TALLINN UNIVERSITY OF TECHNOLOGY

LABORATORY PRACTICE INSTRUCTIONS

IEE1860 – BIOMEMS

LAB 6: HEAT TRANSFER SIMULATION

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CONTENTS

1 INTRODUCTION

This lab is based on the journal paper titled "Development of a Low-Cost, Wireless Smart Thermostat for Isothermal DNA Amplification in Lab-On-A-Chip Devices", published in 2019 by T. Pardy et al. We will perform simulated thermal analysis and verification on a Lab-on-a-Chip system. The purpose of this lab is to show the full potential of simulation as a tool in Lab-on-a-Chip system design. As stated during lectures, to make sure your simulation model gives you valid results, you must first verify it against experimental data. We will use experimental data from the publication as the basis of our analysis and will derive more information from the simulation than what would be possible to measure.

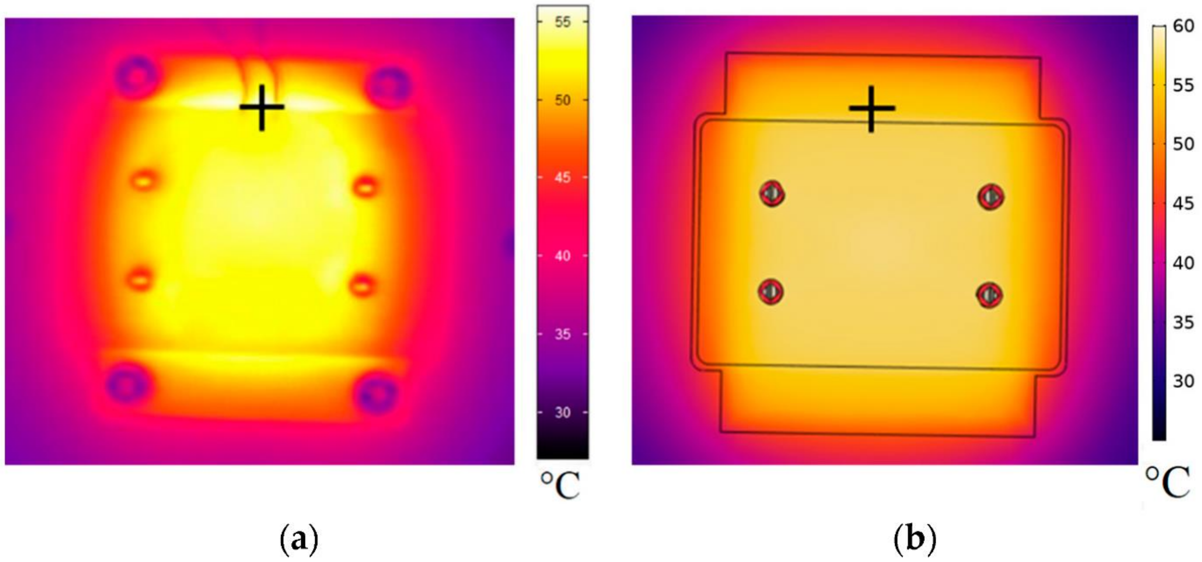

FIGURE 1: INFRARED IMAGE (LEFT) COMPARED TO SIMULATED THERMAL DISTRIBUTION (RIGHT).

2 METHODOLOGY

2.1 SETUP

The Lab-on-a-Chip system we simulate is a thermostat made for heating microfluidic cartridges 2 cm x 3 cm in size, holding 0.05 mL liquid. The system (Figure 2) consists of:

- Enclosure and user interfaces (I. and II.)
- Microfluidic cartridge (III.)
- Heater (IV.)
- Electronics assembly (V.) and battery (VI.)
- Plastic cover (VII.), which insulates the microfluidic cartridge

A thermistor is inserted in the microfluidic cartridge to measure reaction temperature. The simulated model is defeatured compared to the experimental setup. Unnecessary features (bolts, screws, filleting etc.) are removed to save memory with the goal of retaining a similar thermal mass.

The thermal model is described in detail in Section 2.3 of the original publication (link). All modes of heat loss are added to the model and the heater is defined as a constant temperature boundary condition. This is done to make the model faster to solve. We simulate in steady state, performing a stationary simulation. We measure the temperature inside the model at the approximate site of the thermistor in the physical device. Furthermore, we calculate how much of the reaction liquid volume is in the correct temperature range (defined as ±1 °C from the set point.)

Note: The option exists to simulate a thermal transient and perform thermal transient analysis on 3D models, but that approach requires significantly more memory and time to solve, and also needs a far more thorough verification. For an example for that, please see [this publication](#).

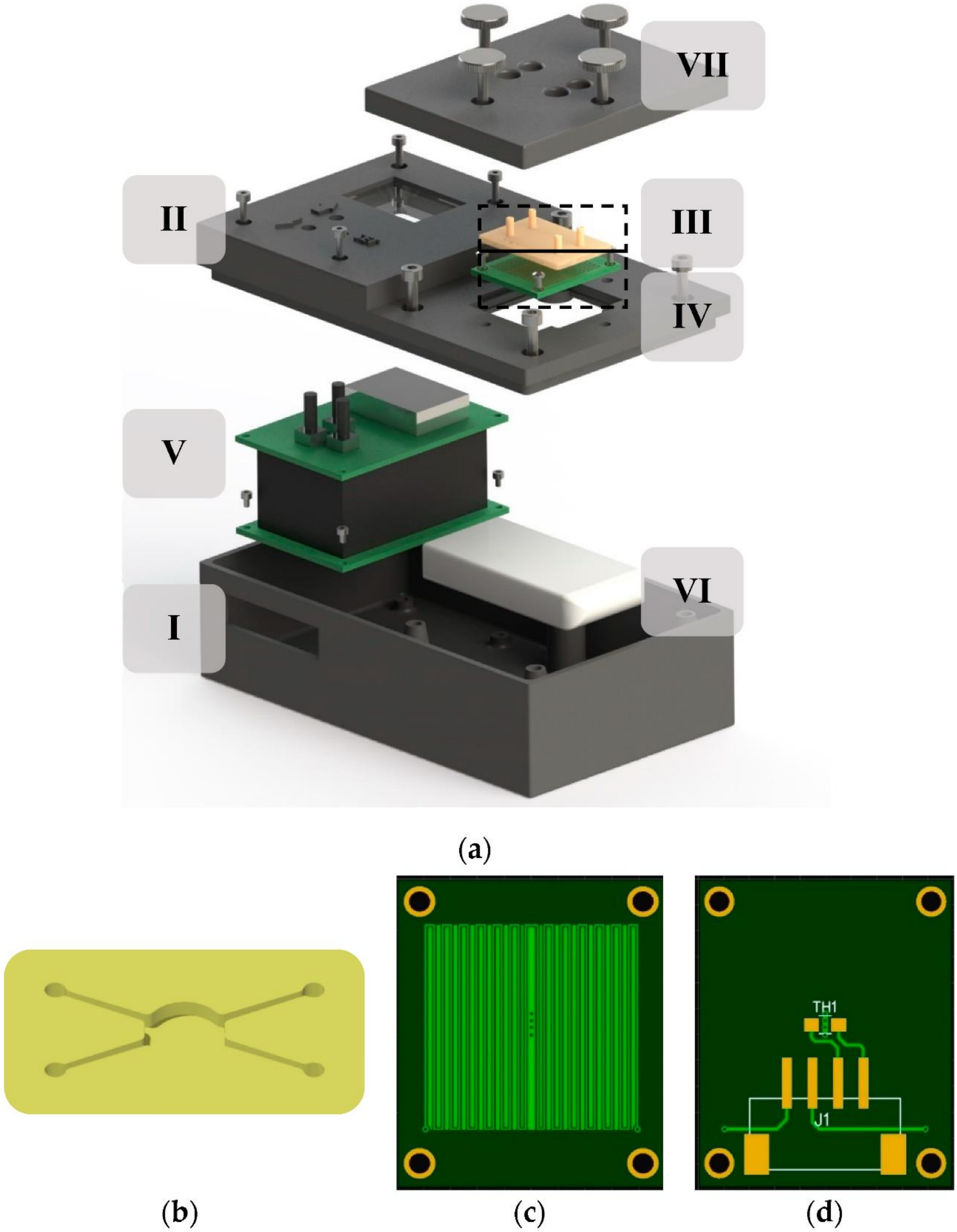

FIGURE 2: LAB-ON-A-CHIP SYSTEM SIMULATED IN THIS LAB

2.2 VERIFICATION

The thermostat was designed to support isothermal nucleic acid amplification protocols. Each of these protocols needs a specific temperature range in the reaction liquid in order to work. The protocols we will verify against cover the widest possible range of targets:

NAAT Protocol	Target Range (°C)	Set Point (°C)	Experimental Steady-State (°C)	Steady-State Power (W)
RAM	35	35	34.52	0.18
RPA, BAD AMP	37–42	40	39.37	0.26
SPIA	45–50	45	44.83	0.37
	45–50	50	49.63	0.49
EXPAR, NEAR	55–55	55	54.92	0.59
TMA, ICA, PG-RCA	60	60	59.54	0.71
LAMP, CPA, NEMA	65	65	64.54	0.81

You will find the same table in the Excel file in Moodle. This is where you will need to add your solution. The verification will also include an analysis of the volumes within the target range using the following formula:

$$\eta = 50 \cdot \frac{1}{n} \sum_{i=1}^{n} \left(\left(T_i > (SP - 0.5)\ (°C) \cap T_i < (SP + 0.5)\ (°C) \right) \in \{0; 1\} \right) \quad (1)$$

where SP denotes the set point, Ti denotes temperature values for each finite element, n the total element number and $\eta \in [0; 50] (\mu L)$.

3 BUILDING THE BASE MODEL

Please watch the video on constructing the model: **Link**.

4 EXERCISES

1. Implement Eqn. 1 by adding 3 formulas as **Variables** (Right click on Component 1 > Definitions, then click Variables). The temperature variable from the **Heat Transfer in Solids** physics interface is denoted ***T***, the heater set point is ***HT_T***.
   Hint: Vol_inRange = (HT_T - 0.5 <= T && T <= HT_T + 0.5)
2. Add a new **Domain Probe** to calculate the volume in range based on Eqn. 1. As the expression provide the variable defined in the previous step.
3. Add a **Parametric Sweep** for the heater set point (**HT_T**).
   Hint: *Parameter value list: 30,35,40,45,50,55,60,65, Parameter unit: degC*

If you need help, watch the second video on how to do the above steps.

In the end, you should create a graph with the same layout as is shown in Figure 3.

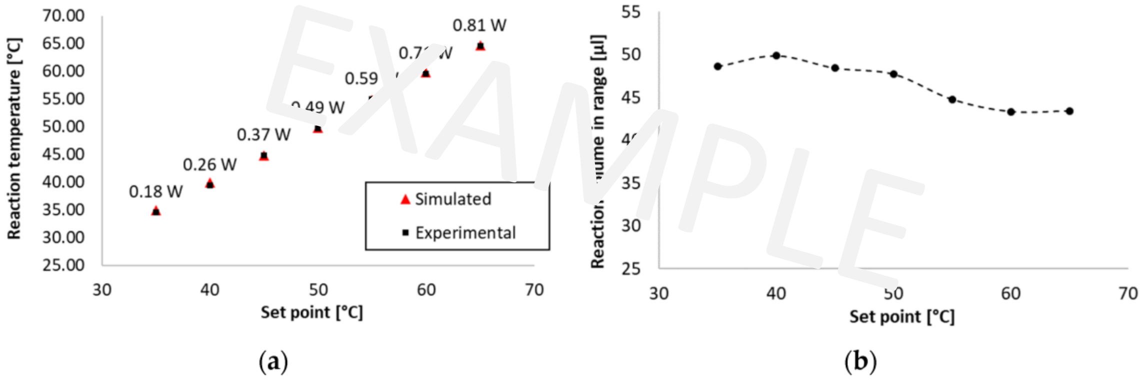

FIGURE 3: SIMULATED VS. EXPERIMENTAL STEADY-STATE REACTOR TEMPERATURES (LEFT) AND CORRESPONDING SIMULATED REACTION VOLUME IN RANGE (RIGHT)