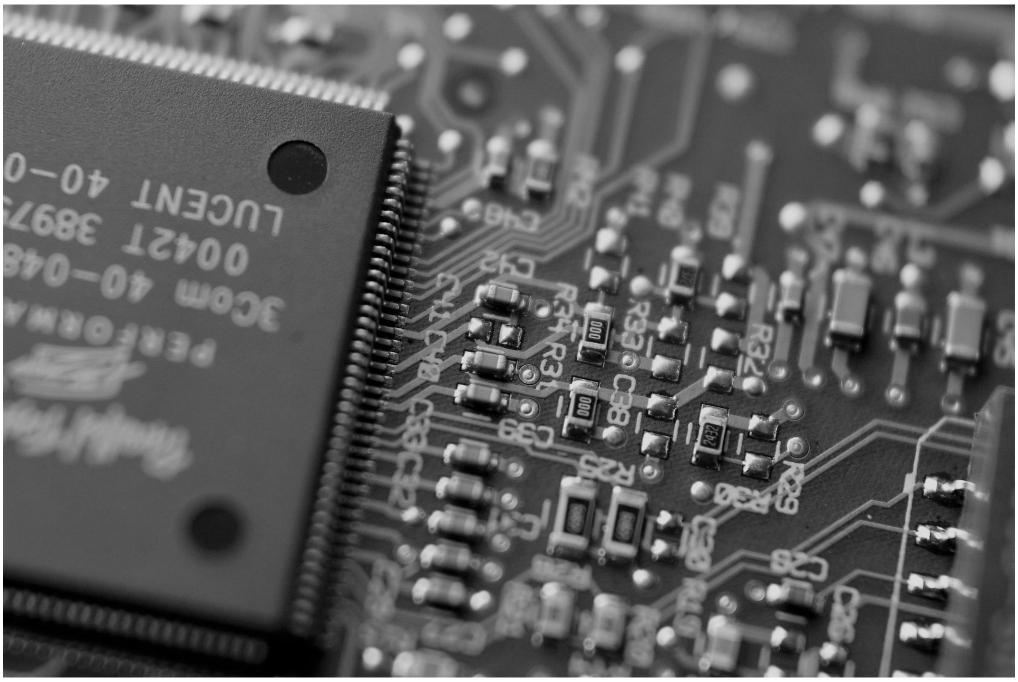
Independent analysis of thermal performance of HF$_x$ compute unit



HF$_x$ Computing AB

December 1, 2022

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1. Background

HF_x Computing AB, a subsidiary company of HydroFlux AB, is a leading manufacturer of multi-purpose compute solutions for real-time calculation and autonomous decision making in industrial systems. The company is currently developing a new compute unit, the HF_x BladeEdge[1], due for inclusion into the HydroFlux suite of industrial solutions. The new compute unit shall act as a control unit for real-time regulation of automated systems. The goal is to provide a scalable and effective solution for deployment in situations where server grade equipment is not suitable due to cost and space constraints.

2. Project specification

The product is currently in early development. The thermal performance of our prototype must be validated by experts outside of our test facilities before production can start. We provide two of these prototype units for your evaluation of the thermal performance.

Currently, two microchips are missing on the prototypes. These additional components will, when added to the circuitry, enable intra- and intercommunicational capabilities to enable the scalability we wish to offer customer. HF_x Computing AB have unfortunately stumbled upon a complicating matter. The microchips are yet to arrive at our research and development center due to production delays at our subcontractor facilities. Since the project is nearing its deadline, we wish to do preliminary, virtual testing of thermal performance as we wait for the final components to arrive.

Hence, we offer your expert group this contract to create an accurate, virtual representation of the provided circuit board and its thermal performance using finite element method (FEM) software[2]. To achieve this, you will have to make temperature measurements on the prototype and use those measurements to verify that your virtual model is accurate. We also want you to add the missing components to the model and deliver a suggestion for where the microchips should be placed on the circuit board to ensure optimal efficiency. See Section 3 for full list of requirements.

We also provide you with a few FLIR® TG267 thermal cameras for temperature measurements. Details about the construction and components will now follow.

2.1 Prototype construction details

Note: The printed circuit board (PCB) and mounted components are material properties of HF_x Computing AB. They have been covered with black masking

[1] Working name
[2] preferably COMSOL Multiphysics®

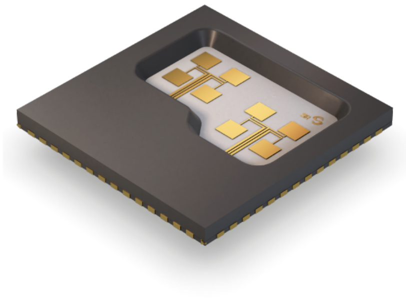


Figure 1: 3D-render of microchip with cross section showing internal layout.

to prevent the possibility of reverse engineering of the provided prototype. The masking should at no point be removed.

The PCB consists of two layers; one FR4-layer with thickness 1.5 mm followed by a 35 μm thick copper layer on the underside of the circuit board. The planar dimensions of the PCB is 30×20 cm^2. Four central processing units (CPUs) are mounted on top of the FR4-layer. They are encapsulated by aluminium housing with dimensions $30 \times 60 \times 10$ mm^3. Their relative positions on the PCB must be measured by hand to ensure model accuracy. Note also that microchips **cannot** be mounted on the underside of the circuit board.

2.2 Thermal design of CPUs

The four CPUs mounted on the prototype are of two different variants, each tailored for different types of real-time calculations. One variant generates slightly more heat than the other one, and is rated at 3 W of heat per unit volume, compared to 2 W of heat per unit volume. The CPUs, and all other components on the PCB, are passively cooled (i.e. through natural convection) by air at room temperature. The heat transfer coefficient for natural convection must be estimated at your facilities such that your simulated model can recreate your experimental measurements.

2.3 Microchip specifications

To enable high-speed inter-connectivity of multiple compute units, we wish to add two microchips, shown in Figure 1, to the current prototype. The microchip model which HF_x Computing AB has selected for this purpose is in itself a product from one of our subcontractors. The microchip has dimensions $30 \times 30 \times 3$ mm^3. Note that the external material of the microchip is silicone - it has no external casing. While additional details of the microchip and its internal layout are classified, we have received information about its heat generation, which is rated at 1.5 W of heat per unit volume. In addition, the efficiency of the microchip, and by extension the communications bandwidth that it provides, is dependent on the distance to adjacent components and on temperature. Hence, the efficiency η of the microchips can be described by

$$\eta(r,T) = \eta_r(r) \cdot \eta_T(T), \tag{1}$$

where η_r and η_T are the separated dependencies on distance to the nearest CPU and temperature respectively. The separated efficiencies have each been measured experimentally. When acquiring these measurements, the chip was placed at a position/temperature such that maximum separated efficiency was ensured with regards to temperature/position, see Appendix A.

2.4 Further development

At $\mathrm{HF_x}$ Computing AB, we wish to provide our customers with products and services of the highest quality. Therefore, based on the virtual model, we would like to investigate possible modifications to the current prototype that will improve the thermal performance. This process is trivial with an accurate FEM-model in hand. With an accurate model, you will be able to easily change materials, add cooling components, change environmental conditions etc. Feel free to test *anything and everything* - your findings may be helpful in developing future revisions.

3. Project order

In summary, to continue the development of $\mathrm{HF_x}$ BladeEdge and possible future revisions, it is invaluable to have a computer model of the system where different situations and ideas can be tested directly. Therefore, $\mathrm{HF_x}$ Computing AB wants you to construct a 3D FEM-model that simulates the provided prototype. Additionally, we want you to use the model to answer some questions of great importance to the company.

We require a high-quality and well-structured technical report (maximum 6 pages), where we wish for you to provide your results and answer the questions stated below. The focus group of the report will be technical engineers working with the computing unit, so there is no need for an in-depth methodology. Do however make sure to include a short project introduction, as the report may be handled by employees not directly working with the project.

A. The numerical model:

- Results from experimental measurements, including uncertainties, presented in a suitable way
- Comparisons between your experimental measurements and respective results from the FEM-model
- Estimated value for the heat transfer coefficient for natural convection in your test facility, used in your FEM-model

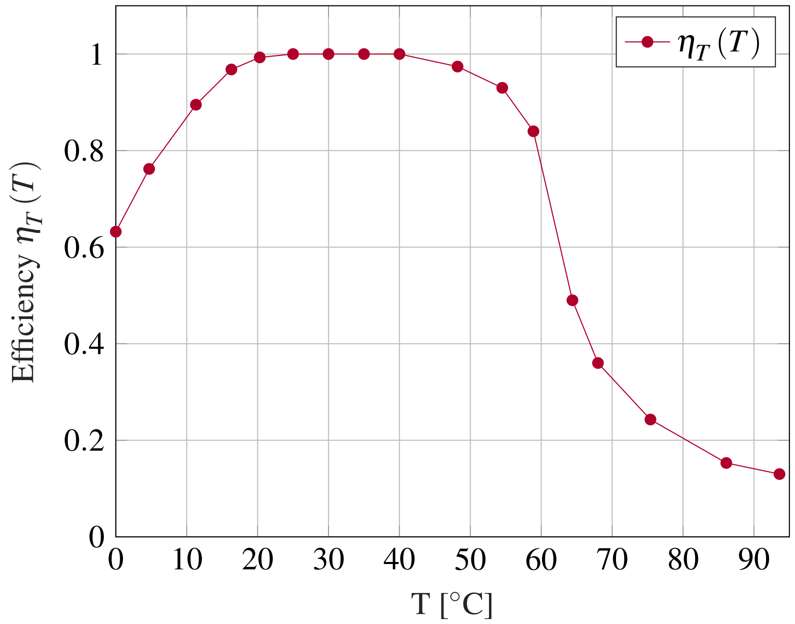
B. Virtual design and analysis:

- Add the two microchips to your numerical model
- Where should the two microchips be placed on the PCB to ensure the best possible efficiency of the microchip(s)?
- Are there any choices with regards to material and operating environment that can be made to improve (thermal) performance?

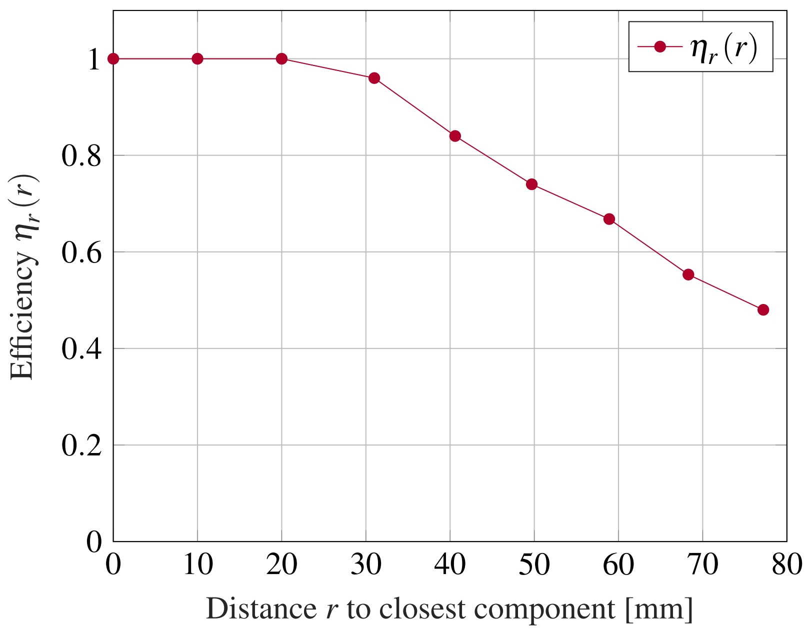
C. Actions:

- A suggestion on where to place the microchips and any possible performance-improving modifications the prototype
- What are the advantages and disadvantages of those actions?
- Which of the actions do you recommend HydroFlux AB, and what are your arguments for those recommendations?
- Any observations on how your FEM-model can possibly be improved

A. Efficiency of microchip



(a) Temperature dependent part



(b) Distance dependent part

Figure A.1: Measured efficiencies of the microchip. The total efficiency is described by Equation (1). Note that the temperatures over 95 °C cause thermal throttling, heavily impacting performance.