Thermal modelling of Raspberry Pi Compute Module 5

Colophon

Release	2
Build date	08/12/2025
Build version	75556ef88b38-dirty

Legal disclaimer notice

Document version history

Release	Date	Description
1.0	01 Dec 2025	Initial release

Scope of document

This document applies to the following Raspberry Pi products:

Compute Modules

CM1	CM3	CM4	CM5
			✓

Contents

Introduction

Raspberry Pi Compute Module 5 (CM5) packs the powerful, feature-rich Broadcom BCM2712 processor into a compact, industry-leading form factor. With such high performance available in such a small package, system designers must adequately address thermal management when using CM5 — particularly in embedded applications.

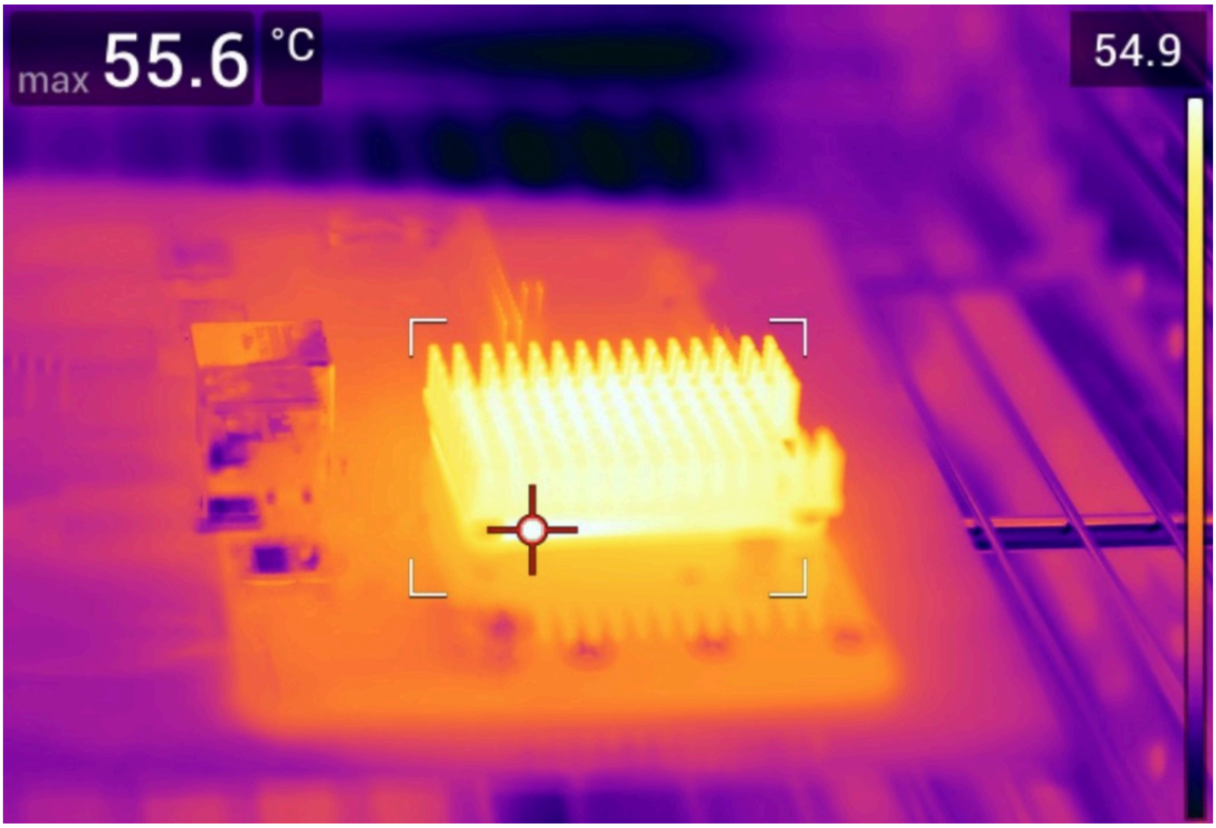
Electronic devices generate heat as a by-product of their operation. Without sufficient thermal management, temperatures may rise to levels that compromise the device's function. CM5 has a built-in protection mechanism that will automatically reduce the clock frequency of the processor to the heat it produces — a feature known as 'throttling'. While this protects the board from damage, it does so by sacrificing compute performance, which is not an ideal solution for those wanting to get the most out of their module.

Prolonged overheating can also degrade component performance, reducing the product's lifespan. In the most severe cases, extreme heat exposure may cause abrupt component failure. The objective of thermal management is therefore to keep a device running within its optimal operating temperature range, preventing throttling and ensuring CM5 performs at its best.

This white paper is intended for design engineers integrating a CM5 platform into an embedded solution, helping them understand the heat produced during its operation. It also supports the development of a thermal resistance network model for CM5's processor, as well as its supporting circuit board material.

The processor generates more heat than every other component on CM5 and must be the focus of any thermal model. Properly managing the heat produced by the processor will provide effective thermal management for the entire module.

Figure 1.
Informative: Thermal image of CM5 and heatsink during thermal stress test



Modelling

The data provided in this white paper may be used to model a thermal resistance network for CM5's processor and PCB. Information on the Raspberry Pi Cooler for Compute Module 5 is included as an optional addition. The materials used to make these components, as well as their thickness and thermal conductivity, are provided; a method of reading the power consumption of the processor is also given.

The model estimates the heat generated by CM5 during operation — at peak performance, the most heat will be produced. The model shall assume that all power consumed by the processor is converted to heat. The power consumption of the processor can be measured using the following CM5 power measurement script.

Processor Junction Temperature

The operating temperature of the processor's silicon (T_j) is the value used to implement throttling. Throttling occurs when the inbuilt monitoring system detects that T_j values have risen above known safe limits; these limits are programmed into CM5. More information can be found here. Maintaining an acceptable T_j value is key to ensuring the optimal performance of CM5.

T_j can be viewed: `$ vcgencmd measure_temp` or monitored continually using `$ watch -n 1 vcgencmd measure_temp` .

Managing the thermal performance of CM5 so that it does not throttle will preserve the thermal lifespan of other components on the board, while also ensuring that all computing power remains available to the system. Thermal performance can be modelled using the arrangement that follows.

Cross-section of the processor and PCB hardware stack

The cross-sectional makeup of the PCB and processor is shown below:

Figure 2.
Cross-section of CM5's PCB and Broadcom BCM2712 processor

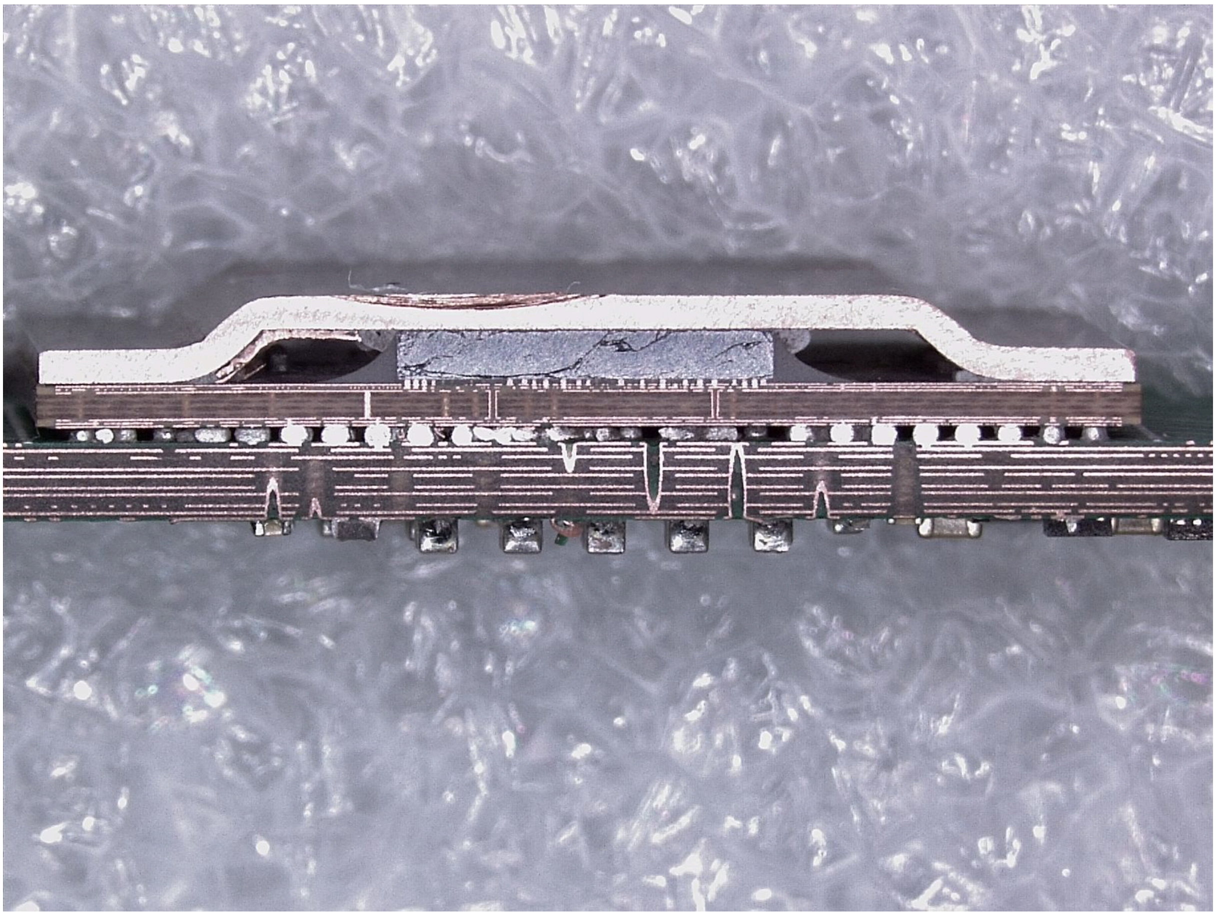


Figure 2 shows the construction of a CM5 that has been sliced in half. At the bottom of the image, the PCB can be seen, with an interface for the processor. Above this is the processor package, including the PCB substrate and silicon encapsulation. The top layer shows the processor's heat spreader.

This image is illustrated below to better describe the stack of hardware components.

Illustrated hardware stack

Figure 3.
CM5 hardware stack

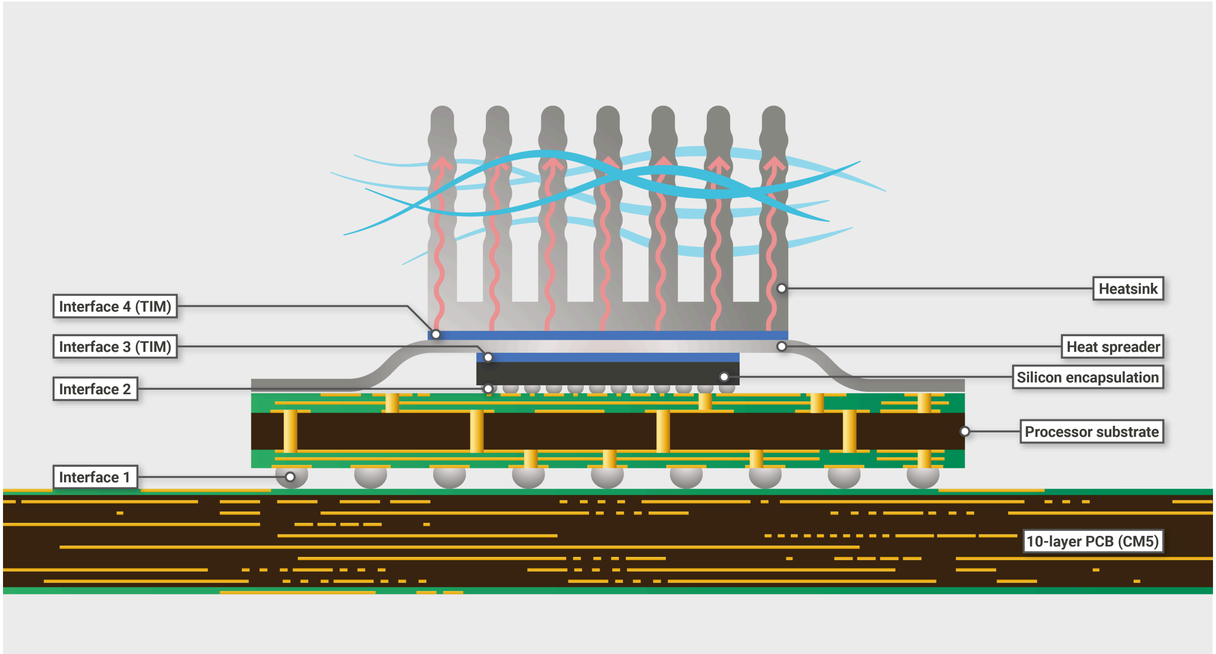


Figure 3 shows CM5's hardware stack. Electrical connections between the processor and the PCB are made using a ball grid array (BGA), which is fused in position during manufacture. In this illustration, a heatsink has been added to help describe the thermal model; this can be seen at the top of Figure 3.

Heat from the processor originates at the bottom of the processor's silicon encapsulation, then propagates through the stack to the top of the heatsink and the bottom of the PCB. The thermal properties of these elements are given in the table below.

Heatsink and processor thermal properties

Description	Layer name	Thinkness (mm)	Material	Conductivity (W/mK)
Top of CM5 — free in space or inside an enclosure				
Heatsink (see Figure 3)	Heatsink 1	5	Aluminium	235
Heat Spreader to Heatsink Interface	Interface 4	0.5	Thermal Pad	3
Heat spreader	Processor 13	0.5	Stainless Steel	15
Processor to heat spreader interface	Interface 3	0.1	Thermal Adhesive	1
Processor silicon encapsulation	Processor 12	0.8	Silicon	140
Processor PCB to silicon encapsulation	Interface 2	0.04	Lead-free solder	58.7
Processor package substrate conductor	Processor 11	0.015	Copper	385
Processor package substrate insulator	Processor 10	0.01	Bismaleimide-triazine–based substrate	0.2
Processor package substrate conductor	Processor 9	0.015	Copper	385

Description	Layer name	Thinkness (mm)	Material	Conductivity (W/mK)
Processor package substrate insulator	Processor 8	0.1	Bismaleimide-triazine–based substrate	0.2
Processor package substrate conductor	Processor 7	0.015	Copper	385
Processor package substrate core (insulator)	Processor 6	0.4	Bismaleimide-triazine–based substrate	0.2
Processor package substrate conductor	Processor 5	0.015	Copper	385
Processor package substrate insulator	Processor 4	0.01	Bismaleimide-triazine–based substrate	0.2
Processor package Substrate Conductor	Processor 3	0.015	Copper	385
Processor package substrate insulator	Processor 2	0.01	Bismaleimide-triazine–based substrate	0.2
Processor package substrate conductor	Processor 1	0.015	Copper	385
PCB to processor interface: BGA	Interface 1	0.4	Lead-free solder	58.7,
PCB solder mask	PCB 21	0.015	Polymer resin	0.2
PCB conductor	PCB 20	0.047	Copper	385
PCB insulator	PCB 19	0.057	FR-4	0.343
PCB conductor	PCB 18	0.03	Copper	385
PCB insulator	PCB 17	0.072	FR-4	0.343
PCB conductor	PCB 16	0.029	Copper	385
PCB insulator	PCB 15	0.150	FR-4	0.343
PCB conductor	PCB 14	0.029	Copper	385
PCB insulator	PCB 13	0.07	FR-4	0.343
PCB conductor	PCB 12	0.029	Copper	385
PCB insulator	PCB 11	0.150	FR-4	0.343
PCB conductor	PCB 10	0.029	Copper	385
PCB insulator	PCB 9	0.07	FR-4	0.343
PCB conductor	PCB 8	0.029	Copper	385
PCB insulator	PCB 7	0.15	FR-4	0.343
PCB conductor	PCB 6	0.029	Copper	385
PCB insulator	PCB 5	0.072	FR-4	0.343
PCB conductor	PCB 4	0.03	Copper	385
PCB insulator	PCB 3	0.057	FR-4	0.343
PCB conductor	PCB 2	0.047	Copper	385
PCB solder mask	PCB 1	0.015	Polymer resin	0.2
Bottom of CM5 — free in space or inside an enclosure				

Mitigation

Following the thermal modelling of CM5, it may become evident that the processor will produce too much heat to remain stable. Designers must ensure that the excess heat is able to escape from CM5. Our comprehensive guide on "Cooling a Raspberry Pi Device" provides useful mitigation suggestions.

All designers must ensure that the top and bottom surfaces of the heatsink and PCB have room for adequate airflow, allowing heat to be removed through conduction and convection. Where physical constraints of the design prevent suitable airflow, it is possible to reduce overheating by underclocking the processor; this will, however, reduce the performance of the module. It is not recommended that CM5 be left to self-regulate using protective throttling.

Contact Details for more information

Please contact applications@raspberrypi.com if you have any queries about this whitepaper.

Web: www.raspberrypi.com

Raspberry Pi