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 | Ur |
|---|---|---|
| | Cross-sectional area (generic) | m |
| | Cross-sectional area of one standoff | m |
| | Thermal conductivity (generic material) | W |
| | Thermal conductivity of the aluminium heat-spreader plate | W |
| | Thermal conductivity of the standoff material | W |
| | 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/ |
| | Aluminium heat-spreader plate spreading resistance | K/ |
| | Standoff conduction thermal resistance | K/ |
| | Generic thermal resistance | K/ |
| | Aluminium heat-spreader plate thickness | m |
| | Temperature rise / difference | K |
| | Contact resistivity | m |

## 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)

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## 1.3. Design Evolution

### 1.3.1. Initial concepts (for reference)

| Configuration | [W/m·K] | Area [mm²] | [K/W] | [°C] |
|---|---|---|---|---|
| 8 mm hex brass, hollow M5 | 120 | 35.8 | 2.13 | 85.4 |
| 10 mm hex Al, hollow M5 | 200 | 67.0 | 0.684 | 27.4 |
| 16 mm round Al, hollow M8 | 200 | 150.8 | 0.304 | 12.2 |
| 16 mm round Al, solid | 200 | 201.1 | 0.228 | 9.1 |

*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:**

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## 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.

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### 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 |

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## 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).

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## 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.

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*Prepared for DC link module thermal design review.*