EPD Core Course – Term 5

2D DESIGN PROJECT
30.100 & 30.101

30.100 – Computational and Data-Driven Engineering
30.101 – Systems & Control

2D Design Project
Peltier-Based Vaccine Cooling System

Assoc. Prof. NAGARAJAN RAGHAVAN
EPD Pillar, 1.302-35
Email – nagarajan@sutd.edu.sg
TA: Balaraman Rajesh Kumar
Email: rajesh_balaraman@mymail.sutd.edu.sg

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

ENGINEERING PRODUCT DEVELOPMENT

2D Design Project – Admin Matters

- Maintain the same groupings as your 1D design project.
- Maximum number of students per team ~ **5-6**.
- Students can form teams from across Cohorts too!
- Each team should nominate a "lead" who takes charge of organizing meetings, managing/reviewing the progress and allocating team responsibilities equally to the members.
- Students who are unable to be part of any group should inform, TA, Rajesh.
- The 2D project will be handled by TA, Rajesh (for 30.100) in the Dyson Lab. He will assist you in the basic setup of the hardware, so please approach him for any difficulty you may have in getting started.

2D Design Project – Theme – PELTIER BASED VACCINE COOLING SYSTEM

- Improper handling and the failure to maintain vaccines in a safe temperature range results in significant losses of vaccines.
- For **vaccine refrigeration** and delivery at the end stage of the cold chain, **active thermoelectric cooling** is a potentially viable alternative because the coolers are small and require few or no moving parts.
- A **vaccine cooling system** can be constructed employing a Peltier-based thermoelectric chip (TEC) affixed to an aluminum block that holds the vaccine vials; a heat transfer compound can be interposed between the block and the TEC for effective exchange of heat between the TEC and the vaccine holder.
- One end of the TEC will be cold while the other end will be hot. The heat generated on the other end of the TEC can be transported away through a remote heat exchanger serving as a "*Heat Sink*".
- With this cooler, we are hoping that vaccines can be maintained at a required temperature ranging around 12-15˚C.

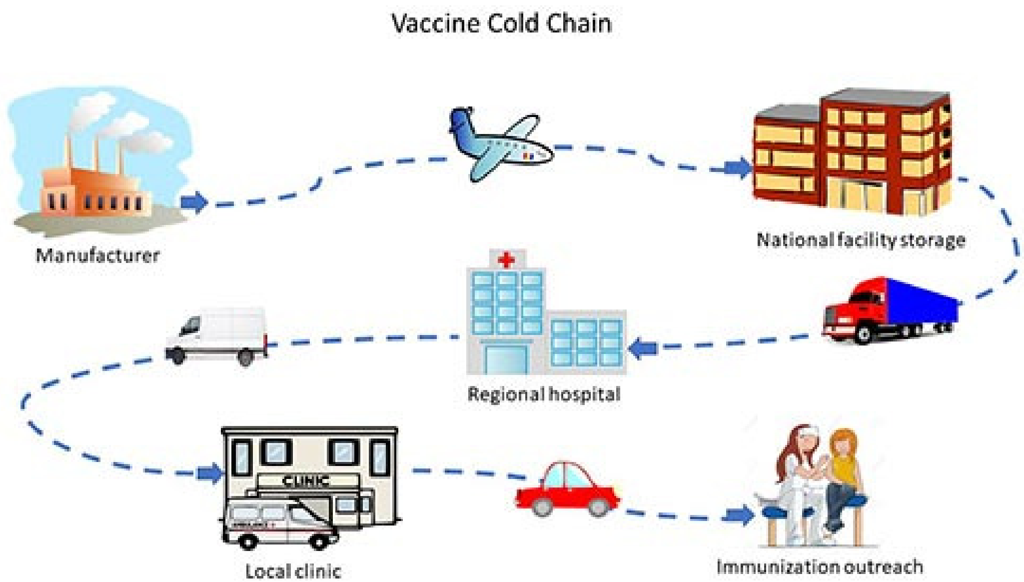
Listing of Causes and Effects that Would Impact A Vaccine Thermostat

Causes

- Temperature Sensitivity of Vaccines
- Inadequate Cold Chain Infrastructure
- Emergency Situations and Outreach Programs
- Energy Efficiency and Sustainability

Effects

- Enhanced Vaccine Storage and Transportation
- Increased Vaccine Accessibility
- Better Emergency Response
- Reduced Vaccine Wastage
- Innovation and Technological Advancement



Critical Engineering Problems to Solve in Designing the Cooling System

- How might we design a system to continuously and accurately measure or “sense” the vaccine temperature from outside without directly contacting it?

- Discuss with your team members how the partial differential equation (PDE) models as well as the Python Codes associated with them can be applied for effective decision making and designing and accurate analysis of the cooling system?

- Vaccine thermostat requirements
  - Control temperature between 12^0C and 15^0C
  - Time it takes to stabilize vaccine temperature within the 12^0C to 15^0C range down from the room temperature.

- How would you design the cooling system taking advantage of the ***aluminium*** and / or ***acrylic*** slabs provided considering that they have very different thermal conductance properties?

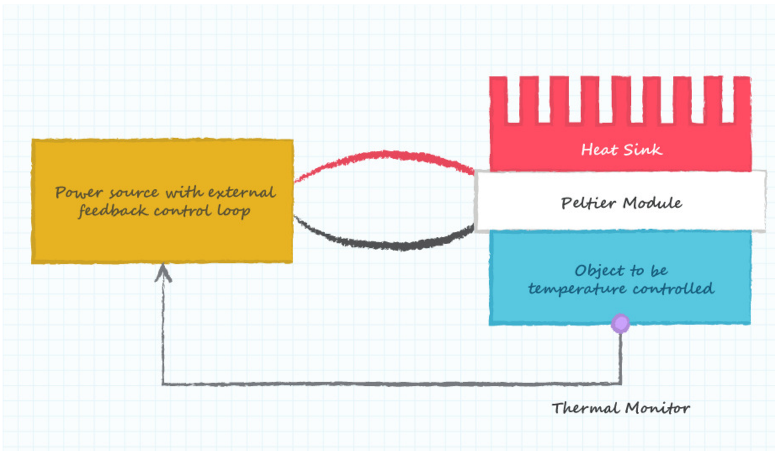
2D Design Project – Report Submission (30.100)

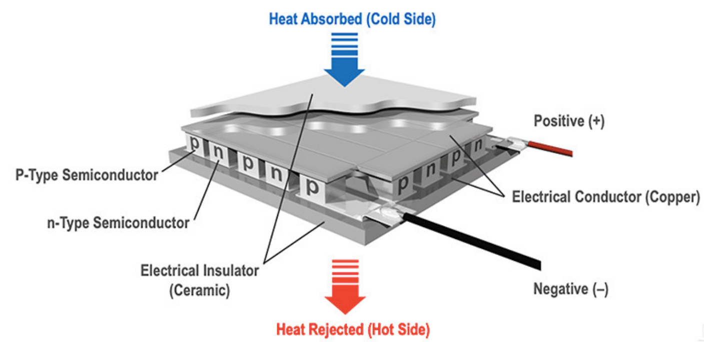
- No oral powerpoint presentation.
- Short video (in MP4 format) capturing your solution showing the effective functioning of the vaccine thermostat.
- Detailed 4-page report including the following.
  - How you model the system using PDE and numerical methods and Python?
  - What are your initial and boundary conditions?
  - How do you stack your components to setup the vaccine cooling chamber?
  - Solving your PDE model(s) and what inferences you can obtain from it.
  - Validating the outcomes of your PDE through sensors installed in the setup.
  - How your model and its estimations helped solve the design problem?
  - What are the reasons for your model's deviation from experimental measurements?
  - How might you better model the system to improve accuracy in the future?
  - How might you improve the design of the system to enable better cooling solution?

2D Design Project – Report Submission (30.100) – Guidelines and Rules

- Length: **4 pages** (including figures, text, data, plots etc…), excluding Annex and References.
- Reports longer than 4 pages **<u>will not</u>** be subject to any penalty. At the same time, reports longer than 4 pages also **<u>do not</u>** get any advantage in scoring as well.
- Students should append their Python or other codes as an Annex to the report document.
- Use minimum 11 point font size and single line spacing for your report.
- Include a cover page of your report (which is not part of the 4-page limit) and make sure to properly list out all the team members and their student IDs and their specific contributions in 1-2 sentences.
- All students of the team should include their digital signature in the cover page to confirm and acknowledge that they have contributed to the report diligently and fairly.
- Team leads and/or members to inform the TA or Prof. Naga if any team member did not contribute adequately to the project.
- All members of the team should contribute to the technical deliverables of the project.

Peltier Module System

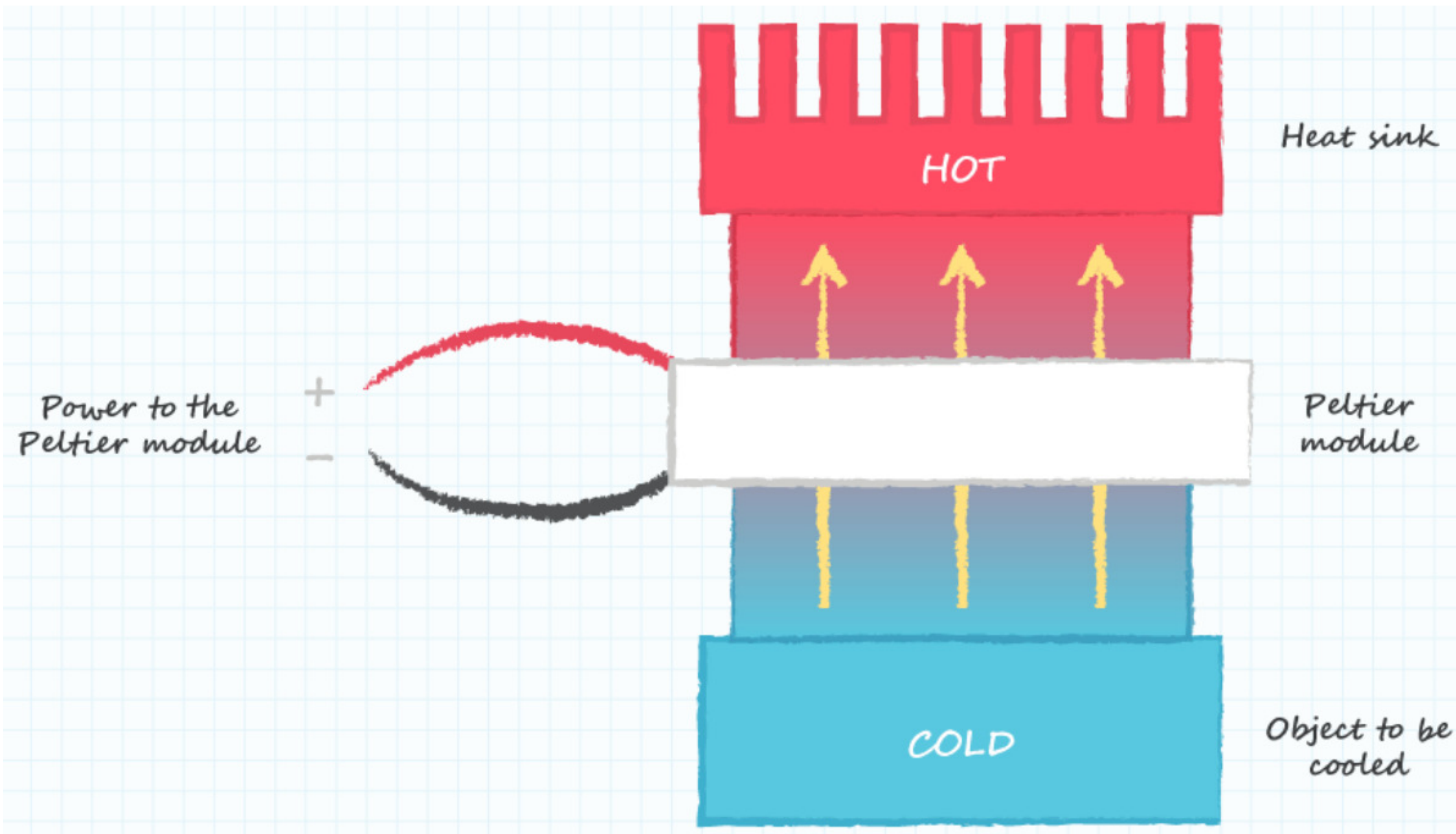




- Also referred to as thermoelectric cooler (TEC)
- An effective thermal management solution when there is a need to precisely control the temperature of an object. To cool objects to below the ambient temperature.
- A TEC module will transfer heat from the object to be cooled, while a heat sink is required to dissipate both the heat transferred through the Peltier module and the heat generated from the power source.
- The power source delivers the current needed to operate the Peltier device and an external feedback loop tied to a thermal monitor allows the system to precisely control the temperature of the object being cooled.

How to Design a Peltier Module System | CUI Devices

Typical Heat Flow through a Peltier Module System



[How to Design a Peltier Module System | CUI Devices]

Modeling the Temperature Distribution with Space and Time

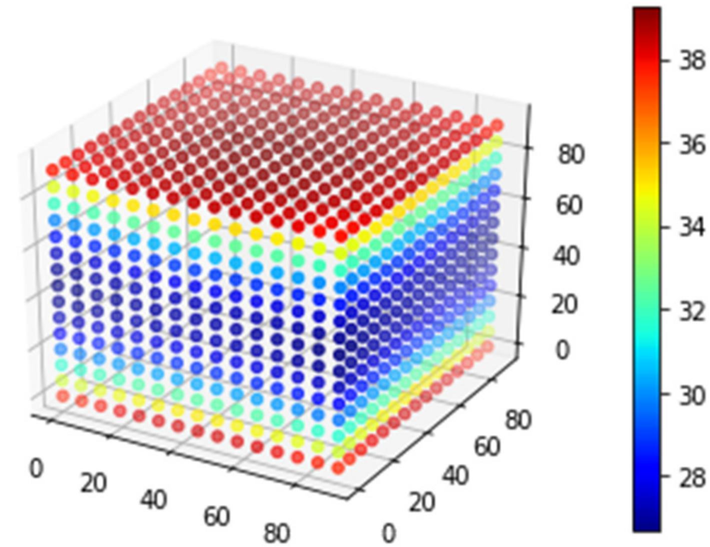
- For modeling the temperature distributions, students will need to solve the heat diffusion equations, either in steady-state or transient or both, depending on their perspectives.

- While there are some Python Codes from Week 10 on E-Dimension that can be used, there are several other Python open source codes for heat diffusion that students can leverage on and use for their modeling work.

- There is no need to consider analytical models and just numerical methods will do.

- Students are free to use any software to implement their codes… They can also consider whether to solve the problem in 1D, 2D or 3D (in space), and justify their choice accordingly.

- It would be good for students to explore explicit, implicit and / or Crank-Nicolson methods to solve their problems – it is again up to the teams to explore and see what works for them.

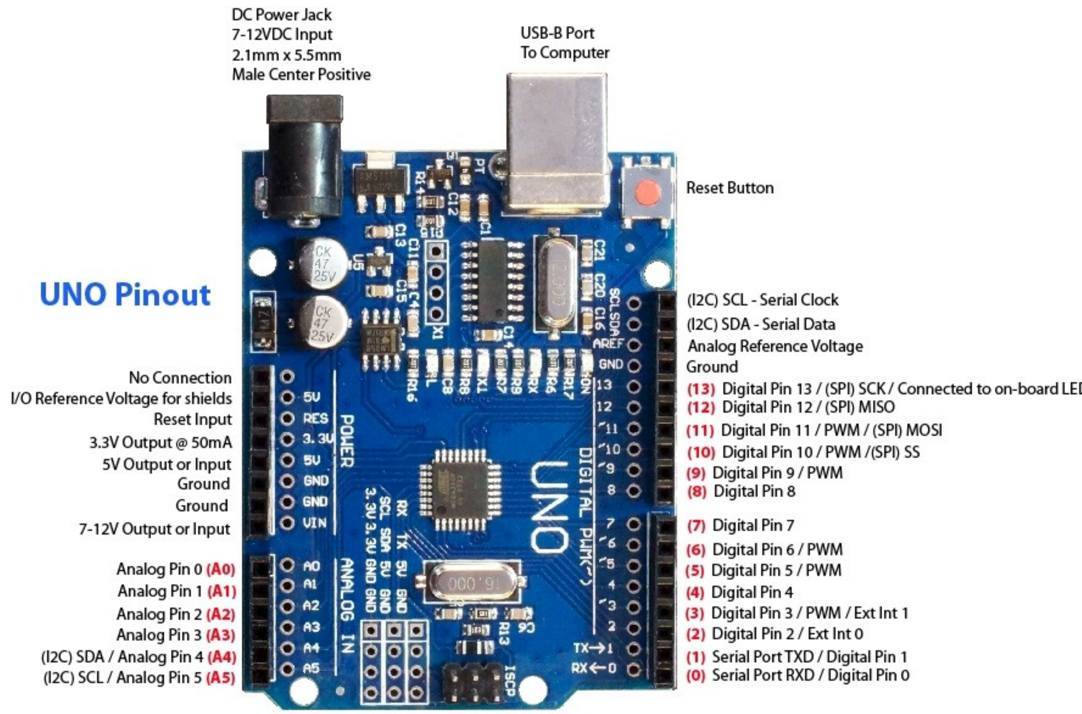


Note: This is just an illustration!

List of Materials Required (1/3)

Arduino UNO SMD (Surface Mount Device)

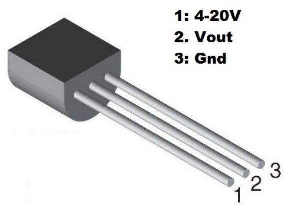
- Microcontroller: ATmega328P-PU
- Operating Voltage: 5V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- Analog Input Pins: 6
- USB Interface: CH340G (for serial communication and programming)
- Power Jack and Vin Pin: To supply external power (7-12V) to the board



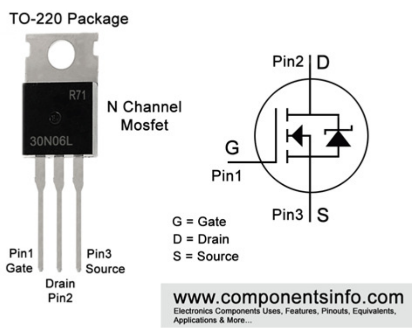
Red numbers in paranthesis are the name to use when referencing that pin.
Analog pins are references as A0 thru A5 even when using as digital I/O

List of Materials Requirement (2/3)

Voltage Temperature Sensor – [MCP9701](MCP9701)



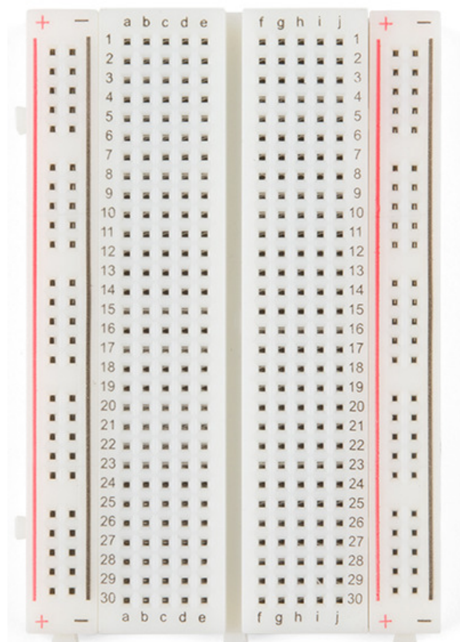
MOSFET Transistor – FQP30N06L



Resistor – 10K ohm

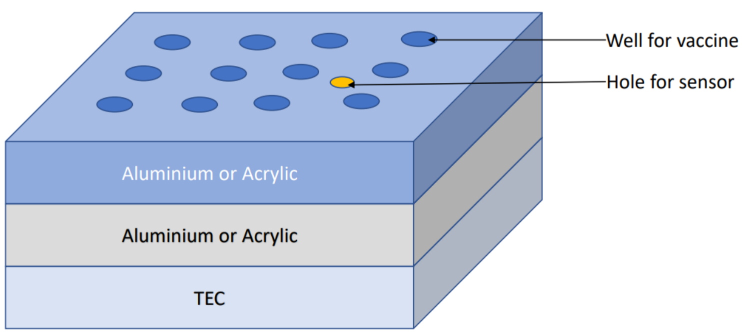
Thermoelectric Cooler - TEC1-12710

Breadboard

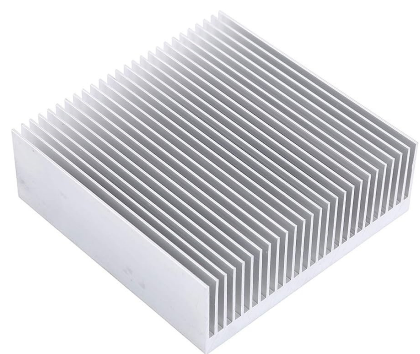


List of Materials Requirement (3/3)

Aluminum or Acrylic Blocks



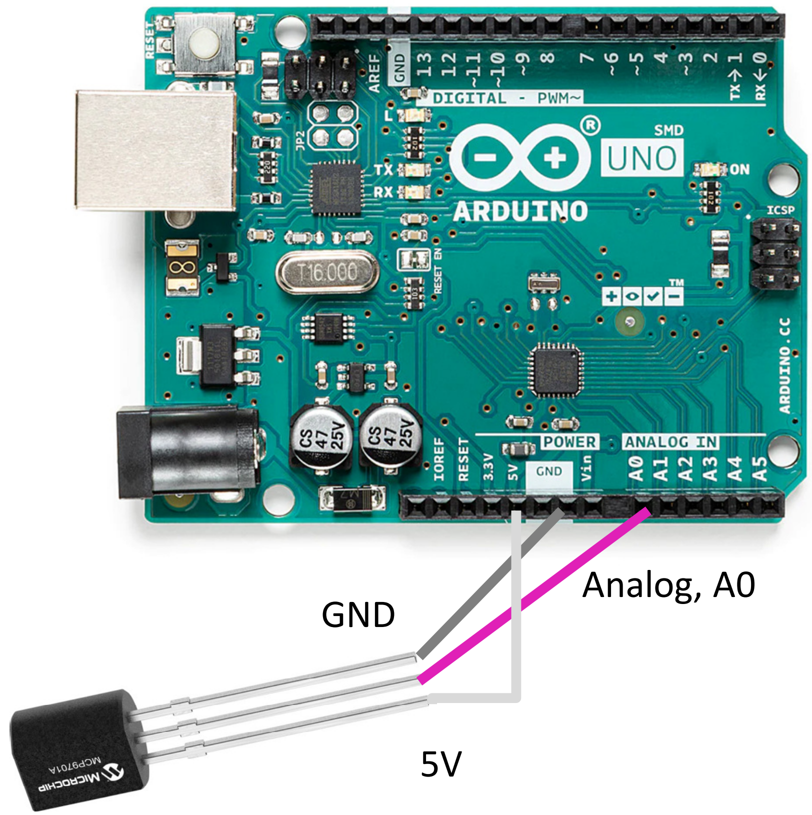
Heat Sink



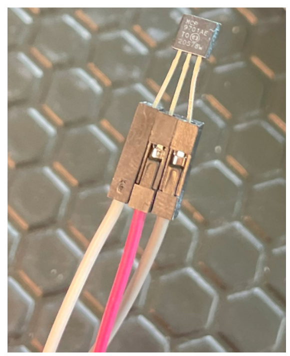
Power Supply

MCP9701 Arduino Temperature Measurement Circuit

- Connect the MCP9701AE temperature sensor to the Arduino UNO
- Connect the V_{out} pin of the MCP9701AE sensor to any analog input pin on the Arduino (e.g., A0). [Pink Wire]
- Connect the Vcc pin of the MCP9701AE sensor to the 5V pin on the Arduino. [White Wire]
- Connect the GND pin of the MCP9701AE sensor to the GND pin on the Arduino. [Grey Wire]



$$V_{in} = ADC \times V_{ref} / 1024$$



V_{in} → Input Voltage
V_{ref} → Reference Voltage = 5000 mV
ADC → Analog to Digital converter
(Sensor Value) → between 0 and 1023

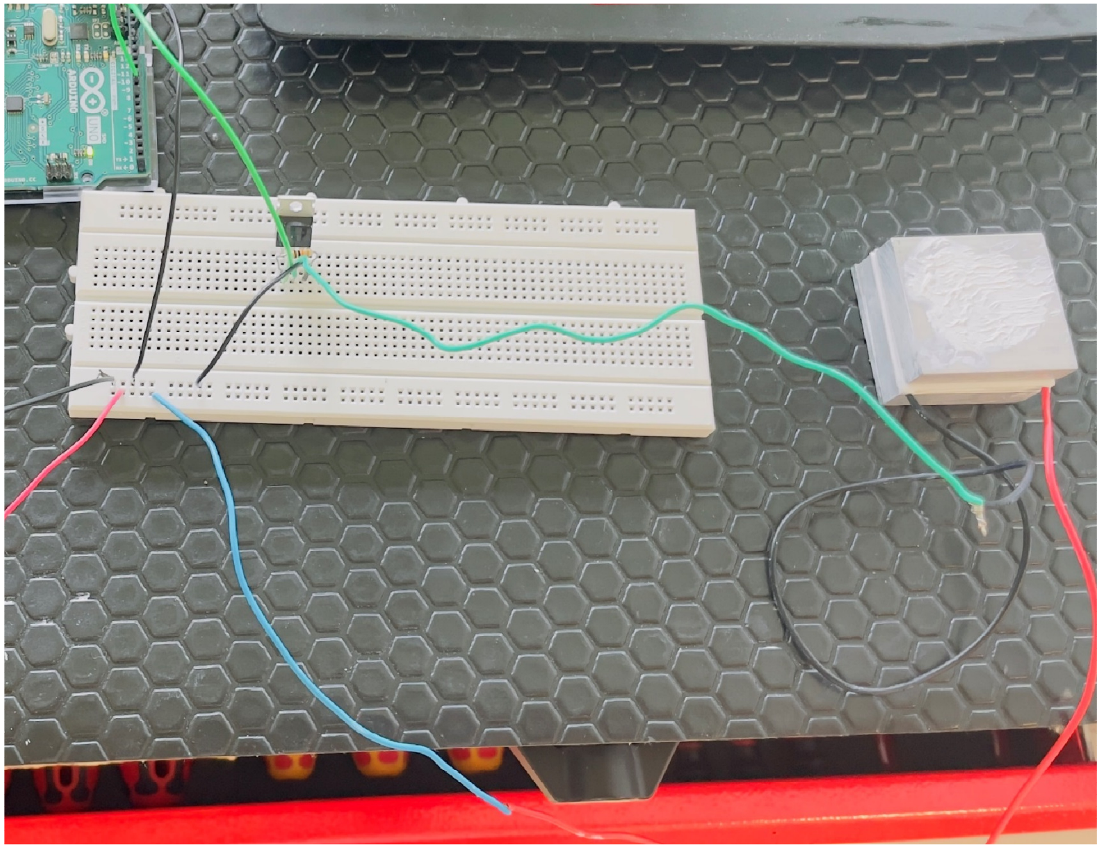
MOSFET FQP30N60L - Arduino – TEC circuit

Connect the MOSFET 30N06L to the Arduino:

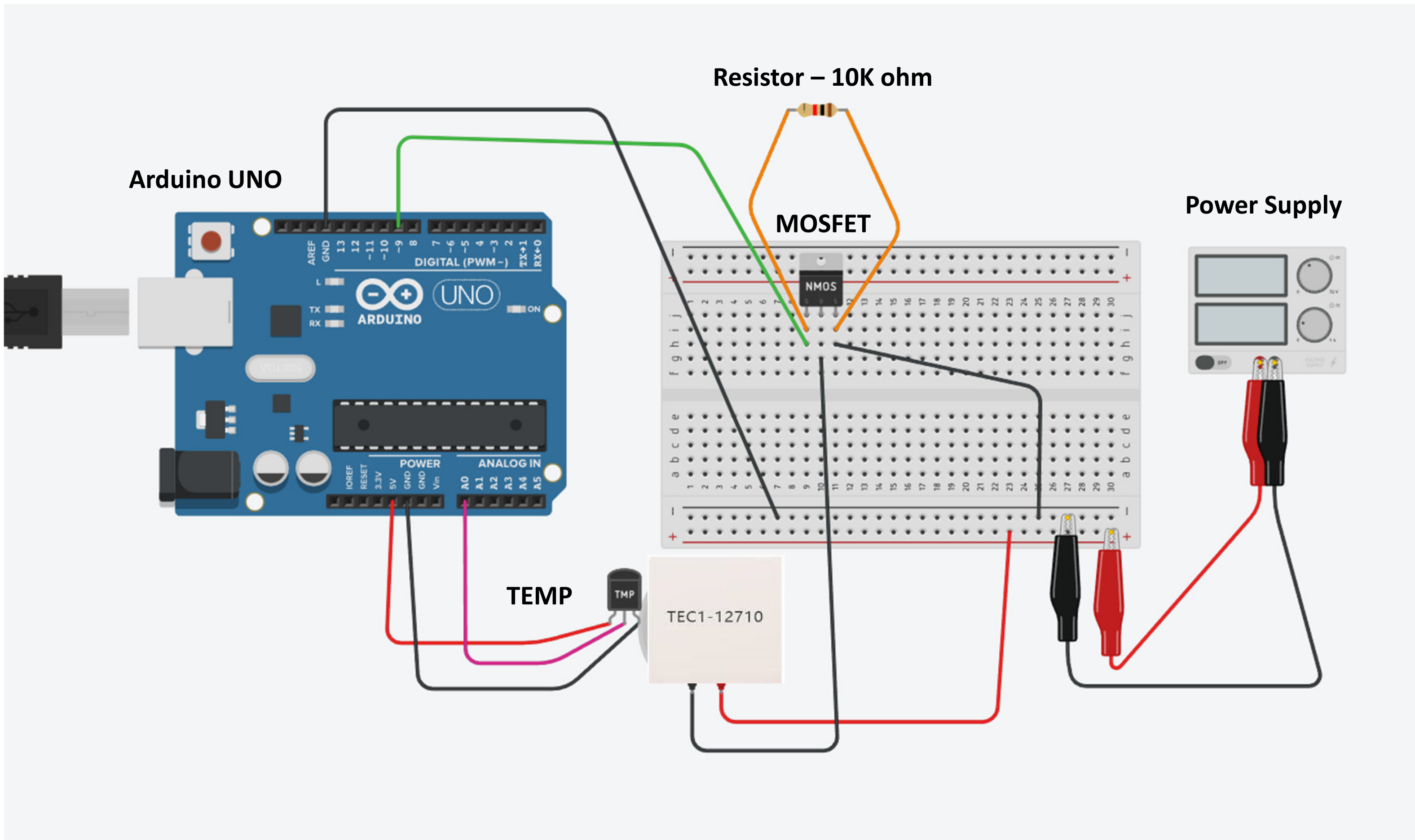
- Connect the Drain pin of the MOSFET to the positive (hot) terminal of the TEC.
- Connect the Source pin of the MOSFET to the GND (negative) terminal of the TEC.
- Connect the 10K resistor between the Drain pin (hot) and the Source pin (negative).
- Connect the Gate pin of the MOSFET to any digital pin on the Arduino (e.g., D9).

Connect the power supply for the TEC:

- Connect the positive terminal of the power supply to the positive (hot) terminal of the TEC.
- Connect the negative terminal of the power supply to the GND (negative) terminal of the TEC.

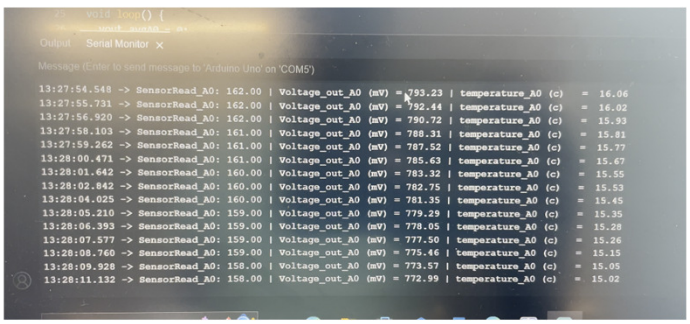


Overall Circuit Schematic for the System



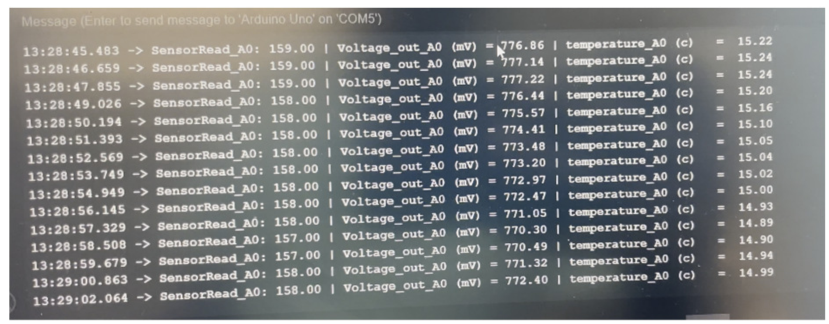
Thermoelectric Cooler (TEC) Operation

When TEC is Power OFF (constant voltage, CV)



Temperature will decrease, when Temp < 15^0C; then TEC will turn OFF.

When TEC is Power ON (constant current, CC)



Temperature will increase, when Temp > 15^0C; then TEC will turn ON.

MC9701 Sensor Transfer function & Performance Distribution

$$V_{out} = T_C T_A + V_{0°C}$$

V_{out}: Voltage output from sensor

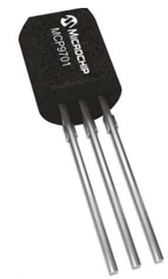
T_C: Temperature coefficient of sensor

T_A: Temperature of sensor

$V_{0°C}$: Voltage generated at 0°C

The MCP9701A accuracy can be improved by performing a system calibration at a specific temperature. For example, calibrating the system at +25°C ambient improves the measurement accuracy to a ±0.5°C (typical) from 0°C to +70°C

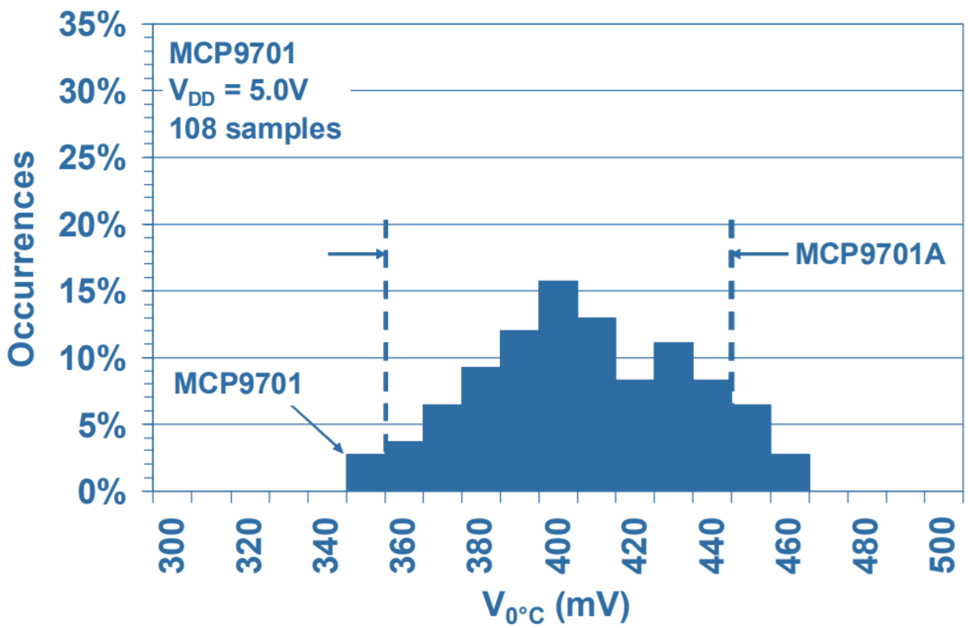
Features



- Tiny Analog Temperature Sensor
- Available Packages:
  - SC70-5, SOT-23-3, TO-92-3
- Wide Temperature Measurement Range:
  - -40°C to +125°C (Extended Temperature)
  - -40°C to +150°C (High Temperature) (**MCP9700,** SOT-23-3 and SC70-5 only)
- Accuracy:
  - ±2°C (max.), 0°C to +70°C **(MCP9700A/9701A)**
  - ±4°C (max.), 0°C to +70°C **(MCP9700/9701)**
- Optimized for Analog-to-Digital Converters (ADCs):
  - 10.0 mV/°C (typical) **(MCP9700/9700A)**
  - 19.5 mV/°C (typical) **(MCP9701/9701A)**
- Wide Operating Voltage Range:
  - V_{DD} = 2.3V to 5.5V **(MCP9700/9700A)**
  - V_{DD} = 3.1V to 5.5V **(MCP9701/9701A)**
- Low Operating Current: 6 µA (typical)
- Optimized to Drive Large Capacitive Loads

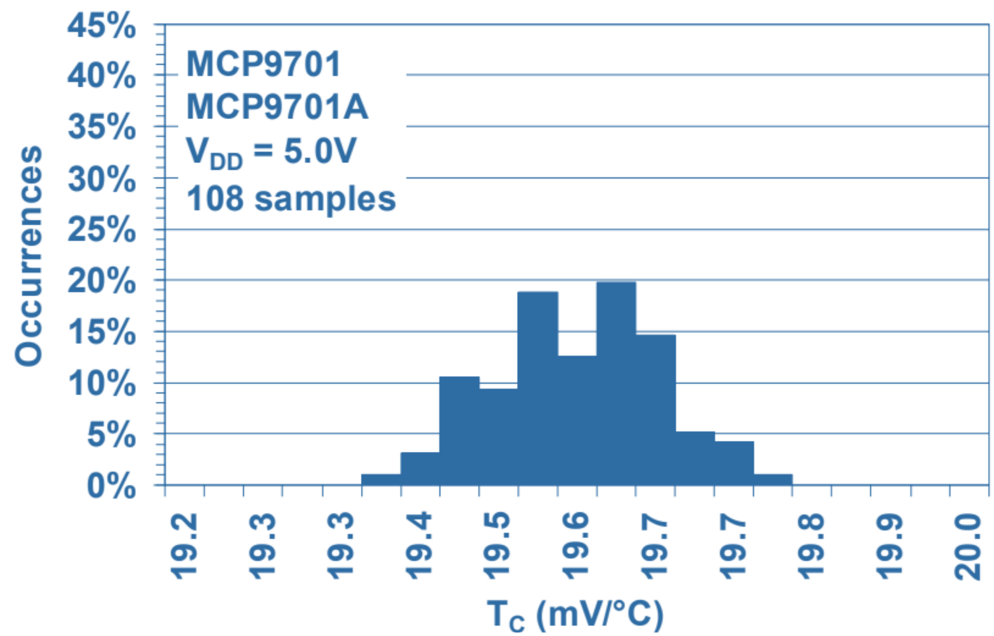
MC9701 Sensor Performance Distribution

Voltage Generated at 0 °C



V_o = 400 – 500 mV (depends on Sensor Calibration)
Recommend: 480mV

Temperature Coefficient, T_c



T_o = 19.3 – 19.8 C
Recommend: 19.5 C

Other Suggestions

- Try not to conduct heat into the MCP9701a through the legs.
- Consider all the sources of error and try to minimize them through calibrations.
- (**OPTIONAL**) Propagation of Errors (PoE) could be used to determine the accuracy of the measured temperature…
- (**OPTIONAL**) Monte Carlo simulations could be combined with your thermal simulations to compute the expected mean temperature and temperature vaccine of the vaccine…

ENJOY YOUR
2D
DESIGN ACTIVITY!

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