.
3. **Ensure adequate clamping force** on the M6 bolts to minimize contact resistance. Target ~5–10 N·m on steel bolts into aluminium.
4. **Verify standoff placement** is reasonably distributed across the plate. Uneven distribution will increase local spreading resistance and hot-spot temperatures.
5. **If power increases above ~60 W**, consider upgrading to 8 standoffs or thicker-wall spacers (e.g., 16 mm OD / 6 mm ID).

1.7. Assumptions & Limitations

- One-dimensional conduction assumed; actual 3D spreading may vary ±20 %.

- Contact resistivity values are typical estimates; actual values depend on surface finish, flatness, and clamping pressure.
- Heat generation is assumed uniform across the aluminium plate. Localised hot spots will increase peak temperatures.
- Radiation and natural convection from the plate are neglected; in reality they provide additional heat rejection, so actual plate temperature may be slightly lower.
- Ambient / heatsink base temperature is assumed constant at 40 °C; if the heatsink warms up under load, the absolute plate temperature rises proportionally.

Prepared for DC link module thermal design review.