

P.U.M.P.E.D: Precision Weighing, User-Friendly Heating, Mobile App Integration, Printed Labels, Expiration Tracking, and Data Management



Group 16 Authors:

Isaiah Robinson - *Computer Engineering*
Jason Devito - *Computer Engineering*
Jamieson Foley - *Electrical Engineering*
Zachary Celentano - *Electrical Engineering*

Reviewer Committee:

Dr. Suboh Suboh	ECE	Associate Lecturer
Dr. Wei Sun	ECE	Associate Professor
Dr. Hadi Kamali	ECE	Assistant Professor
Victoria Rodriguez	Sponsor/Engineering support	
Matthew Aberman	Sponsor/Engineering support	

Mentor:

Dr. Chung Yong Chan

Sponsors:

Victoria Rodriguez
Matthew Aberman

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Chapter 1 - Executive Summary:

Feeding an infant with expressed breast milk demands precise control of volume, storage time, and temperature—tasks that quickly become burdensome for new parents. PUMPED (Precision Weighing, User-Friendly Heating, Mobile-App Integration, Printed Labels, Expiration Tracking, and Data Management) streamlines every step through a unified hardware–software ecosystem conceived and built by senior computer and electrical engineering students at the University of Central Florida. The countertop device and its Swift-based iOS companion app work together to weigh, label, catalog, monitor temperature, and safely thaw bagged breast milk, giving caregivers accurate data and peace of mind.

Precision Weigh-and-Label Station:

A 5 kg single-point load cell paired with an HX711 24-bit instrumentation amplifier delivers sub-gram resolution. When a bag is placed on the platform, an onboard microcontroller timestamps the reading and drives an embedded UART thermal printer that produces an adhesive label listing weight, date, time, and a QR code for rapid inventory scans. The label eliminates handwriting errors and enforces first-in-first-out freezer rotation.

Safe Thawing & Temperature-Monitoring Module:

A watertight chamber incorporates nichrome resistive heating elements and a Type-K thermocouple read through a MAX6675 cold-junction-compensated amplifier. Closed-loop PID control brings thawing water to a baby-safe setpoint and holds it within ± 0.5 °C. The same probe can be inserted directly into warmed milk to confirm serving temperature before feeding. Every temperature sample is logged alongside weight and timestamp, creating a complete thermal history for each bag.

iOS Inventory, Temperature & Analytics App:

Via Bluetooth Low Energy, weight- and temperature-events sync to an encrypted PostgreSQL database on the user's iPhone. The app displays real-time inventory levels, expiration countdowns, and temperature logs for each bag, issuing alerts if any reading breaches safety thresholds. Usage-trend visualizations help parents—and lactation consultants—optimize pumping and feeding schedules.

Intuitive Local Interface:

A 16 × 2 I2C character LCD and tactile membrane buttons let users cycle between “Measure,” “Warm,” and “Review” modes. Clear prompts, progress bars, and audible cues make one-handed operation possible while holding an infant.

In practice, the parent weighs a freshly pumped bag, affixes the printed label, stores the bag, and later selects “Warm” to thaw milk safely. All weight and temperature data are logged automatically for later review in the app, closing the loop from pump to pantry to baby.

This report documents PUMPED's conception and realization. It begins with the public-health context motivating automated milk-handling, then surveys the sensing, thermal, and wireless technologies that enable the system. Subsequent chapters justify component choices—highlighting the HX711, MAX6675, UART printer, load cell, LCD, and resistive heaters—present electrical, mechanical, and firmware schematics, and explain the iOS software architecture. Fabrication methods, test results, regulatory considerations, and risk mitigations follow. The document concludes with measured performance versus design objectives and recommendations for future iterations, complemented by appendices containing standards, data sheets, and references.

Chapter 2 - Project Description:

In this chapter we will be exploring the project's background, some previous work and existing products, the project's motivation, the goals and objectives, the project's features, required engineering specifications, hardware and software diagrams, the prototype illustration, and the house of quality. All of these are the basic fundamentals with how we will approach this project as a whole.

2.1: Project Background

Breastfeeding parents often face the challenge of measuring, labeling, heating, and storing breast milk effectively. Traditional methods require manually writing the weight, date, and time on a milk storage bag or container, which can be both time-consuming and prone to human error. In addition, accurate records are crucial not only for understanding how much milk is being stored and consumed but also for ensuring the milk's freshness and safety for the infant.

The purpose of this project is to design and implement a device and application that pair together to accurately measure, heat, catalogue, and provide feedback on the amount of breast milk stored, how long it has been stored for, and show possible allergens to be aware of. With this, parents and healthcare providers can easily manage the supply of breast milk available for infants without risk of human error, all while saving significant time that would have been used to accomplish the same task.

There is a growing need for systems that can store personal healthcare and dietary data. In the context of newborn dietary information, it is clear how this growing need translates; dietary data management for children is of the utmost importance for both the children themselves and also the parents, as being able to easily manage an infants amount of food available saves time and avoids issues that are otherwise unnecessary, like human error when recording pumping amounts and dates.

2.2: Previous Work & Existing Products

This project does not iterate directly from any previous work; the idea itself was formed by sponsors Victoria Rodriguez and Matthew Aberman in response to

problems they encountered when managing the food supply with accurate labels for their children. The issue that they want resolved is that there were cumbersome amounts of expired milk that could no longer be used or even donated to hospitals, for the reason that they could not effectively track the data on what has been pumped.

There are few products that perform separate individual functions of the proposed project. Namely, there are many brands that make milk bags that have measurement markings externally to show the amount stored within the bag. The advantage these products have is their convenience. With labels and markings on the bag itself, it takes away the extra effort of needing to manually manage the milk that is pumped. Where our system differs is that it offers a mobile app that will provide reminders and updates on pertinent information, like approaching expiration of milk. Another product that can be used in this context is a label maker. A parent can pump their milk, record the amount, then put the information regarding the milk into a label maker. Our product would remove the intermediate step and directly record the data of the milk and print a label immediately. Furthermore, there are also milk bag organizers sold that allow milk bags to be separated and stored in freezers; these organizers exclusively help with storage, where ours would not necessarily aid in physical storage, but rather in reminding parents when their supply is low, expiring soon, or some combination of the two scenarios.

When using the breast milk that has been stored, many parents have to heat the milk up to a temperature suitable for the baby's consumption. What is common practice is to place cold or room temperature milk bags in hot water baths to heat the milk, which can take excessive amounts of time. Adding the capability to warm up the milk bags in our design while also monitoring the temperature of the bag could help even further by saving parents time needed to ensure their children's food is at the temperature needed. In our case, it would make sense to model our heater after technology used in mug warmers. Mug warmers are ideal to take inspiration from because they typically do not heat past a temperature of 200 °F, which is the temperature most polyethylene plastics begins to melt. In our design, using similar topology, we would monitor the temperature to ensure product safety, while keeping it hot enough that someone could place their milk on for a short duration and prepare the milk to consume in a reasonable time frame. The monitoring of the temperature would most effectively be achieved through thermal coupling. Through this, we can send temperature data from the milk bag to our mobile app, where parents will be alerted of the temperature of their children's food.

Parents who use these products previously described must manually take inventory of what is pumped, the time it is pumped, and the amount they have stored, while also keeping track of potential expirations, ideal temperature, and allergens. All of these devices and aids share a common flaw; that being time consumption. The previously mentioned products require an extra step, and thus more time to manage and maintain a parent's supply of breast milk. While parents already have much to keep track of for their children, adding these additional few things can be cumbersome, which is what our device aims to minimize. While all of these systems accomplish their specifically designed task, there is no product that combines all of the strengths of the individual products to provide in-depth data monitoring and ease of use for parents who are not able to manage the many complexities that can arise when pumping breast milk. The system we aim to design would be available on a large commercial scale in a form factor that is cheap for parents, boast similar portability that of kitchen appliances, in both the device itself, as well as the application that allows consumers to track their data at any time.

2.3: Project Motivation

This project was motivated by:

1. **Sponsorship:** Having a sponsored project as college students is a substantial motivating factor because of our lack of funding, while also giving us valuable project experience for our field.
2. **Accuracy:** Providing consistent and precise measurement of breast milk weight.
3. **Traceability:** Using an integrated mobile app to track stored milk bags, expiration dates, and consumption over time.
4. **Peace of Mind:** Helping parents avoid confusion about which bag was pumped when and how long it remains viable, thus improving overall feeding management.
5. **Convenience:** Automating the labeling process to save time and reduce mistakes.

By combining a custom scale with printing functionality and automatically syncing data to a mobile application, this device addresses a real need for modern, tech-savvy parents who want a seamless solution to manage their breast milk supply.

2.4: Goals & Objectives

Our project aims to design an affordable device that accurately measures the amount of milk in a breast milk storage bag. To ensure the user will not waste the milk they produce, we plan to include a label printer to create labels with the measured volume, current date, and time so that the user can keep track of their supply. Additionally, we will develop a mobile app that allows the user to interact with the data, which will be automatically stored in memory after the device prints a label. With milk storage being one of our main goals, we also want to include a milk warmer. The user will have the functionality to either heat or weigh their milk. Below are our general goals and specific objectives for achieving this plan.

Basic Goals:

- Build a product that allows parents to easily weigh, label, and store milk bags.
- Build an application that allows an accessible interface with the data of bagged milk.
- Build a system that ensures milk is stored and used at safe temperatures, helping prevent spoilage or degradation of nutrients.

Basic Objectives:

- Implement a load cell and ADC for accurate weight measurement. Convert the measured weight to fluid ounces for parents ease of use.
- Integrate a label printer to produce labels containing all relevant information, including fluid ounces, date, time, and temperature.
- Show real-time weight, date, and time on the LCD prior to label printing.
- Measures the temperature of bagged milk using thermal coupling.
- Implement a heating element to allow parents to more freely manage milk temperature.
- Implement a custom power supply to power the device and all peripherals.
- Any surface that makes contact with the milk bags will be able to be taken apart for sanitation purposes.
- Develop an iOS app to interface with a database of information regarding stored milk.

- Provide features for viewing, editing, and managing milk inventory.
- Send alerts for impending expiration dates and low general storage.

Stretch Goals:

- Include an option to track allergens in milk bags.
- Include a cloud storage system
- Track all bagged milk for up to a year.
- Suggest how much milk a Mother needs to pump.

Stretch Objectives:

- Build a custom thermal printer and its subsequent PCB to minimize form factor.
- Design the power supply to be able to work with batteries so the product can be portable.

2.5: Project Features

As stated previously, the overall functionality of the project is to provide a quick and easy alternative to manually writing down the current date, time, and weight of breast milk in a storage bag. To accomplish this task, and more, our project consists of five main features.

- **Scale:** The function of the scale is to measure the weight of the breast milk bag and convert that weight into weight. The device would then store that measured weight for use in all the other features.
- **LCD Screen:** The function of the LCD screen is to display the current date, time, and measured weight provided by the scale.
- **Button Functionality:** Buttons will serve a way for the user to choose which action they want the device to run.
- **Label Printer:** The function of the label printer is to, with the press of a button, print out a label with all the required values. This label could then be directly attached to the breast milk bag, allowing for easy access to all the information on each bag when stored.
- **Mobile App:** The function of the mobile app is to keep track of each breast milk bag in storage. It should be able to automatically load information from a database. Additionally, the app should be able to track

how much milk is left in each bag and send alerts about upcoming expiration dates. In the case of a trip or vacation, the app should be able to portion out the amount of breast milk required over a specified period of time.

- **Bluetooth Connectability:** The function of Bluetooth is to allow the device to directly connect to the users phone, allowing access to the mobile app
- **Temperature Sensor:** The function of the temperature sensor is to measure the temperature of the breast milk bag while it is on the scale.
- **Heating Element:** The function of the heating element is to provide a controlled warming feature for the breast milk bag. This allows users to gently heat milk to an optimal feeding temperature without needing a separate bottle warmer.
- **Custom Power Supply:** To power the heating feature, we will design a DC switching power supply, researching the appropriate topology to efficiently meet the heater's power requirements. The heating process will be closely monitored to prevent overheating and ensure uniform temperature distribution.

2.6: Required Engineering Specifications

Table 2.1 - Engineering Specifications

Parameter	Value	Description
Weight Measurement	± 1 Grams	Accurate weight measurements.
Temperature Measurement	± 1 °F	Accurate temperature measurements.
Label Size	2" x 1"	Large enough to display all data.
LCD Display Time	< 1 Second	Fast response time.
Power Consumption	< 80 Watts	Overall power consumption device.
Bluetooth Connectivity Response Time	< 5 Seconds	Efficient interface connectivity.
Local Data Storage Capacity	> 20 entries	Enough data storage capabilities to give parents enough information.

Heating Temperature	90-100 °F	Must heat milk to the proper temperature of consumption.
Cost Estimate	< \$800	Needs to be cost effective to manufacture.

2.7: Hardware Block Diagram

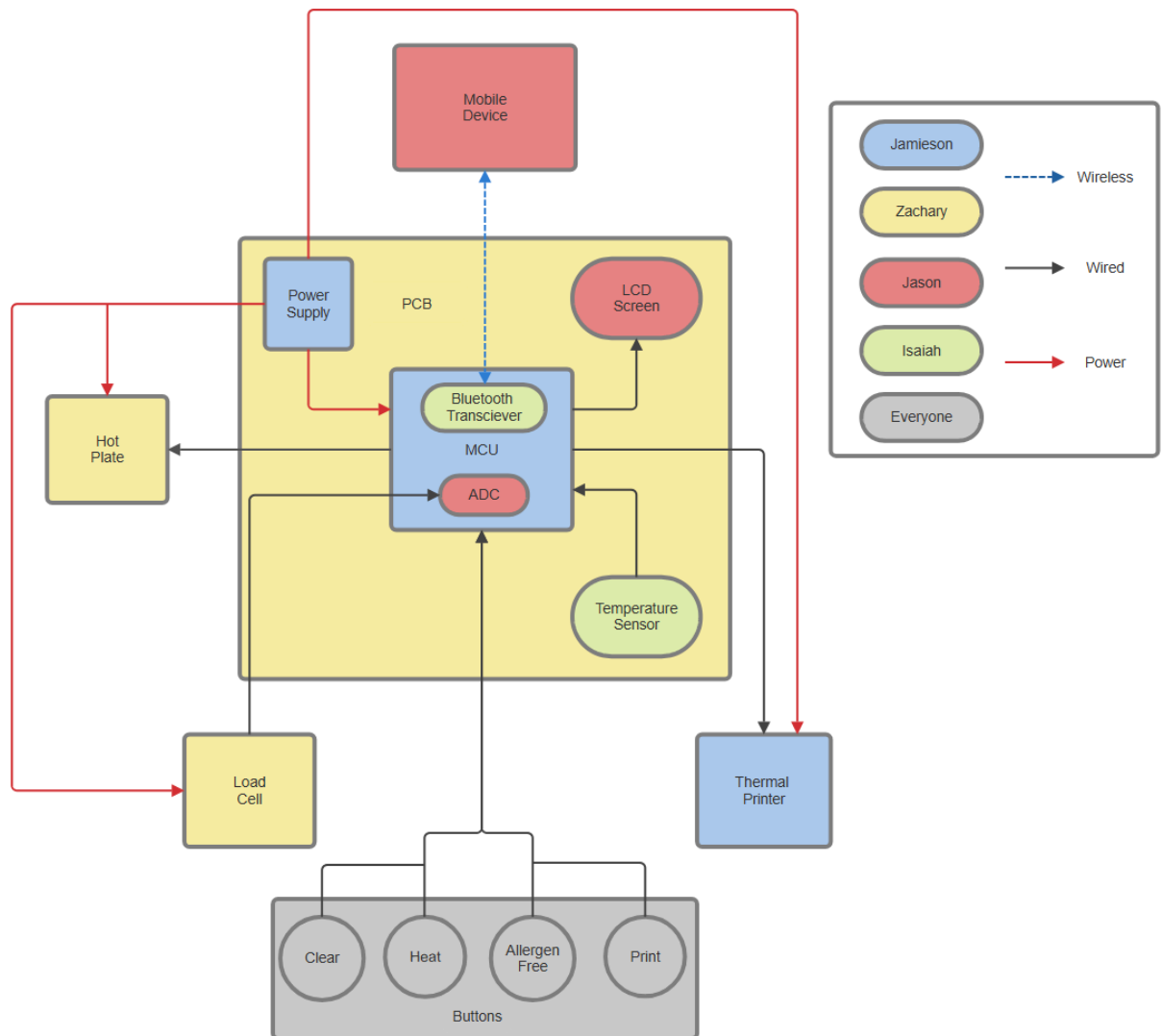


Figure 2.1 - Hardware Block Diagram

2.8: Software Flowchart

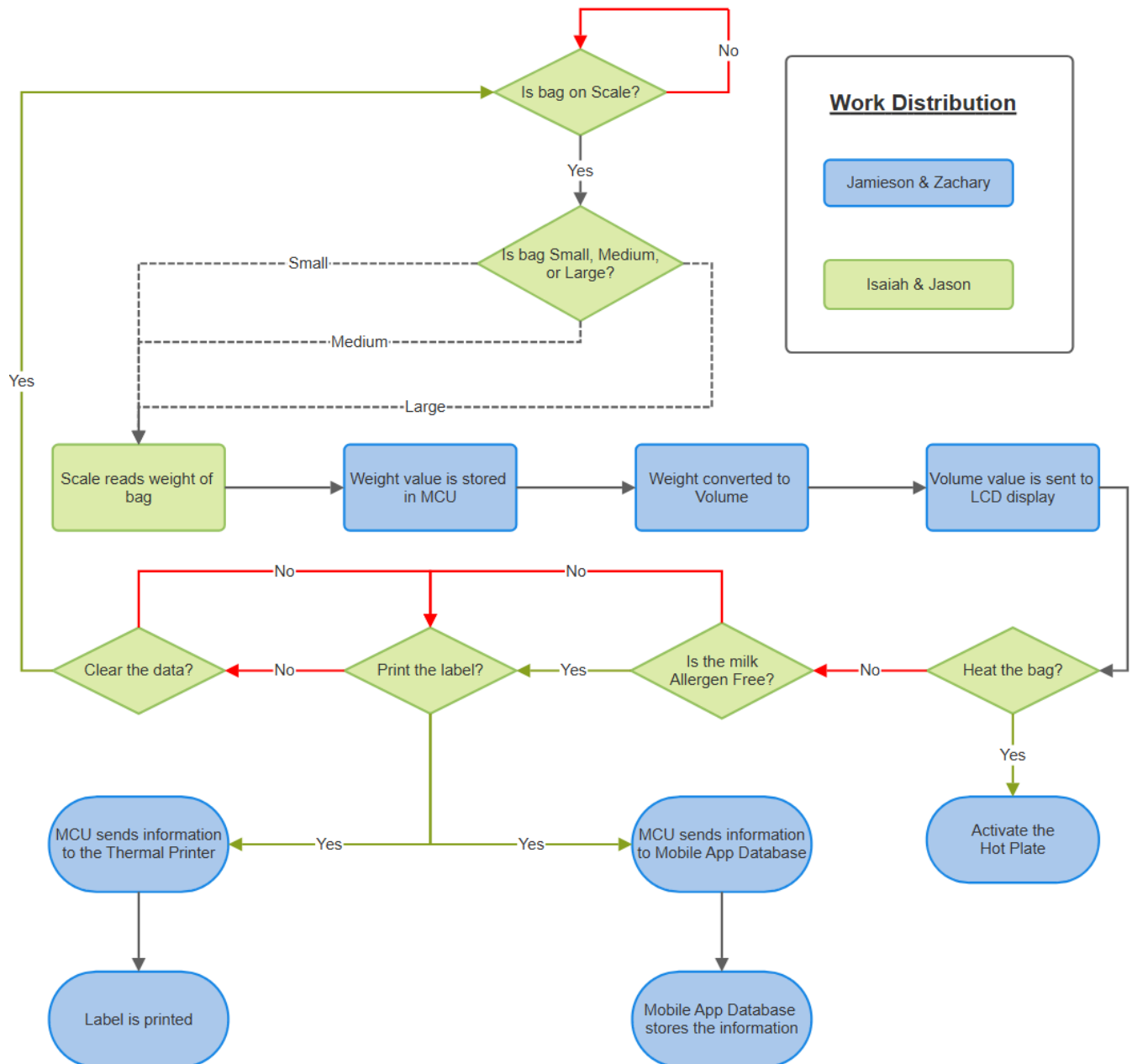


Figure 2.2 - Software Flowchart

2.9: Prototype Illustration

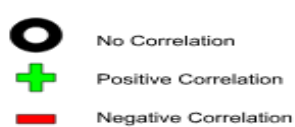


Figure 2.3 - Prototype

Diagram Caption: The illustration above shows a prototype of what we want the device to look like upon its completion. This image was created by AI, and given to us by our sponsors as what they would roughly like the product to look like once it's finished. The Milk bags will sit in a cylindrically encapsulated space, allowing for it not to fall. The bag will sit on top of the scale which will have functionality to both measure and heat its temperature using buttons. Additionally, there will be a button to print a label which will contain the bag's volume in fluid ounces, the current time, and date.

2.10: House of Quality

Table 2.2 - House of Quality



Column #		1	2	3	4	5	6	7
	Functional Requirements							
	Direction of Desirability	Size	Weighing Accuracy	Cost	Temperature Accuracy	Label Size	Wireless Connectivity	Heating Element
Customer Requirements								
Direction of Desirability		▼	▲	▼	▲	▼	▲	▲
Affordability	▲	↕	↑↑	↑↑	↑↑	○	○	↑↑
Portability	▲	↑↑	○	↓	○	○	○	↑↑
Energy Efficiency	▲	↑	↑↑	○	↑↑	○	↑	↑↑
Power Delivery	▲	↑↑	↑	○	↑	○	○	↓
Reliability	▲	↑	↑↑	↑	↑↑	↑	↑↑	↑↑
Ease of Use	▲	○	↓	○	↓	↑	↓	↑
Communication Range	▲	↑↑	↑	↓	○	○	↑↑	○
Compatibility	▲	○	○	○	○	○	↑↑	○
Connectivity	▲	○	↑↑	↑	↑↑	↑	↑↑	↑
Ease of Maintenance	▲	↕	↓	↓	↓	○	○	↕
Product Efficiency	▲	↑	↑↑	↑↑	↑↑	↑	↑↑	↑↑
Product targets		< 1" x 1" x 1"	± 1 Grams	< \$600	± 1 °F	< 2" x 1"	< 5 seconds	> 100 °F

Relations	Direction
Strongly Positive	↑↑
Weakly Positive	↑
No Relation	○
Weakly Negative	↓
Strongly Negative	↓↓

Direction of Desirability	
High	▲
Low	▼

Chapter 3 - Research:

The purpose of this chapter is to investigate the technical aspects for this project's design and development. Each section contains analysis of components relevant to individual parts of our design as well as subsystems that will go into our design to measure, heat, and categorize milk. Contained in the subsections will be information regarding things such as physical architecture to power the system to the software that will enable the users to interface with the data the system intends to store. Sections will provide key technical knowledge to best guide the design of the system to meet all design requirements and constraints. Comparisons given in the chapter serve to provide the most optimal design choices that do not compromise functionality while remaining efficient and effective for all users.

3.1: Hardware Technologies

The first section of this chapter is dedicated to the research of design elements of the physical system. For this, we will be considering many factors for the physical design. Firstly, we will consider how the system will be powered, since that is what the system hinges upon. Afterwards, we will discuss components, such as what MCU will be used, how temperature will be measured, how the bags will be heated, how information will be displayed, among other design choices that must be investigated.

3.1.1: Temperature Measurement Methods

For this section of research for our design, we are considering the method for which we will implement measuring the temperature of the milk and heating elements for our device. This is essential for ensuring that the milk is safe for consumption, so choosing the ideal measurement device is of great importance. The following subsections compare different sensors that we compared to choose the ideal option in our implementation.

3.1.1.1: Contact Temperature Sensors

The first potential method for measuring the temperature of the milk is with a Contact Temperature Sensor. These sensors must physically touch the object to measure its temperature and from there that sensor's output is then converted into a temperature reading. When making contact they absorb heat from the object which causes a change in electrical resistance, voltage, or current. This change is often the heat transfer between the object and sensor reaching thermal equilibrium. Contact Temperature Sensors best measuring happens when contact is made between the sensor and the object. The advantages of using contact sensors is that they have high accuracy when properly calibrated, they're suitable for continuous monitoring, and they are the more cost effective option. The disadvantage of the contact sensors is that they require direct contact which could be invasive and also lead to physical degradation of the sensor.

3.1.1.2: Non-Contact Temperature Sensors

The next method that we considered for the temperature sensor is a Non-Contact Temperature Sensor. These sensors do not physically touch an object to measure its temperature rather they detect infrared radiation emitted by the object's surface. All objects above absolute zero (-273.15°C) emit infrared radiation, so the milk would be able to have its temperature taken by a Non-Contact Temperature Sensor as long as its temperature remains above absolute zero. After the sensor captures this radiation it converts it into an electrical signal which is then sent to a microprocessor or analog circuit which then calculates the temperature. This temperature calculation is often based on the intensity of the infrared radiation. Non-Contact Temperature Sensors are ideal for measuring moving objects or hard to reach areas due to the lack of contact being present. They also have a fast response time with almost instant readings. With the ability to not have to make contact to measure temperature they are also great at measuring very high temperatures. Some disadvantages of these types of sensors is that they can be affected by the ability of a surface to emit infrared radiation, they are also less accurate for reflective surfaces like metals, and are more expensive than contact sensors.

3.1.1.3: Temperature Sensor Method Selection

Table 3.1 - Temperature Detector Method Comparisons

Method	Cost	Implementation	Accuracy
Contact Temperature Sensor	Low (between \$ and \$\$)	Easy to Moderate	High (Loses accuracy over time due to physical exposure)
Non-Contact Temperature Sensor	Moderate (between \$\$ and \$\$\$)	Moderate to Hard	High

The final choice for our method of Temperature Sensing comes down to accuracy and cost. Contact Temperature Sensors provide excellent accuracy overtime, but due to its physical exposure it will degrade. That is a problem we will have to overcome by choosing the right sensor material and to apply a protective coating or encapsulation. With the Contact Temperature Sensor being at a low cost and easy implementation, the physical exposure to the sensor is the only major disadvantage of using this sensor.

3.1.2.4: Contact Temperature Sensors

Now that we have chosen our method for which we will measure the temperature of the milk, we must consider what contact sensor we will implement into our PCB design. There are many options for Contact Temperature Sensors, so for this section we will discuss several that could be used.

3.1.1.5: Type K Thermocouple with MAX6675 Amplifier

The Type K Thermocouple is a device that consists of two different electrical conductors that form an electrical junction. At the electrical junction the change in temperature creates a slight but measurable voltage that can be used to calculate the temperature. Thermocouples can be made of different metals and

the use of different metals affect the voltage range, cost, and sensitivity. The K type thermocouple is made out of chrome and alumel conductors that has a general temperature range of -200 to 1260°C (-328 to 2300°F).

With the Type K Thermocouple we will also have the MAX6675 Amplifier. The Amplifier is connected to the thermocouple so that it can read the voltage difference at the reference junction and output a temperature. The MAX6675 amplifier communicates with the microcontroller that it is connected to by SPI communication protocol and the data is output in 12 bit resolution.

3.1.1.6: PT100 (RTD - Resistance Temperature Detector)

The PT100 is a highly accurate Resistance Temperature Detector (RTD) that is widely used in industrial applications. It can measure temperatures from -200°C to 850°C with an accuracy of $\pm 0.1^{\circ}\text{C}$ to $\pm 0.5^{\circ}\text{C}$, depending on the quality of the sensor.

Unlike thermistors, RTDs have a nearly linear resistance-to-temperature relationship, making them very precise. However, PT100 sensors require a signal conditioning circuit, such as a Wheatstone bridge and an amplifier, to interface with a microcontroller. They are ideal for precise temperature control in water heating systems, industrial boilers, and laboratory setups.

For a high-precision industrial heating device, the PT100 RTD is the best option, although it requires additional signal conditioning.

3.1.1.7: NTC Thermistor (Negative Temperature Coefficient Sensor - 10K Ω or 100K Ω)

An NTC thermistor is a simple and cost-effective sensor that changes its resistance inversely with temperature. A commonly used variant is the 10K Ω or 100K Ω NTC thermistor, which can provide a temperature range of -40°C to 150°C with moderate accuracy.

Thermistors are highly sensitive but non-linear, meaning you need to use a lookup table or Steinhart-Hart equation for accurate readings. They are often used in thermostats, electric kettles, and water heaters for basic temperature regulation.

For a cheaper solution, an NTC thermistor is sufficient but requires calibration and compensation for non-linearity.

3.1.1.8: Temperature Detector Selection

Table 3.2 - Temperature Detector Comparisons

Temperature Detector	Cost	Integration	Maintenance
Type K Thermocouple with MAC6675 Amplifier	Moderate \$4-\$13	Easy to integrate. Uses SPI making it easy to connect to most microcontrollers	Low, durable with minimal upkeep. Cleaning will need to occur to prevent degradation of the sensor.
PT100(RTD-Resistance Temperature Detector)	High \$10-\$100+ Varies significantly with accuracy and material	Moderate to Complex. Requires an excitation current, specialized amplifier and signal processing	Moderate to High as it is more fragile and needs careful wiring. Needs to be calibrated overtime
NTC Thermistor (Negative Temperature Coefficient Sensor - 10K Ω or 100K Ω)	Low \$0.50-\$5	Easy to Moderate. Requires voltage divider, but is more sensitive to noise	Moderate as it is prone to aging and drift. This also needs to be recalibrated over time

The final temperature detector selection was based on cost efficiency, simple integration, and low maintenance. With the three options displayed above, We decided to choose the Type K Thermocouple with MAC6675 Amplifier. Although it is moderately priced, the extra cost is made up for because of its low maintenance and easy integration. The PT100(RTD-Resistance Temperature Detector) is the exact opposite, with its high cost, moderate to complex

integration, and its fragile durability. The PT100 was put last on the list of options as its high cost and lack of durability is not ideal for our device. The close runner up to the Type K Thermocouple with MAC6675 Amplifier was the NTC thermistor. With its low cost and easy integration it seemed like the ideal option, but the problem arises due to the sensor being prone to aging. The sensor aging would not be ideal for temperature readings that are needed for safe consumption and storing. So the overall choice is the Type K Thermocouple with MAC6675 Amplifier because it meets a moderate to low cost, integrates easily, and has the lowest maintenance being that only basic cleaning is needed.

3.1.2: Weight Measurement Methods

A vital piece of information in our design is the weight of the milk that is being measured. For this system, we want to be able to give parents the most accurate measurements for the amount of food they have, as this will aid in keeping track of when their child will need more milk based on how much they consume, while also allowing our database to give alerts to when their supply is running low. This section will discuss several methods to measure the weight of the milk for our system, as well as implementation.

3.1.2.1: Load Cell (Strain Gauge-Based)

The first potential method of measuring the weight of the milk in our device is through a Load Cell. Essentially, this works by measuring the force caused by the deformation of the element. This deformation generates a voltage difference, which is proportional to the amount of force on the element. What makes this method for measurement ideal is that it has high precision in its measurements, with a large range for weights that it can measure accurately. When it comes to implementation, there are a few drawbacks that must be considered. Most notably, the signal output of a Load Cell is typically small, in the mV range. This means that in our PCB design, we will need to include an amplifier. Furthermore, Load Cells are susceptible to error due to temperature variation; this is because resistance changes with temperature, which could potentially be problematic in our design as we are going to be involving heating in our design. In addition to this, Load Cells being sensitive measuring tools means that their mounting is

important to their measurement accuracy, which could mean that assembly of the final design is more troublesome.

3.1.2.2: Piezoelectric Force Sensors

The next method that we considered for the weight measurement aspect of our system is Piezoelectric Force Sensors. Piezoelectric Force Sensors utilize the Piezoelectric Effect, which allows materials to generate a voltage in response to some applied force. The key difference between the Piezoelectric Force Sensor and the Load Cell is that the load cell measures force in terms of difference in resistance caused by an applied force, whereas the Piezoelectric Force Sensor generates a charge when a force is applied, and needs a charge amplifier to actually utilize the measurement, as the charge generated is incredibly small. Piezoelectric Force Sensors are best utilized where the force applied is temporary, which for our design is not ideal, as we will be dealing with objects that will not be changing force applied during measurement. An even deeper disadvantage in our case is the fact that the charge generated by the sensor depletes over time, making them even less suited for our use. Aside from these disadvantages, the Piezoelectric Force Sensor is also typically very expensive compared to other measurement options.

3.1.2.3: Capacitive Force Sensors

The last method for which we considered to measure the weight of milk is through the use of Capacitive Force Sensors. Similarly to Load Cells, Capacitive Force Sensors work by measuring variation in impedance, instead now using variation in capacitive changes instead of resistive changes with the Load Cell. Capacitive Force Sensors are of particular interest because they also provide incredibly precise measurements. However, the precise measurements come with the drawback that they are best used in compact PCB design where the expected force measured is expected to be small. Since Capacitive Force Sensors are very precise, they are also going to be subject to more noise in their measurements. If we were to utilize Capacitive Force Sensors, we would also need to implement a separate IC for capacitive sensing, adding to the cost.

3.1.2.4: Weight Measurement Method Selection

Table 3.3 - Weight Measurement Comparison

Method	Cost	Implementation	Accuracy
Load Cell	Moderate (Anywhere between \$ & \$\$\$)	Moderate (Requires an amplifier IC)	High (Does not lose accuracy over time)
Piezoelectric Force Sensors	High (Between \$\$ & \$\$\$)	Difficult (Requires Charge amplifier)	Moderate (Loses accuracy with time, best for alternating forces)
Capacitive Force Sensors	Low (Between \$ & \$\$)	Moderate (Requires Capacitive Sensing IC)	Moderate (Sensitive detection, best for low force detection)

The final choice for our method weight measurement comes down primarily to accuracy and cost. Load Cells provide excellent accuracy whilst not completely sacrificing in terms of implementation difficulty. Furthermore, while Load Cells can potentially be costly, on average, they are cheaper than Piezoelectric Force Sensors and equal in most cases to Capacitive Force Sensors. A problem that we will have to face in our design with respect to Load Cells is their sensitivity to temperature variations; to combat this, we will likely have to consider insulation for the load cell, depending on how it is impacted by our heating element.

3.1.2.5: Load Cells

As we have chosen the method for which we will measure the weight of the milk in our system, we now must consider the actual load cell which we will implement into our PCB design. There are many options for Load Cells, so for this section we will discuss several that could potentially be used.

3.1.2.6: Phidgets CZL635 (5kg)

The Phidgets CZL635 (5kg) is a load cell that has a maximum capacity of 5 kg. What is beneficial about this is that while all load cells will require amplification and an ADC for accuracy, this manufacturer has an IC that can be purchased to decrease the overall design time that can be directly connected to the Load Cell.

3.1.2.7: SparkFun SEN-14729 (5kg)

Similarly, the SparkFun SEN-14729 (5kg) is a load cell with a maximum capacity of 5 kg. What makes this option potentially more viable is the competitive cost. As we would be using only the load cell and no proprietary IC for amplification.

3.1.2.8: TAL220B (5kg)

The final Load Cell option is the TAL220B (5kg). Again, the maximum capacity is 5kg, which is ideal for our design. This option benefits similarly to the previous SparkFun SEN-14729 (5kg), in that we would be designing the amplifier on our own, thus saving money in the manufacturing process.

3.1.2.9: Load Cell Selection

Table 3.4 - Load Cell Comparison

Product	Cost	Implementation
Phidgets CZL635 (5kg)	\$7 per unit + \$30 - \$95 for proprietary IC	Easy (Can implement amplifier IC into PCB design)
SparkFun SEN-14729 (5kg)	\$13.12 per unit	Moderate (Requires amplifier design and implementation)
TAL220B (5kg)	\$11.95 per unit	Moderate (Requires amplifier design and implementation, which is provided by the seller)

The load cells all function identically and all require an amplifier IC. What this means is that the main selling point for which one we choose is the cost. While the Phidgets CZL635 is the lowest cost per unit, it also necessitates the purchase of a proprietary IC that could potentially cost hundreds of dollars if one malfunctions. To that end, the TAL220B is the cheapest per unit comparatively to the other options. Additionally, the manufacturer offers the schematic design of the amplifier IC necessary for the load cell to operate. For these reasons, the TAL220B is the best option for our load cell selection.

3.1.3: Display Methods

The next consideration for our device is the means to which information about measured material and the device in general will be displayed. We will be comparing LCD and LED displays because they are the most commonly used display technologies. Below is information on both of them including their working principles, advantages, and disadvantages.

3.1.3.1: LCD Display

LCDs (Liquid Crystal Displays) use liquid crystals that are between two layers of glass or plastic. These crystals do not emit light directly but rather manipulate it from a backlight source to create an image. The structure of the display is in a grid of pixels which then consist of subpixels (Red, Green, and Blue) controlled by an electrical current to allow different amounts of light to pass through. The advantages of the LCD displays are their low cost, less power consumption, better in bright environments, do not suffer from burn in problems, and they can last a long time with minimal degradation in display quality. The disadvantages of the LCD display is their slower response time compared to the LED display.

3.1.3.2: LED Display

LED (Light Emitting Diodes) displays use light emitting diodes to produce an image. Each pixel is an LED display which consists of three LEDs (red, green, and blue) that light up at different intensities to form the colors needed to display

an image. LED displays do not require a separate backlight because they produce their own light. The advantages of the LED is their superior picture quality (due to providing better contrasts), energy efficiency, faster response times, slim design, and longer lifespan compared to LCD displays. The disadvantages of LED displays are their higher costs and risk of burn-ins due to use.

3.1.3.3: Display Method Selection

Table 3.5 - Display Method Comparison

Display Method	Cost	Implementation	Maintenance
LCD Display	Lower Cost	Easy	Moderate (may require backlight replacement or repairs overtime)
LED Display	Higher Cost	Moderate	Lower (LEDs have longer lifespans and require minimal maintenance)

3.1.3.4: LCD Displays

As we have chosen the method for displaying the data, we now have to consider what LCD display we want to implement into our design. For the following subsections, we will compare various LCD display options and determine which is most well suited for our implementation.

3.1.3.5: 16x2 Character LCD (HD44780 - I2C or Parallel Interface)

The 16x2 LCD is a widely used display that can show two lines of 16 characters each. It uses the HD44780 driver, which allows easy interfacing with microcontrollers like MSP430, Arduino, and ESP32. You can connect it using a parallel 4-bit/8-bit interface or an I2C module for simplified wiring.

The refresh rate is very fast (milliseconds range), ensuring an update time well below 1 second. This display is great for showing temperature readings, system status, and basic control options.

The HD44780 is a simple LCD screen that is easy to read and implement. This choice, although not the best looking, is practical and can work with our design to display the needed information.

3.1.3.6: 128x64 Monochrome LCD (ST7920 - SPI/I2C/Parallel Interface)

The 128x64 graphical LCD provides more flexibility than a character LCD, allowing you to display numbers, text, and simple graphics such as temperature graphs or heating status indicators. The ST7920 driver supports SPI, I2C, and parallel communication, making it easy to interface with microcontrollers.

The update speed is typically under 100ms per full screen refresh, ensuring real-time data display. This type of screen is practical if you need more detailed information or a better user experience compared to a simple character display.

3.1.3.7: 2.8-inch TFT LCD (ILI9341 - SPI Interface, Full Color)

The 2.8-inch TFT LCD with the ILI9341 driver is a great choice. It offers a 320x240 pixel resolution with full-color support, allowing you to create a graphical user interface (GUI) with buttons, charts, and real-time temperature readings.

This display communicates via SPI, ensuring fast updates typically 50-200ms per refresh. This is all dependent on the complexity of the graphics that are implemented. The ILI9341 is ideal for a touchscreen-based control panel. This would allow for a more modern feel to our device.

3.1.3.8: LCD Display Selection

Table 3.6 - LCD Display Comparison

LCD Display	Cost	Integration	Maintenance
16x2 Character LCD (HD44780 - I2C or Parallel Interface)	Low \$3-\$10	Easy integration with simple character display and uses I2C	Low as it is durable with no complex graphics. Has minimal issues
128x64 Monochrome LCD (ST7920 - SPI/I2C/Parallel Interface)	Moderate \$6-\$15	Moderate integration and requires SPI/I2C/Parallel interface. Also needs a graphics library to support simple graphics and texts	Low as it is reliable, but backlight or contrast may degrade overtime
2.8 inch TFT LCD (ILI9341 - SPI Interface, Full Color)	High \$10-\$30	Complex integration, requiring graphics library, more memory and processing power needed	Moderate as it is more fragile. Color display may degrade and the touchscreen may wear out

The final LCD Screen selection was based on cost efficiency, simple integration, and low maintenance. While the 2.8 inch TFT LCD (ILI9341 - SPI Interface, Full Color) is a more modern approach to an LCD screen its higher cost, lower durability, and complex integration make it a less optimal choice when looking for an LCD screen that can achieve the three specifications set above. The 128x64 Monochrome LCD (ST7920 - SPI/I2C/Parallel Interface) is a good middle ground when it comes to cost and integration. Its maintenance is also low which makes it a suitable fit for our device. The only problem is the backlight or the contrast could degrade overtime due to use. With the three specifications we set, the 16x2 Character LCD (HD44780 - I2C or Parallel Interface) is the most optimal LCD for our device. With its low cost, simple integration for character displays using I2C, and its high durability make it optimal for our device.

3.1.4: Label Printing Methods

In this section, we will be considering the type of printer that we will use for printing the labels for the milk bags. When considering the printer, we must consider how it will be integrated in our final PCB design, cost comparatively to other options, and power consumption.

3.1.4.1: Thermal Printing

Thermal printing uses heat to create images or text on special thermal paper. It is widely used in point of sale systems such as grocery receipts, barcode printing, and shipping labels. Direct Thermal Printing uses the special thermal paper to heat specific parts of the paper through a heated printhead to create an image or text. This process requires no ink, ribbon, or toner to produce text or images. Thermal printers have fast printing speeds, high durability, low maintenance due to fewer moving parts, and are ideal for barcodes, receipts, and industrial labels. The downside to thermal printers is that the labels created by them fade over time especially when exposed to heat and excess light. They are also limited to monochrome printing and special thermal paper is required for this type of printer.

3.1.4.2: Laser Printing

Laser printers use a laser beam and toner to create high quality prints at an efficient pace. They are commonly used in offices for documents, shipping labels and marketing materials. Laser Printers work by charging a rolling drum with static electricity, which is then shot at by a laser beam in specific places to remove the static charge. After some of the static has been removed in specific areas the roller is then covered in toner (a fine powder). The drum then rolls the toner onto the paper, which is then put into a fuser unit that heats and presses the toner onto the paper making the print permanent. The advantages of the laser printer is the high speed printing which is helpful for bulkier jobs, sharper professional quality text, no smudging due to fusing the toner to the paper, and toner lasts the longest on paper. While those sound ideal for a printer the advantages are quickly outweighed by the disadvantages. Those being that a laser printer is the most costly printer, it is also limited to standard paper, and laser printers are bulkier and heavier than other printers.

3.1.4.3: Inkjet Printing

Inkjet Printers spray tiny ink droplets onto paper to create text or images. They are widely used for home and office printing, as well as for photo and label printing. The printer is pretty basic when it comes to the process of printing. Inkjet Printers have a nozzle that releases ink droplets in a controlled pattern. The ink then quickly dries forming an image or text. The advantages of the Inkjet Printer is that it is affordable and widely available, good for high quality color printing and photos, can print on a variety of surfaces, and the printer is compact which saves space. The disadvantages of an Inkjet Printer is the cost of ink cartridges, its slow printing speed compared to a laser printer, the ink can smudge if it is not dried properly, and the printheads can clog if not regularly maintained.

3.1.4.4: Label Printer Selection

Table 3.7 - Label Printer Comparisons

Label Printer	Cost	Implementation	Maintenance
Thermal printer	Low \$50-\$100	Easy	Low (fewest moving parts, no toner or ink)
Laser Printer	High \$100-\$500	Moderate	Moderate (toner needs to be replaced often. Regular cleaning needs to take place)
Inkjet Printer	Moderate \$50-\$300	Easy	Moderate (regular cleaning of the printhead to avoid clogging)

After examining our options, we chose to go with the Thermal Printer. The laser printer and the inkjet printer are great choices, but with their costs going into the

hundreds we want a cheaper alternative. Not only is the cost a deterrent, but the maintenance is something we do not want to pass on to the customer as one more thing to do. With the Thermal Printer there is low maintenance at an affordable cost. Not only that, but with that it has the easy implementation out of the three printers. The only obstacle we will have to overcome with the Thermal Printer is finding one that can fit in our device's size dimensions.

3.1.4.5: Thermal Printers

As we have chosen to use thermal printers for our project, the following subsections will focus on comparing various thermal printers and choosing the one that can best be implemented into our project.

3.1.4.6: MUNBYN IMP001 58mm Thermal Printer (Serial/UART & USB)

The MUNBYN IMP001 is a compact 58mm (2.28 inches) thermal printer, making it well-suited for printing small labels or receipts. It supports serial (UART) and USB communication, allowing easy interfacing with microcontrollers like MSP430, Arduino, and Raspberry Pi.

The printer offers fast printing speeds (90mm/s) and high resolution for clear text and simple graphics. It is ideal for printing temperature logs, timestamps, and heater status updates. Additionally, it operates on DC 5V-9V, making it adaptable to embedded systems.

For direct microcontroller integration (TTL Serial/UART), the Adafruit Mini Thermal Printer is the best option.

3.1.4.7: PRIMUZ Micro Thermal Printer

The PRIMUZ Micro Thermal Printer is a small and efficient thermal printer designed for embedded applications. It communicates using a serial port and usb port, making it easy to integrate with a microcontroller. This printer supports thermal label paper sizes of 58 millimeters.

It prints efficiently and supports basic text and graphics. Since it operates at 12V-24V, it is well-suited for low-power applications like a water heater system where periodic data printing is required.

For high-speed printing and reliable data logs, the PRIMUZ Micro Thermal Printer is a solid choice.

3.1.4.8: ASPIRON 58mm Embedded Thermal Printer Module (UART & TTL Interface)

The ASPIRON 58mm Embedded Thermal Printer Module is designed for direct PCB integration. It supports TTL UART and RS232 serial communication, making it easy to connect with microcontrollers like MSP430, Arduino, or ESP32. This printer is commonly used in embedded systems, ATMs, kiosks, and industrial devices where real-time data printing is needed.

It supports 2-inch (58mm) thermal paper and can print at a speed of 50-80mm/s, ensuring quick updates on temperature logs, timestamps, and system alerts. The module operates on DC 5V-9V, making it compatible with standard power supplies in PCB-based designs.

The Aspiron also has mounting holes for secure attachment to a PCB or enclosure.

3.1.4.9: Thermal Printer Selection

Table 3.8 - Thermal Printer Comparisons

Thermal Printer	Cost	Integration	Maintenance
MUNBYN IMP001 58mm Thermal Printer (Serial/UART & USB)	Moderate \$40-\$80	Moderate as it uses UART or USB connection	Moderate maintenance as needed depending on use of paper, also dependent on jams.

PRIMUZ Micro Thermal Printer	Moderate \$45-\$65	Moderate, can be connected through USB or through serial port	Ventilation may be a concern, as overheating could possibly occur.
ASPIRON 58mm Embedded Thermal Printer Module (UART & TTL Interface)	Moderate \$45-\$70	Moderate; connected through USB or through serial port	Similar ventilation problems are possible, also may need additional protection from dust buildup.

Ultimately, what is the primary concern for our printer is the cost. All of the printers perform nearly the same, with similar communication methods. What differentiates them all is the ease of integration with respect to their cost. The best choice for our integration is going to be the Aspiron Embedded Thermal Printer, as it allows for serial communication and USB connection if desired. At its cost, it is extremely competitive with our other options, and is ideal for our design.

3.1.5: Heating Methods

This section will dive into the aspect of heating the milk. The safest and recommended way of heating breast milk is heating water to desired temperature and placing the milk in the water until heated to the desired temperature. With this consideration in mind, we must find a method to heat the water that is safest for the user and most effective. The following sections are the research into methods of heating water and their key differences.

3.1.5.1: Induction Heating

Induction Heating is the method of heating utilizing electromagnetic fields to heat elements. Using induction, an alternating current is passed through some coils of wires, which generates a magnetic field around the coil of wires. The magnetic field generated by the bundle of wires generates a current in another conductive material. This current experiences a resistance in the material, which generates heat. This method for heating is incredibly efficient, as it is not heating the heating element itself, only the conductive material, and environment

immediately surrounding the conductive material. Since induction is an efficient method of heating, consequently it is typically energy efficient, as less energy is wasted in the process of heating the conductive material. However, a major drawback of using induction is the physical space required in order to accommodate the induction coils. Furthermore, powering such a circuit would be complicated, as we need to have an alternating high frequency current to sufficiently generate enough current in the conductive material.

3.1.5.2: Conduction Heating

The next method viable in our project that we can implement for heating is conduction heating. Conduction heating uses direct contact to transfer heat from an element to a subject. Conduction heating is effective where localized heating is best, and solid materials are the subject of heating. In our case, conduction heating is an incredibly simple and effective potential solution to heating the milk. Since we will likely utilize a cup of sorts with water inside, having it in contact with a conductive heating element would be an effective means for heating the water. While Conduction is viable, it is not necessarily without flaws. Conduction as a heating method is inefficient, as it loses heat to its environment, which in our use case, is a significant drawback where we are trying to save energy and maintain the other components in our PCB.

3.1.5.3: Convection Heating

Convection heating is the final method to discuss, which uses the motion of fluids to heat a specific subject. This motion of fluids is caused by hotter elements rising in an area and cooler elements sinking in an area, which ideally distributes the heat evenly through a subject as the air moves constantly. By forcing further movement of the fluids through a fan or some other means, the heating efficiency can be increased without needing significantly more energy. The drawbacks of convection come with the nature of our project. Convection requires significant space in order to sufficiently circulate the fluid that is being heated and moved. Additionally, convection takes more time to heat the subject because it depends on the motion of the fluid. Since our project does utilize a fluid medium in order to heat the milk, this method will inherently be used. While it will be used by virtue of the fact that we will be using a medium to heat the milk, it is important to consider how other methods will interact with this

method, while also potentially acknowledging ways to improve the efficiency of our system.

3.1.5.4: Heating Method Selection

Table 3.9 - Heating Method Comparisons

Method	Efficiency	Implementation
Conduction	High (Element makes direct contact with subject, and direct heat transfer is better for small area heating)	Easy as the heating element is directly in contact with the water which would transfer the heat efficiently
Convection	Moderate (heats large spaces well, requires consistent fluid motion)	Moderate (implementation of forced convection would require moving parts to move fluid)
Induction	High (requires significant space for coils generating magnetic current, energy efficient)	Difficult (requires complex power management due to AC requirement for operation)

We chose conduction for our heating method due to its efficiency in heating. If our conduction is efficient enough then convection will also be present as we are heating a stainless steel cup filled with water. Although the operational cost of using conduction over the other two heating methods is higher, its efficiency and ability to heat an element directly is the primary reason for it being chosen.

3.1.5.5: Heating Elements

The following subsections will compare the various options for heating elements that we want to incorporate into our design. We also want to ensure that these heating elements are able to heat the milk in our system with efficiency and reliability.

3.1.5.6: Electric Heating Pad - 14cm x 5cm by Adafruit

The Electric Heating pad is a small rectangular resistor that heats up when a voltage is applied to it. This heating pad is flexible, thin, and is able to be mounted to a surface using an adhesive. The use of this pad is mainly for low-power heating applications which is ideal for our device. Control over this device can be done through a MOSFET or relay, which is connected to a microcontroller.

At only 14 cm x 5cm it is a relatively small heating pad which could be mounted on the stainless steel cup and used for conduction heating. The power required to heat up this heating pad is 5W. Which is a lower wattage for a heating application. The heating pad itself is also going to have to be paired with a temperature sensor to regulate how much voltage is being applied to it.

This Heating Pad is mainly used for maintaining mild warmth over a surface or heating small amounts of water in insulated conditions.

3.1.5.7: MECCANIXITY Silicone Heating Pad

The Silicone Heating Pad is a flexible pad that is used to distribute heat evenly over its surface. For its application it is mainly attached directly to a metal or plastic container using an adhesive backing. Much like the previous Electric Heating Pad it requires a MOSFET or a relay to control power input.

This device will also be used for conduction heating. At 10 watts of power, which is moderate out of the three heating applications, the Silicon Heating Pad is a break through the hard and weak points of traditional heaters. Due to its flexibility it is a more convenient way of getting a heating application closer to the heated object.

The Silicone Heating Pad is best used for small scale applications such as, for lab equipment or preheating surfaces.

3.1.5.8: MakerTechStore Cartridge Heater

Cartridge Heaters are metal cylindrical heaters that are designed to be inserted into a metal block or a reservoir of water. In our design the cartridge heater would be inserted into the reservoir of water placed into the stainless steel cup. Their application is based on high temperature heating applications due to their ability to heat up rapidly. Due to their ability to heat up quickly, a heat sink or proper mounting would be necessary to prevent overheating. Much like the other two applications mentioned above, a MOSFET or relay is required to handle the higher current draw.

The Cartridge heater would display conduction like we intend, but would also cause convection in the water. This is ideal as it would create an equally heated vat of water that is warm enough to heat up the milk. Its temperature control is best handled with a thermocouple or a high temperature thermistor. These would allow for the Cartridge heater to avoid overheating and inefficiency.

Cartridge Heaters are best used for direct water heating in a metal enclosure or heating metal surfaces that then transfer the heat to water.

3.1.5.9: Heating Element Selection

Table 3.10 - Heating Pad Comparisons

Heating Pad	Cost	Integration	Maintenance
Electric Heating Pad 14cm x 5cm by Adafruit	Low \$6	Easy to integrate as it is thin and flexible and can be attached to a surface by an adhesive. Requires MOSFET or Relay for control	Low maintenance as there are no moving parts. The adhesive will weaken over time
Silicone Heating Pad 15cm x 5cm by Meccanixity	Medium \$10	Easy to integrate as it is thin and flexible and can be attached to a surface through an adhesive. Requires MOSFET or Relay for control	Low maintenance as there are no moving parts. Very durable choice. Adhesive may degrade overtime

Cartridge Heater by MakerTechStore	Low \$4	Moderate to integrate as it requires a hole or slot to be inserted into a heating block or reservoir of water. Requires MOSFET or Relay for control	Medium maintenance as it can accumulate limescale. Requires regular cleaning.
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The Heating Element that we want to implement into our design is the Electric Heating Pad by Adafruit. Although it does not have a silicon protective layer, we are choosing to look past that for a cheaper option that can do without the protective layering. The thickness of the silicon layer is also another constraint we would have to work around when it comes to optimizing our device. We also chose the Electric Heating Pad because there is no maintenance when it comes to cleaning the heating application. With the Cartridge Heater the user will have to clean the surface for maintenance. While it is the best application to heat a vat or water we do not want our heating application to be a burden on the user. Electric Heating Pad is sufficient in what we want to incorporate into our design due to its low cost, easy integration, and low maintenance. We will have to look into how to prevent the degradation of the adhesive over time due to heat and use.

3.1.6: MCU

This section goes into considerations and requirements necessary for Microcontroller Unit (MCU) selection. The MCU is the central processing unit for embedded systems, which will be responsible for processing data and interfacing with sensors, communicating with outside systems, as well as any other potential processing needs. There are plentiful options to choose from in terms of MCUs, so comparison of options will give a better idea of which MCUs strengths best suit the needs of our design.

3.1.6.1: MCU vs FPGA

Something to be considered when designing our system is choosing whether to utilize an MCU for our design or an FPGA (Field-Programmable Gate Array). FPGAs offer significantly greater processing power and the potential for parallel

processing. However, using an FPGA comes with certain disadvantages for designing our system. FPGAs are highly complex and often difficult to program. Furthermore, FPGAs require a large amount of power to function.

With respect to our design, an MCU is likely to be the best option. MCUs are much cheaper than FPGAs, as they are power efficient and cost effective as they have fixed architecture. MCUs are also much easier to program, as you can use a high level language such as C. MCUs are ideal in situations where there is simple sensor interfacing, which is the case of our design. As the primary purpose of the MCU in the case of this design is to interface with the peripherals and not high-speed processing, MCU will be our choice.

3.1.6.2: MCU Selection

With the previous information, there are several factors to consider when choosing an MCU. The project entails several design specifications; firstly that the device itself can interface with a mobile app and database with ease. Additionally, the device must also be able to interface with our sensors that we will be integrating.

There are several microcontrollers that fit the basic requirements for our design, including bluetooth capability and the ability to interface with multiple sensors. Given the wide variety of choices, this allows us to choose the MCU that will best fit our needs and allow us flexibility in the future as the project evolves and develops.

3.1.6.3: ESP32

The ESP32 is an option for our project that stands out among other options for its cost effectiveness and capabilities. In terms of features, the ESP32 is incredibly feature dense, sporting Wi-Fi and Bluetooth capability, allowing for a wide range of wireless applications. Additionally, it houses a 2-core processor that can run at up to 240 MHz, potentially allowing for demanding applications where real-time data management and multitasking are of importance. The ESP32 can also have SRAM up to 520 KB of SRAM with support for I2C and SPI protocols.

Most important of the features is pins allowing for ADC and PWM. Seeing as we are looking for an MCU that will allow for multiple sensors to be integrated, the ESP32 has great potential. However, there are several drawbacks to the ESP32. Where the ESP32 lacks comparatively is in terms of power consumption; the ESP32 consumes more power comparatively due to the WiFi and Bluetooth capabilities. Furthermore, the accuracy of the ADC in the ESP32 is comparably worse to the other MCUs. Despite these drawbacks, the ESP32 is still potentially an excellent choice in circumstances where wireless communication and real-time processing are primary considerations.

3.1.6.4: STM32

The STM32 is a family of microcontrollers from STMicroelectronics. They offer high performance MCUs with low power consumption, while also supporting a wide variety of peripheral sensors. There are various models of the STM32 that support specific integrated circuit requirements, such as low-power consumption, or chipsets with expanded memory. The STM32 family outperforms other MCUS in real-time processing, accurate ADC results, and power consumption.

One major drawback of the STM32 family is that they lack Wifi/Bluetooth capability in the chip. However, it outperforms most MCUs in this context when it comes to accuracy. Furthermore, it can support significant peripherals, such as ADC channels. The chip is most competitive in scenarios in which precision in measurements is of great importance, such as ours.

Another drawback with the STM32 comes with the difficulty of programming. Compared to something like the ESP32, the STM32 requires specific software tools, namely STM32CubeIDE. Programming with the STM32 is much more industrial focused, and thus has less community and availability in terms of educational information to access. While the barrier to entry is higher due to difficulty to program, the device's performance largely makes up for this drawback. Ultimately, the STM32 family of microcontrollers is an excellent choice for a microcontroller in use cases where peripheral GPIO support and accuracy are high importance design factors, but lacks a key feature in WiFi and Bluetooth support without external devices.

3.1.6.5: Nordic nRF52840

The Nordic nRF52840 is another microcontroller option that we considered. It is designed with Bluetooth Low Energy (BLE) as a main priority, making it an ideal choice in networking projects with low power consumption. While it does offer BLE support, it does not support bluetooth classic.

While the MCU does not possess WiFi capability without external devices, it does utilise BLE 5.3 which is a longer range Bluetooth that is also a low-power variation of Bluetooth. Further in the vein of power consumption, the microcontroller has the ability to run on ultra-low power, and is a superior choice compared with other options for applications in which the device is going to be powered with a battery.

While the Nordic nRF52840 is a great choice for applications that may be constantly powered, requiring low power utilization, or for devices that are going to be portable, there are several downsides. As previously stated, it does not natively possess WiFi capabilities, only BLE. Furthermore, it has lower processing power than the previously mentioned microcontrollers. Comparatively, it is more expensive than the ESP32, but less expensive than certain models of the STM32. All considered, the Nordic nRF52840 is a viable option for applications in which the device is going to be consistently powered, and where long range local connectivity is important.

3.1.6.6: MCU Comparisons & Choice

Table 3.11 - MCU Comparisons

Name	WiFi	Bluetooth	RAM	Clock Speed	Cost
ESP32	Yes	Yes	520 KB	240 MHz	Low (\$ per unit)
STM32	No	No	512 KB - 1MB	84-216 MHz	High (\$\$ per unit)
nRF52840	No	Yes	1 MB flash, 256 KB RAM	64 MHz	Medium (\$-\$ per unit)

Based on the table above, we will choose the ESP32. For our project, the ESP32 series of microcontrollers is most feature complete; it enables both bluetooth support as well as WiFi support, which is a main concern for our MCU of choice. While the primary concerns of ADC reliability are valid for our project, sacrificing Bluetooth and WiFi capability is not ideal, as adding separate modules for those could be potentially costly in the final design.

3.1.7: User-Input Device

This section will cover the various user-input devices that will allow the user to directly interact with the system. These devices should serve as physical or digital control elements that, when interacted with by the user, will send signals to the digital system. Our system makes use of multiple peripheral devices, so we might need multiple different types of input devices to interact with them.

3.1.7.1: Switch

Switches are one of the most basic user-input devices that make use of toggles to directly interact with a system. There are multiple different types of switches, but most of them must be actuated, to change from one state to the other. Depending on the state of the switch, both the system and user will know whether a certain function of the device is active or inactive. Switches are the most useful in situations where a function of a system is determined by a single toggle. In the case of selecting whether or not the milk in the milk bag is allergen free, the user would only need to check the state of the corresponding switch.

3.1.7.2: Button

Buttons are also one of the most basic and versatile user-input devices that can be used in a multitude of ways in a system. One of the greatest advantages to using buttons is their simplicity in implementing them into a system as they tend to be both user friendly and easy to use the signals they send when pressed to interact with the system. For our system, we would need to make use of multiple buttons, each with their own function. The biggest difference between buttons and switches is that buttons have the option of being toggled multiple times, allowing for the same signal to be sent repeatedly to the system. In the case of selecting the size of the milk bag being weighed, we have the options of having

three different buttons (for each size) or using a single button that, when pressed, can send a signal to change the size.

3.1.7.3: Touch Screen

A touch screen is a type of display that can be directly interacted with by the user's touch to send signals to the system. Touch screens are different from both switches and buttons as they act as an input/output device, with the touch panel acting as an input and a visual display as an output. One of the greatest advantages of a touch screen is that it allows for the system to only be connected to a single input/output device, that a user can interact with to send the same signals that would require multiple different buttons or switches. However, the biggest drawback to touch screens is the drastic increase in price compared to the other input devices, as well as the difficulty in coding such a device to be implemented in the system.

3.1.7.4: User-Input Device Selection

Table 3.12 - User-Input Device Comparisons

Input Device	Ease of Use	Versatility	Code	Cost
Switch	Easy	Low	Easy	Low
Button	Easy	Moderate	Easy to Moderate	Low
Touch Screen	Moderate	High	Hard	High

3.1.7.5: Buttons

For our project, we decided that buttons would work best for our system as they are cheap, user friendly, relatively easy to code into our system, and can be used in multiple ways. We must now decide which types of buttons to be implemented into our system.

3.1.7.6: Momentary Button

The momentary button is the most basic type of push button that most are familiar with. This type of button is always in the “off” state, until the user presses the button. As long as the button is pressed/held down, it will send a signal to the system until the user releases the button. For our project, we don’t expect the user to constantly hold a button down to activate a function of the system, so instead our code will focus on the initial detection of the signal. This type of button comes in multiple different shapes and forms, the most useful one for our project being the LED version.

3.1.7.7: Latching Button

The latching button is also a type of push button, with the key difference being that it makes use of maintained contact. This type of button works similar to a switch, in that it remains in the “on” state when pressed and requires another press to return to the “off” state. As long as the button is in the “on” state, it will be constantly sending a signal to the system. This type of button also has the option of having an LED version, which could be useful for showing the user which state the button is in.

3.1.7.8: Button Selection

Table 3.13 - Button Comparisons

Buttons	Variations	Integration	Cost
Momentary	High	Easy	Low
Latching	Moderate	Moderate	Moderate

Similar to our decision to use buttons instead of switches for our project, we decided that using momentary buttons would be for the best. Momentary buttons come in more forms, allowing for them to be used in multiple different ways depending on each function of our system. However, the biggest reason why momentary buttons are better for our project is that most functions of our system require repeated signals. The only situation that a latching button could be better is when the user is selecting whether or not the milk is allergen free. In this case we might use a single latching button to act as a toggle for the milk being allergen free, but use momentary buttons for all of the other functions.

3.1.8: Power Supply

For this section, we will be delving into the details of powering our system. Our system will feature a variety of peripheral devices and measurement tools that we will need to power. The following section will discuss the methods and specific technological methods we considered for the design of our system.

3.1.8.1: Lithium Ion Battery Pack

The Lithium Ion Battery Pack is one of the most commonly used power sources for small electronic devices. They have various forms, such as prismatic, cylindrical, and pouch cells and typically a single lithium ion cell operates around 3.7 Volts. This voltage can be changed through series or parallel configuration to reduce or increase voltage for the demand needed. Their high energy density allows them to store a significant amount of power relative to their size and weight, making them perfect for a portable electronic device.

However, Lithium Ion Batteries require careful management to ensure safe and efficient operation. A Battery Management System (BMS) would need to be implemented to prevent overcharging, deep discharge, and overheating. The BMS would prevent damage done to the lithium ion battery and prevent safety risks like thermal runaway. When using the Lithium Battery pack the charging circuits must also match the specific requirements of the battery pack to prevent damaging the battery cells. Even with these complications, Lithium Ion Batteries are favored for their rechargeability, long life cycle, and their relatively low self discharge rate.

The application for the Lithium Ion Battery Packs mainly include handheld devices and remote sensors.

3.1.8.2: Grid Power

Using Grid Power is a simple and effective way to power an electrical device as long as there is a power outlet available. An adapter must be implemented so that a standard input AC voltage of 110 or 220 can be converted into a lower DC voltage that is suitable for the device, such as five, nine, twelve, or twenty-four volts. The range of power can vary from a few watts to our intended 60 watt maximum.

The main advantage of using Grid Power is its reliability and convenience. Unlike the previously mentioned Lithium Ion Batteries, there is no need for recharging or replacement. When it comes to using Grid Power there is no uninterrupted power supply as long as the device is plugged into a power outlet. The plugs that are in the wall have adapters that come with a built-in voltage regulator to ensure a consistent output voltage, which would prevent fluctuations that could damage the electronics in the device. While Grid Power is reliable and convenient, the dependency on a wall outlet makes our device unsuitable for being a portable device.

Additionally, when using Grid Power we need to select an adapter that matches the voltage and current requirements of the device to prevent damage. Some high-quality adapters include protections against overvoltage, overcurrent, and short circuits, further ensuring the safety of connected electronics.

3.1.8.3: Small Solar Panel with Battery Storage

For a greener and offgrid option, a small solar panel system with a battery storage could be implemented. The solar panel converts sunlight into electrical energy, which then could directly power the device or store in the battery for later use. The power output of the solar panel depends on its size and efficiency, but most of the small panels have a power output ranging from 10 watts to 60 watts, which is ideal for our device.

The biggest constraint when using solar panels is the dependency on sunlight to power the device, as well as a battery storage system. To ensure overheating, overcharging, and deep discharge do not occur a charge controller is necessary to regulate these functions. The stored energy from the battery will allow a constant and reliable power source that can be accessed during cloudy days or nighttime. While it is a greener option from the two previously mentioned options, the efficiency of the machine depends on the solar panel orientation, weather conditions, and the battery capacity.

Solar-powered systems are commonly used for off grid and remote applications, such as outdoor sensors and renewable energy projects. Compared to the other two previously mentioned options, the solar panel will be more costly to implement, but they offer a long-term benefit through lower operational costs and sustainability. With advancements in solar panel technology and battery

storage continuing to improve in efficiency, this could make solar energy increasingly viable for powering our device.

3.1.8.4: Power Supply Selection

Table 3.14 - Power Supply Comparisons

Power Supply	Cost	Integration	Maintenance
Grid Power	\$5-\$50, depending on voltage and current requirements	Requires a power jack and voltage regulation circuit	Low, as it relies on existing power infrastructure
Battery Storage	\$20-200, depending on capacity, chemistry, lifespan and energy needs	Requires charging circuit, battery management system and protective enclosures	Medium, because of charging cycles and the battery degrading over time
Solar with Battery Storage	\$50-\$500, depending on solar panels, charge controllers, a battery storage system, and power output	Requires solar panels, charge controllers, and power management circuitry	High, because of environmental exposure the solar panels and batteries degrade overtime

The final power supply selection was based on cost efficiency, simple integration, and low maintenance. While the battery pack is a phenomenal idea we wanted to incorporate into our design initially, we chose not to due to the included battery management system and possible degradation of our devices battery over time. The solar panel with battery storage was also a great idea and was the greener option when it came to all three of our choices, but due its dependency on light and the problems with battery degradation we chose to go an alternative route. We wanted something that could sufficiently power our device with efficiency, be reliable to constant use, and have low maintenance. We opted to go with Grid Power because it hit all three of our categories listed above. The Grid Power, although it makes the device not portable, is the most reliable and low maintenance option while also being the most efficient. In the

long run it is also the lowest cost to implement being that it relies on an existing power infrastructure and all it requires is a power jack and voltage regulation circuit.

3.1.8.5: Grid Power

For our power supply we have chosen the method of Grid Power. We must now consider how we want to connect our device to the grid. There are many options, so for this section we will discuss several options that could potentially be used.

3.1.8.6: MEAN WELL LRS-100-24 (SMPS Adapter)

This open frame power supply provides 24V at 4.5 amps (108 Watts). This is ideal for a medium power application such as our device. With a built-in Universal AC input meaning it can accept 110V (60 Hz) or 220V (50 Hz) making it suitable for grid power world wide. The LRS-100-24 also has a high efficiency at 88% which is great for reduced heat generation. Not only does it have reduced heat generation, but being that it is in a ventilated metal case it can allow for passive cooling without a fan. The dimensions of the LRS-100-24 are also a great feature as it is compact which is easy for installation purposes. It also comes with some protections such as short circuit, overload, and overvoltage to ensure the components in our device do not get harmed.

3.1.8.7: Alitove Power Supply Adapter(AC/DC Adapter)

The Alitove AC/DC Power Supply provides a stable 24V DC output at 10A (240 Watts). Also with a built-in Universal AC input it too can accept 110V (60 Hz) or 220V (50 Hz). This adapter can power the necessary requirements for our project being that the power output is 240 Watts. With its compact design, it is easy to integrate into the design process as there will not be any bulky wires to interfere with space. This AC/DC Adapter comes with some built in safety protections, including overvoltage, overcurrent, and short circuit protection which is a preventative measure to ensure no damage to our devices circuit. Another great feature about this adapter is there is no internal fan making it noise free. Now the heating aspect is taken care of with a passive cooling feature and an efficiency of 85% which will also reduce heat generation.

3.1.8.8: Bel Signal Transformer with Rectifier Circuit

The Bell Signal Transformer is a step down transformer designed to convert 120V AC input into a lower AC Voltage. This lower AC voltage is then put through a Rectifier circuit. This Rectifier Circuit will take the input AC voltage and then only allow the positive half of the AC sinusoidal wave to pass through. Once that is completed, capacitors will be put into place to flatten out the sine wave to create a constant DC voltage that we can use in the circuit. If we go with this power supply we will have to build and connect everything by hand, but that allows us to create our power supply to the specific requirements needed by our PCB. The downside of doing this power supply is that this will be the most tedious as we will have to build and connect everything by hand. Another problem we will have to face if we try this power supply is the cost of all of the individual parts.

3.1.8.9: Grid Power Selection

Table 3.15 - Grid Power Comparisons

Product	Cost	Implementation	Maintenance
Bel Signal Transformer with Rectifier Circuit	Moderate (\$30-\$50)	Hard (We will have to self build everything to our design specification)	High (with a lot of individual parts, there is a possibility of having to fix individual parts if problems arise)
LRS-100-24 (SMPS Adapter)	Low (\$17)	Easy to Moderate (Comes pre-built)	Moderate (cleaning may need to occur to prevent dust build up)
Alitove Power Supply(AC/DC Adapter)	Low (\$23)	Easy to Moderate (Comes pre-built)	Moderate (cleaning may need to occur to

			prevent dust build up)
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We chose to go with the Bel Signal Transformer with Rectifier Circuit because it will allow us to create a power source that can fulfill our device's power consumption. Although implementation will be hard, as well as maintenance and a higher cost, we want to go this route so that we have a more hands on approach with our power supply creation.

3.1.9: Communication Protocol

For the final section of our hardware research, we will be going over the various communication protocols and determining which one will best be implemented for our project. Communication protocols are a set of rules that allow for multiple devices in a system to communicate with each other and enable data to be transferred efficiently.

3.1.9.1: Serial Peripheral Interface (SPI)

The Serial Peripheral Interface (SPI) is a synchronous serial communication protocol that can be used for high-speed data transfer between a microcontroller (Master) and peripherals (Slaves), such as sensors, displays, and memory chips. SPI follows a Full-Duplex configuration, meaning that data can be simultaneously transmitted in both directions between the master and slaves using MOSI/MISO communication. This allows for the devices to function continuously without interruption.

3.1.9.2: Inter-Integrated Circuit (I2C)

The Inter-Integrated Circuit (I2C) is a synchronous serial communication protocol that can be used for short-distance data transfer between multiple masters and multiple slaves using an I2C bus structure. Such a structure is especially important when there are multiple microcontrollers in a device system. I2C follows a Half-Duplex configuration, meaning data can be transmitted in both directions, but not at the same time.

3.1.9.3: Universal Asynchronous Receiver/Transmitter (UART)

The Universal Asynchronous Receiver/Transmitter (UART) is an asynchronous serial communication protocol that transmits data bit by bit, without using a shared clock signal to synchronise data between the transmitter and receiver. What makes UART different from other communication protocols, is that it transmits data using two wires connected between the transmitter and receiver. UART has multiple distinct ways of configuration, such as Simplex, Half-Duplex, and Full-Duplex.

3.1.9.4: Communication Protocol Selection

Table 3.16 - Communication Protocol Comparisons

Protocol	Communication	Configuration	Data Transfer Rate	Amount of Devices	Complexity
SPI	Synchronous	Full-Duplex	>10 Mbps	Multiple Slaves	Moderate
I2C	Synchronous	Half-Duplex	100 Kbps	Multiple Masters & Slaves	High
UART	Asynchronous	Simplex, Half-Duplex, Full-Duplex	1 Mbps	Single Master to Slave	Low

For our project, we decided that the Serial Peripheral Interface (SPI) communication protocol was the best fit for our system. Compared to the other protocols, it has a significantly higher data transfer rate, with a moderate amount of complexity depending on the scale of the system. The SPI protocol is also best for our system as we plan on having only a single microcontroller (Master) control multiple other devices (Slaves).

3.2: Software Technologies

A crucial factor in our design is ensuring accurate and timely data flow from the milk-weighing device to the caregivers who rely on this information. Beyond simply measuring the milk's weight, the system must seamlessly record, store, and process these readings so parents can know precisely when they need to replenish their supply. To achieve this, our software must not only retrieve data from the hardware but also maintain a robust and user-friendly interface for real-time updates and historical tracking. In this section, we explore the various software technologies—ranging from front-end development tools to backend frameworks and database options—that collectively form the backbone of our solution. By carefully selecting, comparing, and implementing these technologies, we ensure our system is responsive, accurate, and capable of delivering notifications whenever inventory falls below user-defined thresholds.

3.2.1: Mobile Application Languages

In order for our milk-weighing system to provide real-time updates and easily accessible information, a reliable mobile application is essential. This app must present users with up-to-date measurements, track historical usage, and seamlessly interface with our backend for database alerts on milk supply and expiration. To accomplish these goals, we need to select a development language capable of delivering responsive performance, rich user interfaces, and simple integration with the hardware's data output. In the following section, we will examine various mobile application languages—each with its own strengths, ecosystems, and potential trade-offs—as they relate to building a robust, user-friendly platform for parents who rely on continuous insight into their child's feeding schedule. By carefully evaluating these options, we can ensure the final app design is well-suited for both day-to-day convenience and long-term system maintainability.

3.2.1.1: Swift

Swift is Apple's modern programming language tailored for iOS development. It compiles to native code, providing high performance and efficient memory management. Consequently, Swift-based applications are generally fast and reliable, achieving robust performance without sacrificing quality.

A key advantage of native development with Swift is the direct access to iOS SDK features and hardware. This capability can lead to optimal performance for

tasks requiring intensive processing. Swift also benefits from Apple's well-supported toolchain, primarily Xcode, which streamlines development workflows. However, this approach is inherently platform-specific, meaning Swift apps are limited to iOS devices unless additional frameworks or platforms are leveraged.

Swift's community continues to expand at a notable pace (around 21% annual growth), positioning it as the predominant language for iOS development over its predecessor, Objective-C. This broad base of experienced iOS developers can ease the process of sourcing talent, although cross-platform flexibility may be limited compared to other frameworks

3.2.1.2: Flutter & Dart

Flutter, developed by Google, is a cross-platform UI toolkit that utilizes the Dart language to build both iOS and Android applications from a single codebase. It achieves near-native performance through ahead-of-time (AOT) compilation and by rendering its interface directly via the Skia graphics library. In practical tests, Flutter's runtime performance on iOS approaches that of Swift, showing only minor variances in CPU, memory, and GPU usage. While heavy, graphics-intensive animations may perform slightly better under purely native solutions like Swift, most use cases will experience comparable responsiveness and frame rates.

From a development standpoint, Flutter streamlines the process with features such as hot reload and a comprehensive set of pre-built UI widgets. This often results in reduced code volume and faster iteration cycles, enabling quicker time-to-market. The single codebase also supports deployment to multiple platforms, lowering maintenance overhead for projects targeting both iOS and Android.

Dart, the language powering Flutter, has seen swift growth—approximately 33% in 2023—leading to around three million users. While this increase is driven largely by Flutter's popularity, the pool of experienced Dart developers still lags behind more established languages like Swift. Another consideration is app size: Flutter's engine includes all the necessary components for cross-platform operation, resulting in binaries that are generally heavier than those produced through purely native development. Nevertheless, with Google's backing, a rapidly expanding community, and an extensive repository of open-source

packages, Flutter remains a strong contender for cross-platform app development.

3.2.1.3: React Native

React Native is a popular open-source framework developed by meta that allows developers to build mobile applications using JavaScript and React. It enables one codebase to run on both iOS and Android devices, which can significantly reduce development time and maintenance overhead. For our project, React Native was considered as a possible approach for the mobile companion app that connects to the breast milk weighing device. Its component-based structure and live reloading features make it ideal for rapidly building and testing user interfaces, especially for data-driven apps like ours that require regular updates and real-time display of weight, date, and inventory alerts.

React Native also has a strong ecosystem of libraries, including tools for handling Bluetooth and QR code scanning, which could align well with the core functions of our system. However, the major limitation we encountered was related to Swift-specific development. Since our final mobile app is focused exclusively on iOS, using Swift directly in Xcode provided more native functionality and tighter integration with Apple's APIs. This is especially important for device pairing, background tasks, and accessing low-level Bluetooth features required for a smooth and reliable user experience. While React Native offers many advantages in cross-platform development, we ultimately chose to prioritize a native Swift-based solution due to better long-term compatibility with the hardware and the operating system.

Another challenge with React Native is performance optimization. While it performs well for general UI and typical mobile tasks, it may fall short when dealing with high-frequency real-time data, hardware communication, or advanced animations. This is because React Native uses a JavaScript bridge to communicate with native components, which can introduce delays or performance bottlenecks, especially in tasks requiring rapid state updates—something that could impact the responsiveness of our app when receiving new weight or temperature readings from the device.

3.2.1.4: JavaScript (Backend Development)

While JavaScript isn't typically utilized for native iOS interfaces, it remains a central technology in backend development through platforms like Node.js. Teams with a background in front-end web development may find leveraging JavaScript on the server particularly appealing due to the prospect of code reuse and maintaining a single, unified language across both the frontend and backend.

Node.js, which runs on Google's V8 engine, is known for its high throughput and non-blocking I/O model. This event-driven, asynchronous architecture allows efficient handling of numerous concurrent connections, making it ideal for real-time applications, streaming data, or IoT scenarios. However, Node.js performs less optimally with CPU-intensive tasks, as these can monopolize the single-threaded event loop. One common approach is to offload such operations to worker threads or external microservices.

JavaScript's flexibility and extensive library ecosystem—primarily through the npm registry—further streamline development. With roughly 22+ million JS developers worldwide, there is robust community support and ample resources. Notably, TypeScript, which adds static type-checking to JavaScript, is also compatible with Node.js, offering an extra layer of reliability for complex projects. Given its performance profile and vast community, JavaScript (via Node.js) is well-suited for server-side components in this project, though it remains separate from the native iOS interface development.

3.2.1.5: App Language Selection

Table 3.17 - App Language Comparisons

App Languages	Mobile Applications	Developer	Strengths	Weakness
Swift	iOS	Apple	High performance & memory management	Limited to iOS devices
Flutter & Dart	iOS &	Google	Reduced	Binaries

	Android		code volume & faster iteration cycles	generally heavier leading to larger app sizes
JavaScript	iOS & Android	Netscape	Allows for unified language across frontend & backend	Not generally used for iOS interfaces
React Native	iOS & Android	Meta(Facebook)	Access to a big library ecosystem	Code syntax more complex, performance optimization

Based on our project requirements—particularly the need for native performance, seamless integration with iOS hardware, and a future-proof technology stack—our team has chosen Swift as the primary language for iOS application development. Swift’s compilation to native code provides the high efficiency and memory management necessary for a responsive and stable user experience, which is critical for applications that demand real-time functionalities. Additionally, Apple’s robust tooling around Swift, particularly Xcode, streamlines the development process and simplifies the integration of iOS frameworks, sensors, and system-level features.

While alternative frameworks and cross-platform solutions exist, Swift’s direct access to Apple SDKs offers a clear performance advantage and minimal overhead—an important consideration for battery usage, user interface responsiveness, and secure data handling. Though adopting Swift naturally limits our codebase to the iOS ecosystem, this trade-off aligns with our goal of delivering an optimized, platform-specific experience that leverages the full capabilities of iOS devices. As the project evolves, we will continue to evaluate ongoing language advancements and ecosystem developments, but Swift

presently remains the most suitable choice for an efficient, high-quality iOS application.

3.2.2: Backend Frameworks

In order to store, process, and securely manage the data coming from our breast milk weighing and labeling device, a reliable backend system is essential. This backend must be able to handle frequent updates—such as new weight readings—while also providing robust data storage, user authentication, and security measures. It serves as the central hub that bridges the hardware device and the mobile app, ensuring that measurements are consistently logged, easily retrievable, and fully protected. In the following subsections, we examine several popular backend technologies—Node.js, Django, and Ruby on Rails—to determine which framework might best meet our needs in terms of performance, scalability, developer productivity, and real-time capabilities.

3.2.2.1: Node.js (JavaScript)

Node.js is a runtime environment for server-side JavaScript that utilizes an event-driven, non-blocking I/O model. This architectural choice makes Node especially adept at handling numerous simultaneous connections without monopolizing system resources, which proves advantageous in scenarios requiring real-time data transfer or frequent updates to multiple devices. For instance, if our breast milk measurement device streams temperature data or sends continuous status notifications to the mobile app, Node's efficient concurrency management would facilitate real-time event handling.

Under the hood, Node runs on the Chrome V8 engine and uses a single-threaded event loop to coordinate incoming requests. Rather than spinning up a new thread for each connection, Node places requests into a queue and processes them asynchronously. This approach yields high throughput for I/O-bound workloads such as database queries or sending notifications. Well-known organizations have adopted Node for its lightweight design and ability to handle numerous open connections concurrently.

A key benefit of Node.js is the unified language stack. Development teams can code both client-side interactions and backend logic using JavaScript, simplifying collaboration and reducing the need to switch between languages.

Node itself provides only the core runtime; security features such as request validation, authentication, or rate limiting require external modules like Express.js and specialized middleware. Incorporating these measures is crucial if the application handles sensitive information—particularly relevant in health-related contexts.

Regarding computationally intensive tasks, Node’s single-threaded model can introduce bottlenecks. Demanding operations, such as complex image analysis or resource-heavy data processing, may block the event loop and delay other tasks. However, in the context of measuring breast milk volume or performing routine database operations, this limitation is unlikely to pose a major issue. If the project eventually expands to require heavier processing, resource-intensive jobs can be delegated to external services. Overall, Node.js offers strong performance, supports real-time interactions, and aligns well with a modern backend approach for connected devices like our milk-weighing system.

3.2.2.2: Django (Python)

Django is a high-level Python framework distinguished by its “batteries-included” philosophy, offering an extensive feature set from the outset. This includes an object-relational mapper (ORM) for seamless database interactions, a configurable admin panel for efficient record management, and built-in safeguards against common exploits like SQL injection, cross-site scripting, and cross-site request forgery. These default features allow projects to begin rapidly without relying heavily on third-party integrations.

For applications with significant data storage needs—such as detailed logs of temperature readings, timestamps, or user records—Django’s ORM can substantially simplify database queries and handling. Highly trafficked platforms such as Instagram and Pinterest have successfully scaled on Django, demonstrating its ability to accommodate large volumes of data and user requests. The framework’s architecture also supports horizontal scaling by distributing load across multiple web servers, with caching and database layers absorbing heavier workloads.

Security is a cornerstone of Django, making it particularly appealing if your application requires user authentication or the storage of sensitive health information. Though Python may not match compiled languages in raw speed or Node.js in asynchronous capabilities, its performance is typically sufficient for

standard web service scenarios. Meanwhile, features like the auto-generated admin panel significantly streamline development, enabling the team to focus on core functionality rather than configuring administrative interfaces. If the team values a structured environment with built-in security measures and straightforward user management—and is comfortable with Python—Django offers a powerful and efficient choice for backend implementation.

3.2.2.3: Ruby on Rails

Ruby on Rails, is a web framework built on the Ruby programming language that emphasizes rapid development and streamlined workflows. Adhering to the Model-View-Controller (MVC) pattern and the principle of “convention over configuration,” Rails allows teams to launch web applications with minimal manual setup. The scaffolding tools can swiftly generate base code for models, views, and controllers, enabling a quick start and letting developers focus on fine-tuning specialized features—such as a web dashboard to accompany a breast milk monitoring device.

Rails is supported by a vast collection of Gems, or pre-built libraries, which can handle tasks ranging from file uploads to background job processing. This ecosystem accelerates feature implementation without the overhead of writing everything from scratch. Well-known services like Shopify and GitHub operate on Rails, demonstrating its capacity for handling substantial workloads when optimized effectively. However, Rails generally consumes more server resources at scale compared to Node.js, so additional server capacity may be necessary to maintain performance under heavy traffic.

On the security front, Rails defaults to safe practices, automatically escaping user input to guard against vulnerabilities like SQL injection and cross-site scripting. It can also be configured to meet stricter standards where sensitive data—such as personal health information—demands encryption and rigorous authentication procedures. While Rails does not specialize in high-frequency real-time updates, it remains well-suited for projects requiring rapid prototyping or moderate concurrency. For teams aiming to build and deploy a robust

backend with minimal setup time, Rails offers a polished, developer-friendly experience that can swiftly bring a product to market.

3.2.2.4: Backend Framework Comparisons

Choosing the right backend technology ultimately depends on our team’s expertise, project timeline, and specific requirements for speed and security. Node.js, with its event-driven architecture, excels at handling multiple concurrent connections, making it especially suitable if the breast milk device needs real-time updates or push notifications to a mobile app. On the other hand, Django’s battery-included philosophy and robust default security measures allow for rapid development of data-centric applications, which can be a huge advantage if the system frequently stores and processes a large volume of records. Meanwhile, Ruby on Rails stands out for its streamlined setup and convention-over-configuration approach, reducing the time it takes to implement and maintain new features—ideal for projects with tight deadlines or smaller teams. Each framework has proven capable of scaling to accommodate growing user bases, but the path to scalability can differ—Node.js emphasizes non-blocking I/O, Django leverages its ORM and caching layers, and Rails relies on multiple servers and optimized database usage. By considering both the nature of our device’s data flow and the level of real-time interaction required, we can identify which backend technology best aligns with our development goals.

Table 3.18 - Backend Framework Comparisons

Framework	Language	Best Fit	Development Speed	Performance	Security	Scalability
Node.js	JavaScript	Real-time apps & concurrency	Medium	Excellent for I/O-bound task	Requires additional libs (e.g., Express + middleware)	Horizontal scaling; easy concurrency mgmt

Django	Python	Data-heavy or content-driven projects	High	Good for web applications	Built-in protections; strong defaults	Horizontal scaling via more servers
Rails	Ruby	Fast prototyping & startup-friendly	High	Slower than Node.js, can handle large traffic with optimizations	Built-in secure defaults	Scales via multiple instances & caching

3.2.2.5: Backend Framework Selection

We ultimately chose Node.js because it delivers the best balance of speed, scalability, and compatibility with real-time data streams coming from our milk-weighing device. Among the frameworks we compared, Node's event-driven architecture is especially well-suited for handling multiple concurrent connections without the overhead of threading, meaning it can gracefully manage frequent updates from the hardware device (such as weight or temperature readings) and swiftly push notifications to the mobile app. The ability to write both frontend(if needed) and backend components in JavaScript also streamlines development, allowing the team to reuse skills and libraries across the entire stack rather than switching between languages. Although Node requires extra diligence in configuring security through frameworks like Express.js and associated middleware, its lightweight I/O model and active community more than compensate by offering an adaptable ecosystem for building and scaling backend services. This combination of real-time capabilities, language consistency, and community support makes Node.js the most suitable choice for our project's backend.

3.2.3: Database Options

The PUMPED project includes a hardware device that weighs breastmilk and prints labels with information about volume, date, and time. A companion mobile app then tracks storage details and sends notifications when supplies are low or about to expire. To support these features, a reliable database must be chosen to store user data, breastmilk bag information, and any additional properties that might evolve in the future. The choice between different database solutions

depends on data structure requirements, potential scalability, and ease of integration with both the backend and the iOS application.

3.2.3.1: PostgreSQL

PostgreSQL is an open-source relational database that organizes data in structured tables, ensuring consistent handling of transactions. This can be especially beneficial for storing precise records, such as the total number of milk bags or any updates regarding the relocation of stored items. PostgreSQL also supports JSON fields, which allows for storing more flexible data if new attributes need to be added later, without sacrificing the core reliability of traditional relational schemas.

Vertical scaling is straightforward, and replication can be set up to manage a growing number of read requests. Advanced features like complex queries, indexing, and multi-table joins mean that PostgreSQL remains strong if the application logic requires intricate data relationships and transactional integrity. Integration is widely supported across major backend frameworks, and the iOS app would simply communicate through an API layer. This makes PostgreSQL a dependable solution when data integrity and structured queries are vital for the PUMPED system.

3.2.3.2: MongoDB

MongoDB is a document-based database that stores data in JSON-like documents rather than structured tables. This setup provides a high degree of flexibility, allowing the application to add or modify fields with minimal effort. A breastmilk inventory app might benefit from this approach if it intends to include varying types of information, such as nutritional content or additional metadata about each milk bag, because each record can adapt as needs change.

MongoDB was also designed to scale horizontally, so distributing data across multiple servers is more straightforward if the application must eventually handle a high volume of writes or very large datasets. The system favors quick writes and simple document retrieval, which can be advantageous in scenarios where performance is crucial and data relationships are relatively simple. However, for certain cases involving multi-document updates, MongoDB transactions have to be used carefully to maintain consistent data. If a Node.js backend is chosen,

MongoDB integrates seamlessly, making it a reasonable option for projects that require flexibility and potential horizontal growth.

3.2.3.3: MySQL

MySQL is a long-established SQL database known for stability and speed, particularly under read-heavy workloads. It uses a structured table format, where data is organized in rows and columns, ensuring that transactions involving breastmilk inventories and user information remain consistent. This is especially useful if the PUMPED system relies on straightforward queries for tasks such as retrieving available milk volume or checking expiration dates.

Scaling MySQL typically involves vertical enhancements or adding replication for read-heavy scenarios. Although sharding MySQL is not as direct as with some other databases, it has been done successfully in large-scale deployments, indicating that with sufficient engineering effort it can accommodate substantial growth. MySQL also supports JSON fields in newer versions, which can be helpful if semi-structured data needs to be stored. It integrates well with most development frameworks and can be set up on managed cloud services, making it an accessible and reliable choice for teams that prefer a well-known relational approach.

Table 3.19 - Database Comparisons

Database Option	PostgreSQL	MySQL	MongoDB
Data Model	Relational (SQL)	Relational (SQL)	Document (NoSQL)
Structure	Strict schema; can store semi-structured data via JSON fields	Strict schema, well-suited for basic tables/joins	Flexible schema (JSON-like documents)
Performance	Good for complex queries and large datasets	Typically fast reads, widely used	Excellent for high write loads and large-scale, unstructured data
Scalability	Vertical scaling common; horizontal replication and sharding supported	Vertical scaling + read replicas; sharding possible with extra tooling	Horizontal scaling and sharding built-in

Transaction	ACID-compliant; advanced SQL features like window functions	ACID (with InnoDB engine); robust for standard operations	Multi-document transactions introduced more recently, optional use
Use Cases	Ideal for structured data, complex queries, strict integrity	Perfect for typical web applications or smaller, simpler database needs	Great when flexibility is paramount or data models evolve frequently
Security	Offers robust authentication/roles; encryption at rest supported	Various security layers (depending on version and engine)	Document-level security in newer versions, requires careful config

3.2.3.4: Database Selection

We decided on PostgreSQL not only for its robust ACID compliance, advanced querying capabilities, and integration with modern frameworks, but also because the group has prior experience with the SQL-based workflow, and finds it more straightforward. Even though MongoDB was effective for certain projects in the past, our team ultimately prefers PostgreSQL's relational structure and powerful SQL features for handling the structured data of our bagged milk inventory. This familiarity with SQL makes schema design, query writing, and general maintenance more intuitive, ensuring that future development and scaling can proceed smoothly. Its ACID compliance ensures reliable handling of critical updates—like inventory counts or expiration dates—while JSON field support allows for semi-structured data if we need more flexibility in the future. Although other databases like MySQL or MongoDB perform well for many applications, PostgreSQL's combination of relational consistency, querying capabilities, and compatibility with modern frameworks made it the ideal choice to pair with our Swift-based mobile app. This approach allows us to maintain strict control over data accuracy and security while also offering room to expand the schema if our project scales to include more detailed analytics or user-driven features later on.

3.2.4: Cloud Storage

Storing breastmilk inventory data in the cloud can bring valuable benefits to an app like PUMPED, but it also raises some important trade-offs. Our team is

considering implementing cloud storage as part of the system's long term functionality. However, for the time being, we will focus on building a reliable, local connection between the hardware and the mobile app. Cloud-based solutions let users synchronize data across multiple devices, prevent data loss through remote backups, and enable features like real-time alerts or shared access among parents and caregivers. However, these advantages must be balanced against potential drawbacks such as relying on constant internet connectivity, navigating privacy regulations, and incurring costs for hosting and maintenance. Ultimately, the decision to adopt a cloud solution depends on whether the project needs multi-user access, real-time syncing, and robust backup capabilities, or if it could suffice with a simpler local-only approach.

3.2.4.1: Benefits of Cloud Storage

Cloud storage makes data available across any device with an internet connection, allowing users to check and update the milk inventory in real time, even if they switch phones or if multiple people need to coordinate the same supply. Having the data off-device also means it is protected against phone loss or damage, as cloud providers typically replicate data across multiple servers for reliability. Sharing data with other family members or healthcare professionals becomes straightforward, because everyone can access the central cloud store rather than passing files around. If the system grows to include more complex information—like nutritional stats or photos—cloud services can usually be scaled up with a few settings, sparing the user's device from storing large amounts of data. Another advantage is that once the data is in the cloud, it can be integrated with backend processes such as automated expiration reminders or analytical tools, enhancing the overall user experience.

3.2.4.2: Drawbacks of Cloud Storage

A primary concern with cloud storage is the need for an internet connection at all times. Users who are offline cannot update or retrieve the latest information unless the app includes an offline caching strategy. Security and privacy are also vital considerations, especially if the system handles data that may be viewed as sensitive or subject to health regulations. Storing data on third-party servers introduces the possibility of unauthorized access if the system is not configured with proper encryption and authentication. In addition, there can be hidden

costs once the free-tier limits are exceeded or if the project scales beyond the initial prototype. Maintaining a cloud-based backend also requires more setup and ongoing management than a purely local solution, though modern services have simplified much of this process.

3.2.4.3: Amazon Web Services (AWS)

Amazon Web Services provides an extensive collection of cloud services that can fit a range of application needs, making it a compelling choice for a system like PUMPED. Developers can deploy a relational database through Amazon RDS and use Amazon S3 for file storage, which allows for separating structured data (such as milk bag details) from unstructured files (such as labeled images or logs from the hardware device). AWS also includes a variety of tools for handling more specialized requirements, such as real-time data processing or IoT integration, which can be particularly useful if the hardware device transmits data to the cloud in real time. While this breadth of features is a major advantage, AWS can have a steeper learning curve because it often involves configuring multiple services that work together. In a production context, AWS can scale efficiently to accommodate significant growth in data or user activity. However, for a smaller-scale or student project, the setup complexity and potential cost for additional services might be more than some teams prefer, unless they make use of frameworks like AWS Amplify, which simplify the process of linking front-end applications to AWS back-end components.

3.2.4.5: Firebase

Firebase is a Google service specifically focused on mobile and web development, offering streamlined, serverless tools that reduce much of the usual overhead associated with building and maintaining a back-end. It centers around NoSQL databases like Firestore or Realtime Database, which sync data in near-real-time and can keep multiple devices up to date, even if they briefly go offline. This functionality suits the PUMPED project if the team wants each user's app to receive instantaneous updates on milk quantities or expiration alerts. Firebase also provides integrated user authentication, file storage, and serverless functions, all accessible through straightforward SDKs. This simplicity means developers can concentrate on building user-facing features rather than juggling different back-end infrastructures. Although Firebase is flexible enough

for many use cases, it may feel limiting if the app demands complex relational queries or requires a wider range of services. It also involves reliance on Google’s ecosystem, which can bring pricing concerns when usage exceeds the free tier, but for many smaller projects, Firebase’s convenience and scalability make it an appealing choice.

3.2.4.6: Google Cloud Platform (GCP)

Google Cloud Platform is a broader suite of services beyond Firebase, giving developers the ability to deploy virtual machines, run managed relational databases through Cloud SQL, and leverage serverless platforms such as Cloud Functions or Cloud Run. These resources can be assembled to create custom architectures that handle a variety of tasks, from detailed data analytics on milk usage trends to automated notifications for low stock or expired inventory. GCP’s approach can feel more cohesive than AWS for some teams, but it still presents the typical considerations of setting up and managing several services. Whether the PUMPED system requires traditional relational data handling or specialized machine learning APIs, GCP can accommodate these demands while retaining the option to integrate with Firebase for real-time synchronization. As with AWS, using multiple GCP services can result in increased complexity and costs, so teams should weigh whether the advantages of Google Cloud’s services warrant the additional configuration steps.

3.2.4.7: Evaluating Potential Cloud Services

Table 3.20 - Cloud Storage Comparisons

Cloud Platform	Developer	Database	Strengths	Weaknesses	Cost
Amazon Web Services (AWS)	Amazon	Amazon RDS	Variety of tools to fit a range of application needs	Requires configuring multiple services together	High (\$ per service)
Firebase	Google	NoSQL	Focuses on mobile apps,	Limited depending on	Low (free tier)

			syncing data & quick development	apps complexity	
Google Cloud Platform (GCP)	Google	CloudSQL	Provides more services beyond Firebase	Requires setting up & managing several services	Medium (\$ per service)

For a project like PUMPED, choosing the right cloud platform can hinge on the desired mix of simplicity, flexibility, and cost considerations. A general-purpose ecosystem such as Amazon Web Services (AWS) is favored for its extensive range of services, including options for running a PostgreSQL or MySQL database, storing images, and integrating IoT devices. AWS is extremely powerful and can accommodate significant growth but has a steeper learning curve.

Firebase, offered by Google, is popular for mobile apps that need real-time syncing and minimal back-end coding. Its straightforward SDKs, built-in authentication, and NoSQL database features enable quick development, making it suitable for prototypes or student projects. If the team wants more control and broader infrastructure options, Google Cloud Platform (GCP) provides additional services such as managed relational databases, serverless computers, and machine learning tools, all under Google's ecosystem.

3.2.5: Data Transfer Methods For ESP32

In a home environment, an ESP32-based device that weighs bagged breast milk must send basic data—weight, date, and time—to a companion mobile app. Several options exist for transmitting small data packets over short distances or through a quick scan. These include Bluetooth Classic, Bluetooth Low Energy (BLE), and methods involving either traditional barcodes or QR codes. Each approach differs in terms of hardware cost, ease of integration, efficiency, security, and user experience.

3.2.5.1: Bluetooth Classic

Classic Bluetooth was originally designed to replace wired connections like serial ports, and is still widely used for applications such as audio streaming. The ESP32 chip supports dual-mode Bluetooth, meaning it can handle both Classic and BLE. This implies minimal additional hardware costs for Bluetooth-based data transfer. In many use cases, Classic Bluetooth offers faster data throughput than BLE, which is valuable for streaming large files or audio.

However, the relatively high energy consumption and limited iOS integration create potential complications for a milk-weighing device intended for home use. Although Android permits easy data exchange via the Classic Bluetooth Serial Port Profile, iOS enforces stricter controls. Integrating an ESP32 with iPhones over Classic Bluetooth typically requires Apple's special licensing program, increasing complexity. Classic Bluetooth also has a generally more elaborate pairing process than BLE, though it remains straightforward in simple single-device setups. Because the volume and date data is small, the higher bandwidth of Classic Bluetooth offers little advantage over BLE. In a scenario emphasizing ease of use across all smartphones, Classic Bluetooth can become a limiting factor on iOS.

3.2.5.2: Bluetooth Low Energy (BLE)

BLE is a more recent standard optimized for low-power, intermittent data transfer—ideal for battery-powered or smaller devices. Despite a lower overall bandwidth, BLE's speed is sufficient for sending short messages, such as the time and weight of a milk bag. Its low energy usage is a distinct advantage if the device runs on battery. BLE also connects quickly, enabling a phone to discover and read data from a device within seconds. The ESP32's built-in dual-mode radio means no additional hardware is needed.

From an integration viewpoint, both Android and iOS come with robust BLE APIs, and many development frameworks provide examples for discovering, pairing, and reading data from a BLE peripheral. Once the device and phone are paired, the data exchange happens securely through encryption. This enhances privacy if the measured data is considered sensitive. Another benefit lies in user convenience: the ESP32 can automatically deliver or “notify” the phone of new

weight data in near real time, removing the need for manual scanning or multiple steps. While BLE still requires initial pairing, it is generally considered easier to integrate across different operating systems than Classic Bluetooth when building custom mobile applications. The seamless nature of BLE makes it highly suitable for a consumer-friendly experience, where the phone automatically collects data whenever the user is in range.

3.2.5.3: Barcodes

A barcode-based solution avoids wireless connectivity altogether by printing an encoded label. Since the device already prints information about milk volume or timestamps, embedding that information in a linear (1D) barcode is straightforward. The user would scan it with their phone's camera. This technique is especially cost-effective and maintenance-free from a hardware standpoint: the printer exists regardless, and modern smartphone cameras, with the right app code, can decode barcodes reliably.

Implementation on the device side is not complex. Many microcontroller-friendly label printers can produce barcodes. Alternatively, a small library can convert a string of data (for instance, "4oz/03-17-2025 10:15 AM") to the corresponding series of bars to print. On the mobile side, developers integrate a barcode scanning feature that leverages the phone's camera. Once scanned, the data is extracted and recorded. Barcodes can be read quickly, but each data transfer requires a manual process: the user lines up the camera with the label and waits for a scan confirmation. Doing so for multiple bags can become time-consuming. Barcodes have no intrinsic encryption, so if privacy is a concern, the label's visible data might be accessible to anyone who sees or scans it. Given that the data (milk amounts, times) is relatively simple, this level of risk may be acceptable in a home context. Overall, barcodes are an easy, hardware-free approach but lack real-time data flow or automation.

3.2.5.4: QR Codes

A QR code builds on the same scanning principle as a barcode but allows more data storage and includes error correction. The device side can generate a two-dimensional code containing weight, date, time, or even structured text. Most smartphones can recognize a QR code at various angles, making scanning

faster and more forgiving than linear barcodes. Error correction capabilities also help if a label is partially smudged or folded, allowing successful decoding even when part of the code is damaged.

Generating a QR code is slightly more involved than generating a barcode, but open-source libraries can handle the conversion from text to a grid pattern. The user experience around scanning can be smoother than with barcodes, as modern phone cameras often natively detect QR codes. Many users now associate QR codes with quick interactions, such as menus or authentication links. Still, the device data only appears in the mobile app upon completion of a manual scan. This manual step must be repeated every time a new label is printed. As a result, while QR codes enhance scan reliability compared to barcodes, they do not overcome the core limitation of needing to physically scan each new label. For low-frequency tasks, this is tolerable. If multiple measurements or high-frequency logging is anticipated, the scanning routine quickly becomes a hassle. As with barcodes, QR code data is generally stored in a visible, unencrypted form. For a controlled home environment, this may be acceptable.

3.2.5.5: Data Transfer Evaluations & Comparisons

An important consideration for a milk-weighing device is whether the data transfer should be instantaneous and continuous, or whether it is acceptable for users to scan each label at their leisure. Bluetooth, especially in its BLE form, enables a near-real-time, hands-off approach. The phone can automatically save each measurement whenever a bag is weighed, eliminating repeated manual actions and potential scanning errors. This is especially attractive in a setting where parents may be busy or where convenience is paramount.

By contrast, barcodes and QR codes excel in simplicity and reliability while introducing a manual scanning step. For single measurements done infrequently, scanning is harmless and avoids the complexities of wireless pairing. The trade-off is that scanning becomes more tedious if a user needs to transfer multiple measurements a day, and it does not provide immediate notifications or background syncing.

Security matters to varying degrees depending on how private the milk data is. BLE can use built-in encryption to protect the data in transit. Neither barcodes or QR codes inherently protects data: once printed, the code can be scanned by

anyone who has physical access to the label. In a home environment, however, the user may accept that risk, treating the label itself as a non-sensitive item. Additional obfuscation or encryption within a QR code is possible but introduces more development overhead.

Hardware costs for all these methods are minimal, given the ESP32 includes dual-mode Bluetooth by default and the printer already produces labels. The primary investment lies in integration effort. BLE demands the most coding to establish pairing, define characteristics, and handle data flow on the phone. Barcodes and QR codes require the phone app to incorporate camera scanning, which also involves code but is arguably simpler or at least more familiar to many developers. Maintenance over time might favor BLE if frequent data updates are desired, as scanning libraries or usage patterns can become cumbersome in high-volume scenarios.

In terms of user experience, BLE stands out if the goal is to “remove friction” from the data logging process. After an initial setup, measurements can be auto-recorded without user interaction. Barcodes and QR codes, while approachable, force an extra task—scanning—for each data transfer event. This is not necessarily inconvenient if usage is sparse, but it does not match the ease of background synchronization. On the other hand, scanning approaches are platform-agnostic and do not depend on firmware versions or potential pairing issues. Any caregiver’s phone can quickly read the code, whereas BLE might require pairing each phone that needs direct data access.

Ultimately, the final decision hinges on the value placed on immediate, hands-free data transfer versus the acceptability of manual scans. Many users in a home environment appreciate a device that seamlessly logs measurements without scanning, which tips the scales in favor of BLE. Others might prefer a scan-based method if the device is used infrequently, and they want to avoid any wireless complexities. Both barcodes and QR codes remain viable, low-cost methods, but do not fully match Bluetooth’s automation or near-instant data push.

Table 3.21 - Data Transfer Comparisons

Criteria	Bluetooth Classic	Bluetooth Low Energy	Barcode(1D)	QR Code(2D)
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Technology Type	Wireless (2.4 GHz), dual-mode Bluetooth on ESP32 (Classic)	Wireless (2.4 GHz), dual-mode Bluetooth on ESP32 (Low Energy)	Optical (printed labels + phone camera)	Optical (printed labels + phone camera, 2D code)
Hardware Requirements	ESP32's built-in Bluetooth (may require MFi licensing for iOS Classic support), no extra module needed but possibly more power usage	ESP32's built-in Bluetooth LE radio, no extra module needed, extremely low power draw	Printer to generate 1D barcodes, phone camera to scan	Printer to generate QR codes, phone camera to scan (or device display if going paperless)
Data Speed	Moderate–High throughput (suitable for streaming or file transfer), but more power consumption than BLE	Moderate throughput (optimized for smaller, frequent data packets), connects/disconnects quickly	Instant data retrieval upon scanning, but only minimal data can be encoded; user must do each scan	Quick scanning even at an angle, supports more data than 1D barcodes (due to 2D format), but still manually scanned
Security & Encryption	Encrypted link is possible, but pairing can be more complex; iOS typically requires special MFi program for full Classic usage	LE Secure Connections offer strong encryption and authentication, typically simpler pairing experience on both iOS and Android	Printed data is visible; no built-in encryption (plain text in the barcode). Physical possession needed to scan	Data is plainly visible unless encrypted or obfuscated. Built-in error correction, but still no inherent encryption for sensitive info
User Interaction	Typically requires manual pairing in OS settings, better on Android than iOS if no MFi license	Usually handled in-app; minimal user intervention once paired (automated data push possible)	User must open scanning app and align the barcode each time; manual scanning of each label	User must open scanning app; faster and more forgiving to scan than 1D barcodes, but still a manual step for every data transfer
Advantages	Higher bandwidth than BLE, widely supported	Ultra-low power consumption, straightforward iOS/Android support, great for small, frequent	Extremely low implementation cost, no radio configuration needed, easy to integrate basic	Faster scanning with built-in error correction, can store more info than 1D barcodes, user familiarity with QR codes is high

		updates	scanner libraries	
Disadvantages	More power-hungry than BLE; iOS support is limited without MFi licensing, pairing can be cumbersome	Lower peak data rate than Classic, still requires initial pairing steps, must maintain BLE code logic in the app	Manual scanning becomes tedious if frequent updates are needed, limited data capacity, no real-time push	Manual scanning still required, data is only transferred at the moment of scan, no real-time updates, label printing or display is mandatory

3.2.5.6: Data Transfer Conclusions

For an ESP32-based milk-weighing device that prints labels, Bluetooth Low Energy offers the most modern, user-friendly, and energy-efficient solution to transfer weight and time data into a companion mobile application. The user gains a near-real-time, hands-off experience, while developers benefit from a robust ecosystem of cross-platform BLE tools. In contrast, barcodes and QR codes function well for smaller-scale or infrequent tasks where manual scanning remains acceptable. These scanning methods minimize wireless constraints but require additional user input and do not update automatically. In a domestic setting where the device is likely to be used repeatedly, BLE's seamlessness may justify the minor initial overhead of pairing and characteristic definition. Barcodes and QR codes can serve as simpler or backup options that rely solely on the camera and printed labels, but they cannot surpass the convenience of automated, background data transfer.

Chapter 4 - Standards & Design Constraints:

In this chapter, we will explore standards and design constraints that will guide and assist in the development of the project. The standards that will be discussed are key in ensuring that our system is in compliance with all regulations, including those that govern safety, as well as adhering to industry guidelines. Such standards that will guide our design include, but are not limited to, the Food and Drug Administration (FDA), Centers for Disease Control and Prevention (CDC), and the National Fire Protection Association (NFPA). In addition, constraints regarding physical size, energy efficiency, and environmental factors will help in meeting user expectations to be utilized in household and other settings.

4.1: Standards & Regulations

Firstly, we will discuss the standards and regulations that must be evaluated when designing our products. Since our product is going to be in contact with food for infants, and moreover, deal with the preparation of the food as well as its catalogue and storage, there will be several regulatory standards to consider in order to ensure product safety and reliability. Additionally, our product will be designed to utilize the mains electricity, which requires regulatory evaluation.

4.2: Food & Drug Administration

The Food and Drug Administration (FDA) is a governing body within the United States that is responsible for the protection of public health by regulating and supervising the safety of food, drugs, cosmetics, medical devices, and other products. [13]

The purpose of the FDA is to set guidelines for the handling, consumption, and distribution of food and other materials for the safety of the general public. The articles and regulations within the FDA are concerned with the material in which food is stored in, how food packaging is labeled, and the condition in which food is stored.

4.2.1: Food Labeling Guide

The Food Labeling Guide as published by the FDA is a guide to how food packaging should be labeled, whilst ensuring that the food within is properly categorized. Although our product will not be dealing with mass distribution of food, using this article as a guideline will protect users from unsafe food. [14]

4.2.2: Food Storage

In the article Once Baby Arrives (Food Safety for Moms-to-Be) as published by the FDA, there are guidelines included with regards to how breastmilk is to be stored to ensure the safety of the food and of the infant. This guideline will be adhered to to ensure that monitoring of food is within acceptable ranges for consumption. [15]

4.3: Center for Disease Control & Prevention

The Center for Disease Control & Prevention (CDC) is an agency within the United States under the Department of Health and Human Services that is in place to protect the public from potential hazards regarding diseases that are currently threatening individuals or could potentially be a threat.

The primary goal of the CDC is to control and prevent disease within the US and across the world. The CDC alerts the public of potential hazards with regards to food borne illnesses, and is crucial in ensuring the safety of food products.

4.3.1: Food Preparation

The CDC has published guidelines that pertain to the preparation of food for infants, specifically the storage, heating, and thawing of breast milk. Our device will have the capability to prepare breastmilk for consumption; ensuring our product is within the guidelines of preparation is essential, as ensuring the safety of the food for an infant is of the highest priority. Furthermore, keeping in mind the ideal consumption temperatures of the breast milk will aid when designing the heating elements within our system, ensuring that it is as efficient as possible. [16]

4.4: Communication Standards

Communication standards play a crucial role in designing how our system connects to mobile devices and remote servers (if needed). It is necessary for there to be effective communication between the microcontroller, sensors, internal devices, and external devices (mobile app). To accomplish this, our project is going to use protocols such as Serial Peripheral Interface (SPI). SPI is a communication protocol that is used to facilitate reliable and efficient short-distance data transfer between microcontrollers and other components. By following these communication standards, our system will have appropriate control, minimize latency, and provide compatibility with multiple peripherals. Beyond SPI, other widely recognized standards such as I2C (Inter-Integrated Circuit) can also come into play, especially if we decide to integrate additional sensors that benefit from multi-master or multi-slave setups. Because both SPI and I2C are standard protocols, numerous off-the-shelf components like temperature sensors, EEPROMs, and display modules can communicate with our microcontroller almost out of the box. Moreover, by selecting open, well-documented interfaces instead of proprietary ones, we can more easily troubleshoot connection errors, achieve consistent data rates, and upgrade hardware in the future. Ensuring each hardware link, whether it is an internal bus like SPI or a short-range wireless channel like Bluetooth conforms to known best practices will ultimately enhance reliability, minimize downtime, and help us maintain an efficient data pipeline from the sensor level up to the user's mobile application.

4.4.1: Serial Peripheral Interface (SPI)

The Serial Peripheral Interface (SPI) is a synchronous, full-duplex serial communication protocol that can be used for high-speed data transfer between a microcontroller (Master) and peripherals (Slaves), such as sensors, displays, and memory chips. The four components that form SPI communication are: Master Out Slave In (MOSI), Master In Slave Out (MISO), Serial Clock (SCLK), and Chip Select (CS). SPI interfaces can only have one main (Master), but can have multiple subnodes (Slaves). The master device generates the clock signal and any data transferred between the master and slaves is synchronized to that clock. The chip select (CS) is a signal used to select a slave, it is usually set as

an active low signal and is set to high when you want to disconnect the slave from the SPI system. If there are multiple slaves being used, then each one needs to have an individual CS signal connected to the master. MOSI and MISO are data lines, with MOSI being used to transmit data from the master to the slaves and MISO being used to transmit data from the slaves to the master. The diagrams below show the SPI configurations for a single slave and multiple slaves system: [37]

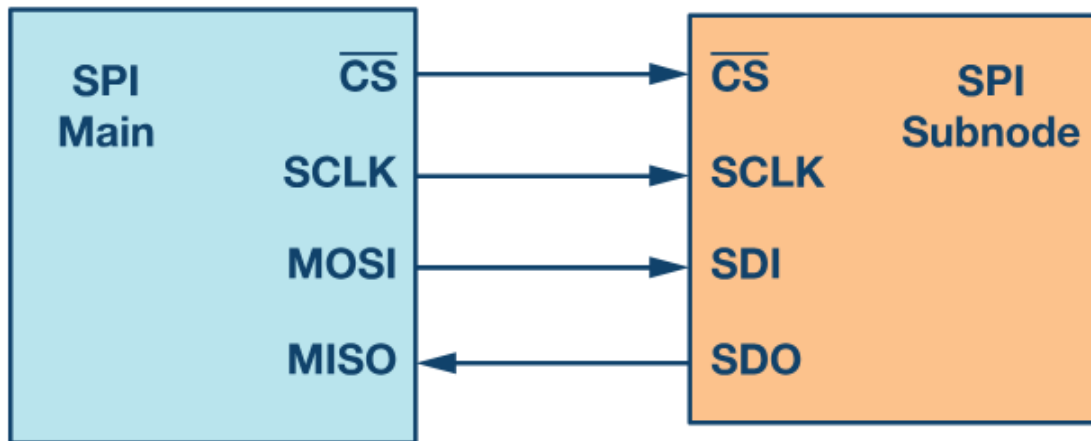


Figure 4.1 - Single Slave SPI Configuration

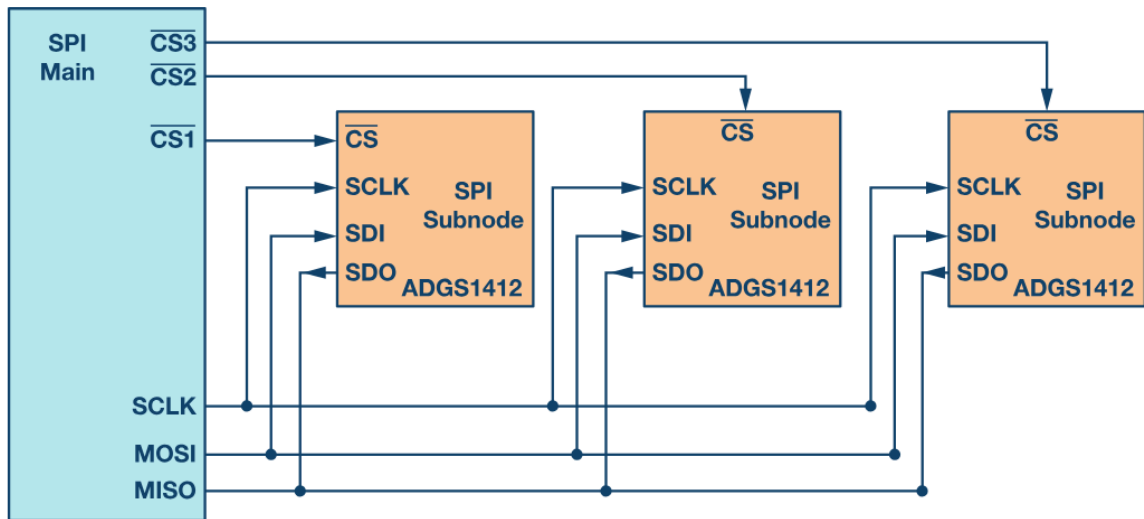


Figure 4.2 - Multi-Slave SPI Configuration

If there are multiple slaves in our system, then each slave will need its own CS signal. This could lead to a situation in which multiple CS signals are enabled at the same time, causing the data on the MISO line to become corrupted, with the master not being able to determine which slave is transmitting the data. To work around this problem, the system can use a daisy-chain method to connect the multiple slaves together. This method works by configuring the slaves so they all share a single CS signal and transfer the data on the MOSI line from one slave to the next. All the slaves will share the SCLK signal as well, with the number of clock cycles being used to determine which data corresponds to which slave. Our system will make use of the daisy-chain method, as we will be using multiple different peripheral devices at the same time and don't want the data transmitted to the microcontroller to become corrupted. Below is a diagram of a daisy-chain SPI configuration: [37]

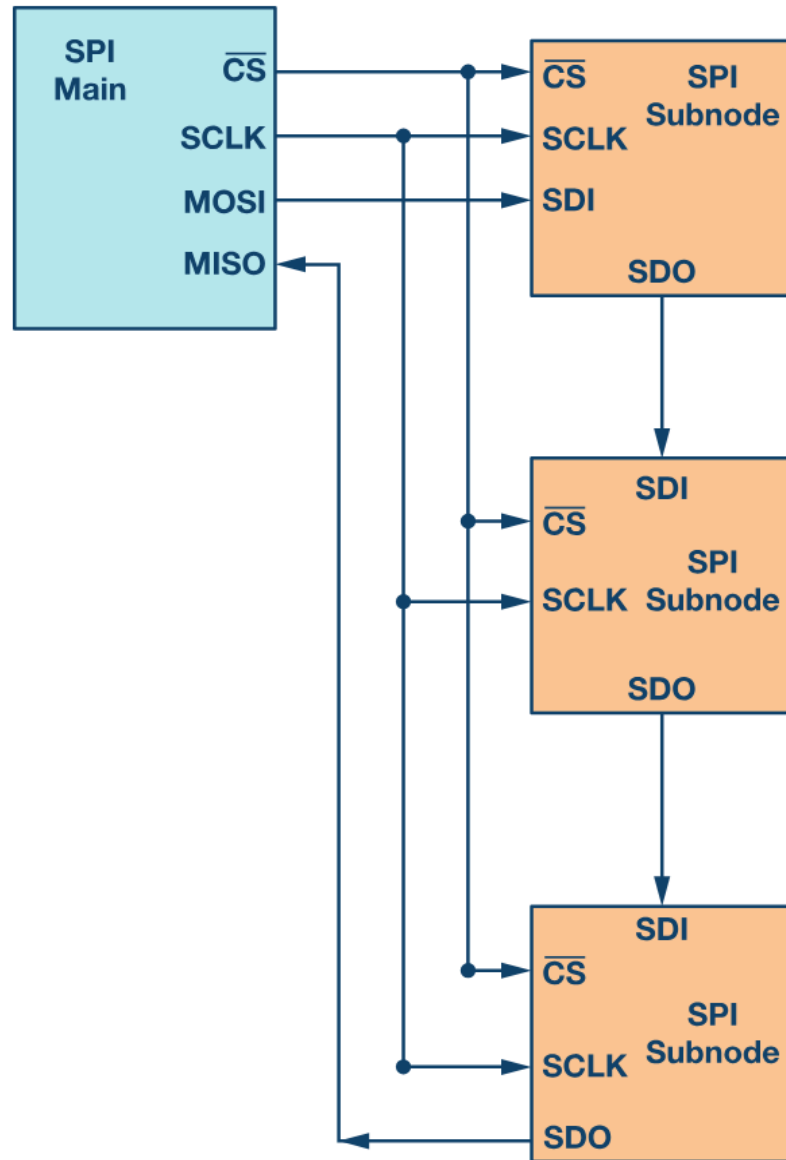


Figure 4.3 - Daisy-Chain SPI Configuration

4.5: User Constraints

When analyzing how our system will impact the users quality of life, there are several factors that must be considered in the design process. The groups that will use the system will be parents and potentially hospital faculty. For parents, the primary concerns that we wanted to address are affordability, safety, and

ease of use. As for healthcare professionals, the concerns overlap in many regards, but also are concerned with device efficacy and regulatory compliance.

4.5.1: Parent Constraints

As parents are the primary audience for the system, the constraints and requirements for them are of great importance in the overall design. First and foremost, parents who would have a need for this system want it to save them money where possible. As discussed previously, there are separate solutions that solve individual components of the problem this device aims to solve; that being to make the processes involved with managing the food supply of an infant. While these separate solutions exist, they are individual solutions that only temporarily solve a problem that requires a more practical and complete solution. That being said, we want the device to supplement these other options, and to warrant their replacement, it needs to be cost effective. On the surface level, the system will be able to save parents money if we design it using the most cost effective parts while not compromising the functionality. However, our design must also account for power consumption of the device. In our design, we want to minimize potential costs by designing in a fashion that consumes only power required, and adding functionality that can reduce power consumption, such as having a 'sleep mode' that turns all non essential peripherals off in cases where the device is not actively used.

In addition to the device needing to be affordable, there also needs to be considerations in place to ensure safety for parents, and safety for children. As mentioned previously, when it comes to preparing breast milk for infants, the major points of contention are when it comes to safely preparing the breast milk and storing the food. When preparing the breast milk for an infant, there are guidelines to ensure the food is at a proper temperature. When designing our system, the temperature measurement needs to be accurate to ensure the safety of consumption, reaching a balance between hot enough as to not potentially breed harmful illness, and not too hot as to harm an infant. This balance will be achieved through ensuring accurate temperature measurements, and through the design of the heating element as to not allow temperatures above a threshold that is acceptable for consumption, while maintaining the ability to heat the breast milk.

Lastly, for parents, our thought process is to ensure that the system is as easy to use for parents without sacrificing performance, features, or safety. While

designing our system, our goal is to alleviate any complications that can arise with overly complex solutions. While categorizing and ensuring the safety of breast milk for infants is a nuanced issue, we aim to make our system complex in its execution of our solution whilst giving an uncomplicated user experience. To accomplish this, our app will provide necessary information as it becomes pertinent, such as expiration dates of food that has been stored in long term storage. Additionally, the physical form factor of our device will display and request only required information. This potentially may include the date and time, or intended use, like if the milk is going to be frozen, or immediately fed to the infant.

4.5.2: Medical Faculty Constraints

As for medical faculty constraints, we wanted to investigate how medical faculty would interact with our device, or specific concerns they have with its functionality. After doing research to determine what constitutes usability for medical equipment, as well as consulting healthcare professionals related to group members, there were several factors that needed consideration. A major constraint that medical faculty have with equipment is efficacy. The device must be accurate in its measurements, especially with regards to temperature measurement. Any temperature deviations in the milk can be potentially dangerous for an infant to consume, either in terms of burning and infants mouth, or if improperly heated or stored potentially causing foodborne illness. With this in mind, the device design should incorporate alternative methods for measurement as a means for checking measurements as a safety procedure.

Furthermore, medical workers must use equipment that adheres to hospital standards and guidelines. Since hospital guidelines differ on a case by case basis in terms of acceptable medical devices, depending on the state, or even country, our design must adhere to the nationally accepted protocols and standards for medical devices to have the system in place for hospitals and other healthcare facilities to use.

4.6: Additional Constraints

While the constraints of users of our system are most important in our design effort and decisions, there are further constraints that must be considered when

designing our system. Such constraints of note will be mentioned in this section with specific details on how certain design elements may be limited by constraints, while discussing how we will best tackle acknowledging constraints that are going to impact how we design our project.

4.6.1: Environmental Constraints

Since our project directly involves the manufacturing of PCBs and their assembly, it is key to understand how it will affect the environment. Ensuring that our project adheres to constraints associated with the environment, such as reducing energy wasted, using safe materials during assembly, or designing our project in a way that its lifespan will be extended, will be helpful in the design process. In addition, we must acknowledge how the environment will interact with our design, and how we will account for factors to ensure our product's utility in different conditions.

Our system will be utilizing standard wall adapters for power, which means it needs to be considered how much energy our system will be consuming. It is desirable for our system to not consume excessive power, as this will save parents from excessive power bills if they have great use for our system. Furthermore, by designing our system to use only necessary power, this will reduce energy waste, which is heavily intertwined with our design, since we will be using conduction heating, which naturally wastes energy in the form of excess heat to the environment.

As technology has evolved and PCB manufacturing with it becomes more necessary, a concern with our project is raised in the form of electronic waste, or e-waste. E-waste typically results from electronic components being disposed of when they reach the end of their lifespan, or when a consumer loses use for them. The problem with this is obvious, as we want our product to last as long as it is needed. In our design, we must design it in a fashion that maximizes its lifespan; we can accomplish this by making as many individual parts of the system replaceable, such as individual components. When choosing components for manufacture, we must also be mindful of hazardous materials, like lead or mercury. Since we are working with a device that potentially can come in contact with food, we will be utilizing lead-free solder, which functions identically to lead-based solder.

Lastly, our system must be able to operate in a wide range of conditions. The heating element in our device will cause the temperature at which the device operates to rise, which must be considered in our design, since several components are sensitive to temperature changes. Bearing this in mind, our design must incorporate some insulative materials to ensure that there are no areas that experience rapid changes in temperature, potentially resulting in our device being compromised.

4.6.2: Power Constraints

Power constraints are critical to consider when designing an electronic device, as they impact efficiency, performance, and safety of a circuit. Power constraints are the limitations imposed by the available power supply, energy consumption, and thermal dissipation of components used. Managing power constraints is vital to a circuit so that it does not exceed voltage or current limits set to prevent damaging internal components.

One of the primary factors in power constraint is the power supply limitations. Every electronic system has a specific operating voltage and current rating and if they are exceeded then component failure is likely as well as erratic behavior by the device. If multiple heating elements are connected, then the total power must be carefully calculated to ensure that the supply can handle the load. Voltage regulators and power management integrated circuits are also commonly used to efficiently distribute power within the system while preventing overload.

Thermal Management is also another critical aspect when it comes to power constraints. Excess power consumption generates heat which must be properly dissipated in order to prevent overheating. Heating elements like resistors convert electrical energy into heat and if not properly managed can cause the performance to degrade or cause permanent damage to the device. Heat sinks, cooling fans, and proper ventilation are great ways to manage heat dissipation in power-constrained systems. Due to how small we intend to make our device, we will also have to look into other passive ways to cool our device down, such as through heat spreading materials and optimized airflow.

Power efficiency plays a role in determining how effectively power is being used within a system. Inefficient components or poor design can cause significant energy loss which is often in the form of heat dissipation. Switching regulators

will be implemented to convert power as they are more efficient with less energy loss than linear regulators. Components like MOSFETs, relays, and resistors will also be chosen to minimize unnecessary power dissipation and create a more energy efficient circuit.

Finally system-level power constraints must be considered when integrating multiple components that draw power simultaneously. If multiple sensors, heaters, and other electrical components are drawing from the same source, then the total power must be calculated to ensure enough power is being supplied to the components. Power sequencing and load balancing must be implemented to prevent sudden power spikes that could destabilize the system. Proper power constraint management ensures reliability, safety, and longevity of electronic systems.

Chapter 5 - Comparison of ChatGPT with Similar Platforms:

In the development of our senior design project—a device to measure and track bagged breast milk—AI tools played a significant role in both the research and coding phases. We specifically utilized two platforms: ChatGPT, a conversational AI for research and planning, and Cursor AI, an AI-powered coding assistant integrated with Visual Studio Code. While both tools were extremely helpful in different contexts, they also presented unique limitations that shaped how and when we used them. This chapter explores specific examples of how each platform contributed to our project and the areas where they fell short.

5.1: ChatGPT in the Software Design Process

ChatGPT was used heavily in the early phases of our project for both technical research and architectural planning. One of the first useful examples came when we were unsure what kind of microcontroller could handle both temperature sensing and Bluetooth communication. ChatGPT helped us narrow our choices to a few realistic candidates, including the ESP32, explaining the pros and cons of each and why the ESP32's dual-core processor and built-in BLE support made it ideal for our use case. This saved us hours of manual searching.

Another concrete example occurred when designing our backend. We asked ChatGPT what types of databases would work best for a small, structured data set involving timestamps and fluid ounce values. ChatGPT compared PostgreSQL, MySQL, and MongoDB, and provided a side-by-side analysis that helped us select PostgreSQL due to its ACID compliance and our group's familiarity with SQL. The ability to get real-time answers to layered questions—like “What database works best with Node.js on iOS?”—was significantly faster than searching and piecing together answers manually from forums or documentation.

However, ChatGPT also showed limitations. For instance, when we asked it how to implement BLE communication on iOS, it suggested outdated or oversimplified Swift syntax that didn't align with modern Xcode requirements. This caused some confusion and led us to double-check everything it provided against Apple's documentation. Another example of its limitation was in

suggesting generic data flow diagrams that didn't quite apply to how our physical device and mobile app would communicate asynchronously. These inaccuracies didn't derail our progress, but they highlighted the importance of treating ChatGPT as a starting point rather than a final authority.

5.2: Cursor AI for Code Generation

Cursor AI was primarily used to support the development of our backend and database systems, and it proved to be a valuable tool during this phase. Since our backend was written using Node.js with Express, and our database was built on PostgreSQL, Cursor's real-time code suggestions and integration with Visual Studio Code allowed us to develop functionality quickly and efficiently. For example, when implementing our user registration and login endpoints, Cursor helped scaffold Express routes, add middleware, and suggest how to use packages for password hashing and input validation. It even flagged missing try-catch blocks in our asynchronous functions, helping us make our code more stable and secure.

Cursor also enhanced our PostgreSQL integration. As we write SQL queries using the pg library in Node.js, Cursor provides real-time assistance with parameterized query structure. It helped catch mistakes such as forgetting to return a response after a successful database insertion or incorrectly formatting SQL strings. These small suggestions saved us significant time during development and prevented many common bugs related to database interaction.

However, when we attempted to use Cursor to assist with Swift development for our iOS app, its usefulness dropped significantly. Since Swift is not natively supported in Visual Studio Code, Cursor struggled to offer accurate or up-to-date SwiftUI code. When we asked it to generate a basic login screen using SwiftUI, the code it provided often used outdated syntax or missed key elements like state binding and navigation handling. This made the process more frustrating than helpful. Additionally, because our app had to be built and tested in Xcode, we were forced to copy and paste code from VS Code to Xcode, and manually resolve any syntax errors or missing functionality. This back-and-forth workflow was inefficient and undermined the benefits Cursor provided during backend development.

In summary, while Cursor was a powerful tool for writing and refining backend and database logic, it proved unreliable for mobile development in Swift. Its lack of deep integration with Xcode and limited understanding of Swift-specific patterns made it more of a hindrance than a help on the iOS side. Nonetheless, its contributions to our backend efficiency were significant and helped us stay on track during the implementation phase.

5.3: Direct Comparison of ChatGPT and Cursor AI

ChatGPT and Cursor AI offered value in different phases of the project. ChatGPT was most helpful during the initial planning and research, while Cursor excelled once we started writing and testing code. For instance, when trying to understand what kind of backend architecture would suit our project best, ChatGPT explained REST APIs, recommended using Express with PostgreSQL, and helped map out the database schema. Once we made those decisions and opened our code editor, Cursor became the go-to tool for actually implementing those ideas.

When it came to documentation and writing explanations for reports, ChatGPT provided polished, professional language that helped us meet our deliverables more quickly. Cursor, on the other hand, helped us write Express middleware, fix syntax issues, and even auto-complete complex SQL queries, which would've taken longer to write and debug manually.

The key difference is that ChatGPT worked best as a thinking partner for brainstorming and research, while Cursor acted as a coding assistant embedded within our development environment. Both tools had clear limitations—ChatGPT's code suggestions often lacked practical context or accuracy, and Cursor struggled with platform-specific syntax, especially outside of the JavaScript ecosystem—but used together, they formed a powerful support system that accelerated our development process.

5.4: ChatGPT in the Hardware Design Process

ChatGPT played a pivotal role in guiding our hardware design process by rapidly providing detailed comparisons and specifications for critical components. For instance, when evaluating heating methods for our device, we consulted ChatGPT to understand the relative benefits of different heating options. It

highlighted several commercially available products such as the 14cm x 5cm Electric Heating Pad by Adafruit, the 15cm x 5cm Silicone Heating Pad by Meccanixity, and the Cartridge Heater offered by MakerTechStore. ChatGPT explained that electric heating pads generally operate via conduction, while other methods like convection and induction—although more common in industrial settings—may introduce unnecessary complexity for a home-use device. With this context, our team was able to weigh factors such as energy efficiency, heat distribution, and ease of integration, leading us to lean towards a PTC-based electric heating pad that would provide rapid and controlled temperature increases.

In addition to heating components, ChatGPT assisted us in exploring power supply options for our system. It compared various choices including the Bel Signal Transformer with a Rectifier Circuit, the LRS-100-24 SMPS Adapter, and the Alitove AC/DC Power Supply. ChatGPT provided insights into the voltage and current requirements of these options, emphasizing that a stable power source is critical for both the heating element and the microcontroller. This discussion helped our group understand the trade-offs between using a robust, regulated supply like the LRS-100-24 versus a more budget-friendly option like the Bel Signal Transformer, allowing us to determine the best fit for maintaining consistent performance under continuous operation.

Moreover, ChatGPT proved valuable when we evaluated different microcontrollers for our device. By comparing the ESP32, STM32, and Nordic's nRF52840, it offered a clear overview of the features, such as integrated Wi-Fi/BLE support, processing power, and peripheral interfacing capabilities. This comparative analysis was particularly useful because it allowed us to focus on the ESP32, which provided the necessary balance of cost-effectiveness, low-power operation, and robust connectivity options essential for a compact, home-based device.

While ChatGPT offered detailed and specific information that greatly expedited our research, there were instances where its recommendations required further verification. For example, its initial suggestions on integrating a rectifier circuit with a Bel Signal Transformer lacked the granular component specifications we ultimately needed, prompting us to consult manufacturer datasheets and industry forums. Nonetheless, these shortcomings were minor compared to the overall benefit: ChatGPT enabled our team to quickly compile and compare a wide range of hardware options, ensuring that our design decisions were both well-informed and aligned with the project's performance and safety requirements.

5.5: Gemini in Hardware Research and its Limitations

Gemini AI was evaluated as an additional resource during our hardware research, particularly when exploring printing options for our milk-weighing device. Our project required reliable label printing to display critical data such as weight, date, and time. We looked into thermal printing solutions—specifically, the MUNBYN IMP001 58mm Thermal Printer (Serial/UART & USB), the PRIMUZ Micro Thermal Printer, and the ASPIRON 58mm Embedded Thermal Printer Module (UART & TTL Interface). Gemini AI provided initial insights into these options, but many of its recommendations turned out to be inaccurate or misleading. For instance, when queried about the MUNBYN IMP001, Gemini AI reported incorrect interface requirements and power specifications that conflicted with the manufacturer’s datasheet, leading us to question its reliability in this domain.

Moreover, Gemini AI offered a comparative overview of printing methods, including thermal printing, laser printing, and inkjet printing, but its discussion was marred by several inaccuracies. While it correctly noted that thermal printers are ideal for producing fast, smudge-resistant labels suitable for our home environment, it confused the benefits and drawbacks of laser and inkjet printers by overemphasizing their use in high-volume industrial applications. This resulted in recommendations that did not align with our specific needs for a compact, energy-efficient device. Additionally, when discussing the PRIMUZ Micro Thermal Printer and the ASPIRON module, Gemini AI sometimes interchanged interface standards—suggesting, for example, that a UART interface was comparable to a TTL interface without acknowledging the subtle differences in voltage levels and signaling.

These inaccuracies forced our team to cross-reference every piece of hardware information with official datasheets and manufacturer resources, which in turn increased our workload and slowed down the design process. Ultimately, while Gemini AI showed potential as a quick reference tool, its frequent errors in detailed hardware specifications underscored the necessity for rigorous human verification—especially in a project where component compatibility and accurate power requirements are critical to performance and safety.

Chapter 6 - Hardware Design:

Chapter 6 will focus on the design elements necessary in the schematics for our eventual PCB's. This chapter is key for the design as it will determine which parts we will choose when assembling the final design, and will allow us to make modifications in the future as needed.

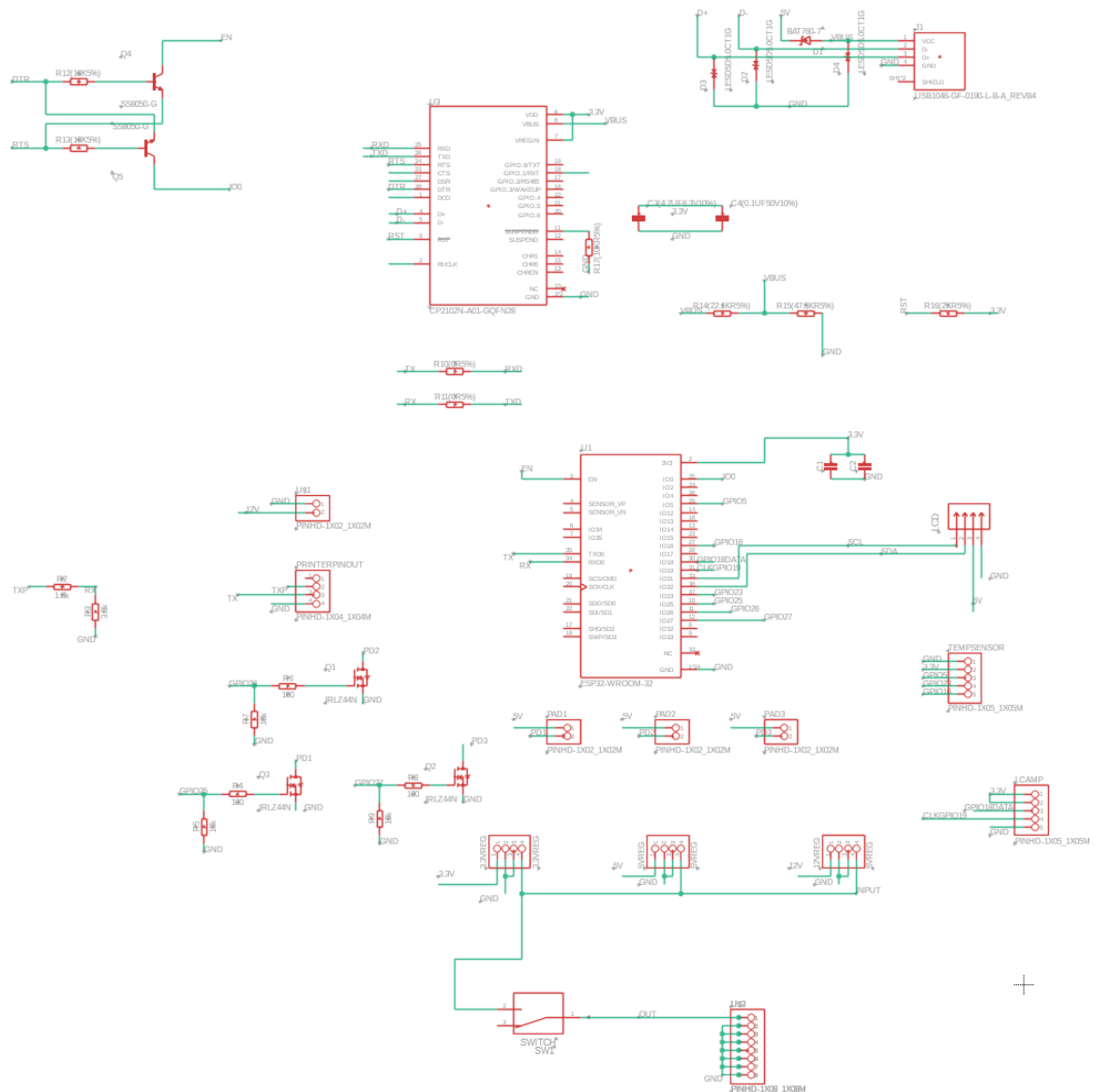


Figure 6.1 - Overall Schematic 1

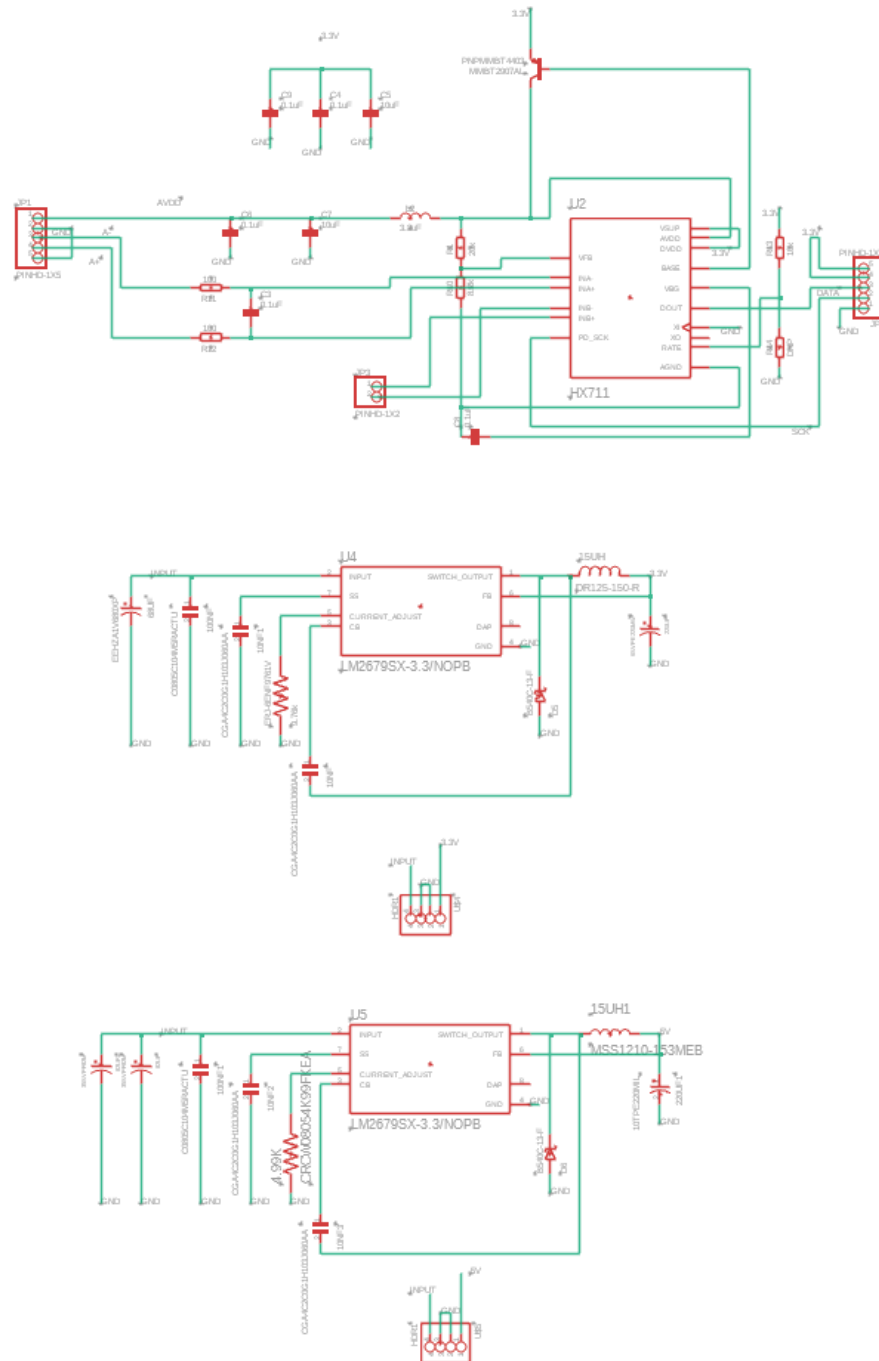
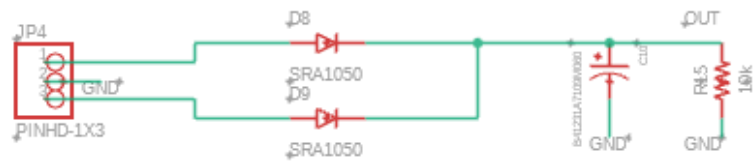


Figure 6.2 - Overall Schematic 2



101

6.1: Rectification for Transformer

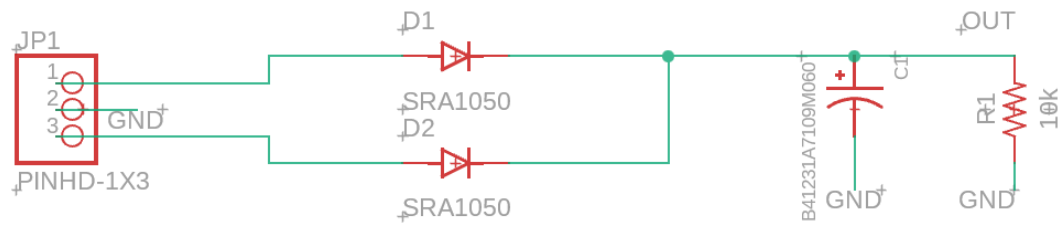


Figure 6.4 - Rectifier Schematic

The schematic shown in Figure 6.4 is the rectification schematic. Since our design relies on grid power, we had to choose how we would go about transforming the power into usable DC power for our design. We chose to implement a signal transformer. Since we use a signal transformer, we need to rectify this output from the transformer into a more stable, consistent signal for our regulators which will be shown later. The two diodes will rectify the signal into a bumpy signal rather than a sinusoid. Afterwards, a capacitor of sufficient size will flatten the rectified waveform to an approximate DC value of 17 volts. [38]

6.2: 12V Regulator PSU

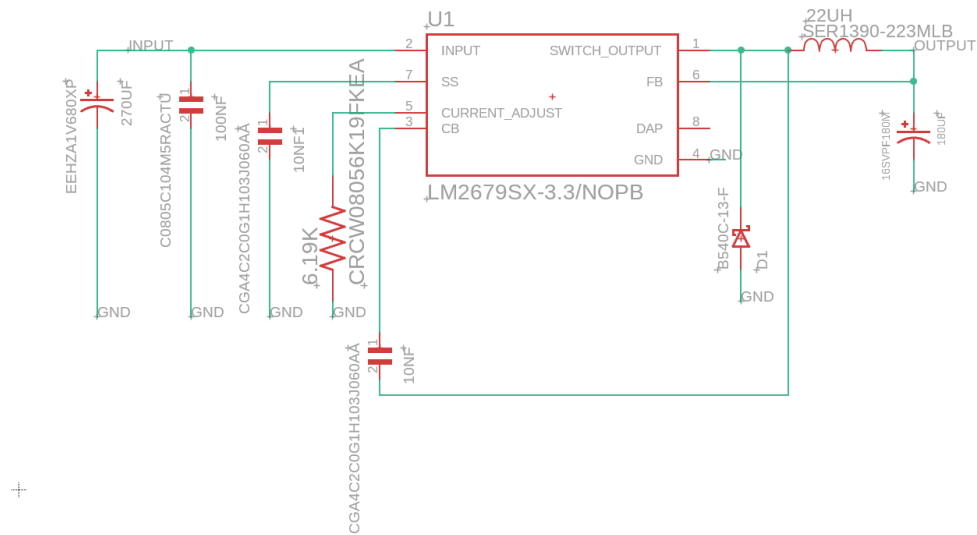


Figure 6.5 - 12V Regulator PSU Schematic

The 12 Volt PSU schematic in Figure 6.5 is solely responsible for powering peripherals that require 12 volts in our design. This design was acquired through the Texas Instrument Power Designer software. By recommendation of peers, the LM2679 IC is an excellent option for regulators, and will be used for all regulators in the future of this design. By putting this IC into the power designer with the parameters of 12 volts output at 4 amps, we attain the design above. [39]

6.3: 5V Regulator PSU

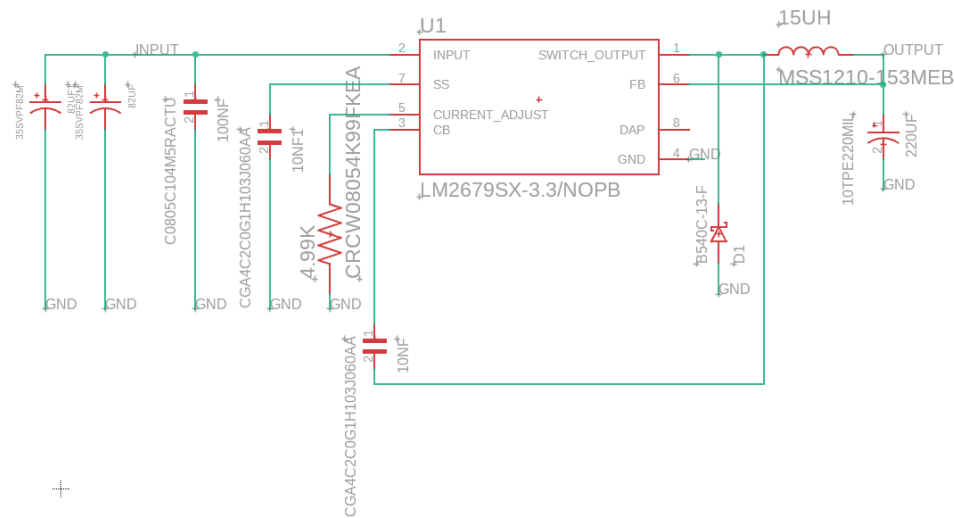


Figure 6.6 - 5V Regulator PSU Schematic

Similarly to the 12 volt regulator, this will be used to power all components of the design that require 5 volts instead by dropping the input voltage from the rectified input to the usable 5 volts. This design was also obtained from the WEBench power designer software, with the parameters changed to 5 volt output at 5 amps. The reason for the high current is because this regulator will power our heating elements, which draw considerable power in the design. This regulator design could potentially change in the future as we test the efficacy of the heating elements. Furthermore, this regulator is needed to power the LCD, which contributes to the power consumption further. [40]

6.4: 3.3V Regulator PSU

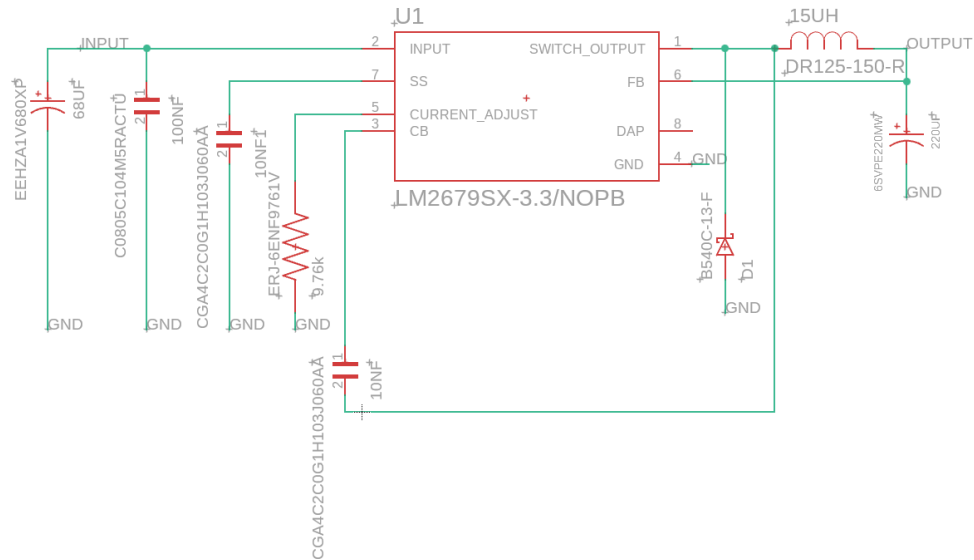


Figure 6.7 - 3.3V Regulator PSU Schematic

Our final regulator is most important of all, as it will power the MCU, thermal sensor, and load cell. This design was similarly acquired through the WEBench power designer software, which changed the components to reach the desired output of 3.3 volts at 2.5 amps, which should be sufficient power for all components that require 3.3 volts. [41]

6.5: Load Cell Amplifier Design

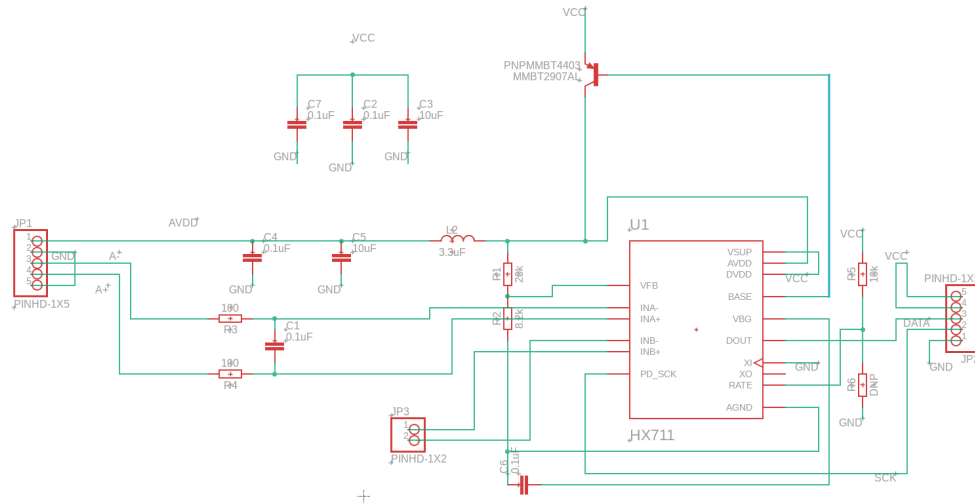


Figure 6.8 - Load Cell Amplifier Schematic

This schematic is for the amplifier circuit necessary for the output reading of our load cell. Since our load cell outputs in millivolts, it is not high enough natively to be read by the MCU. This amplifier schematic comes from SparkFun, which also makes the load cell we are using. They recommend utilizing this IC when using the load cell we chose, and included the schematic for the load cell while offering an option to buy the amplifier IC. We chose to use their schematic in our design to be as cost efficient as possible. [42]

6.6: MCU Design

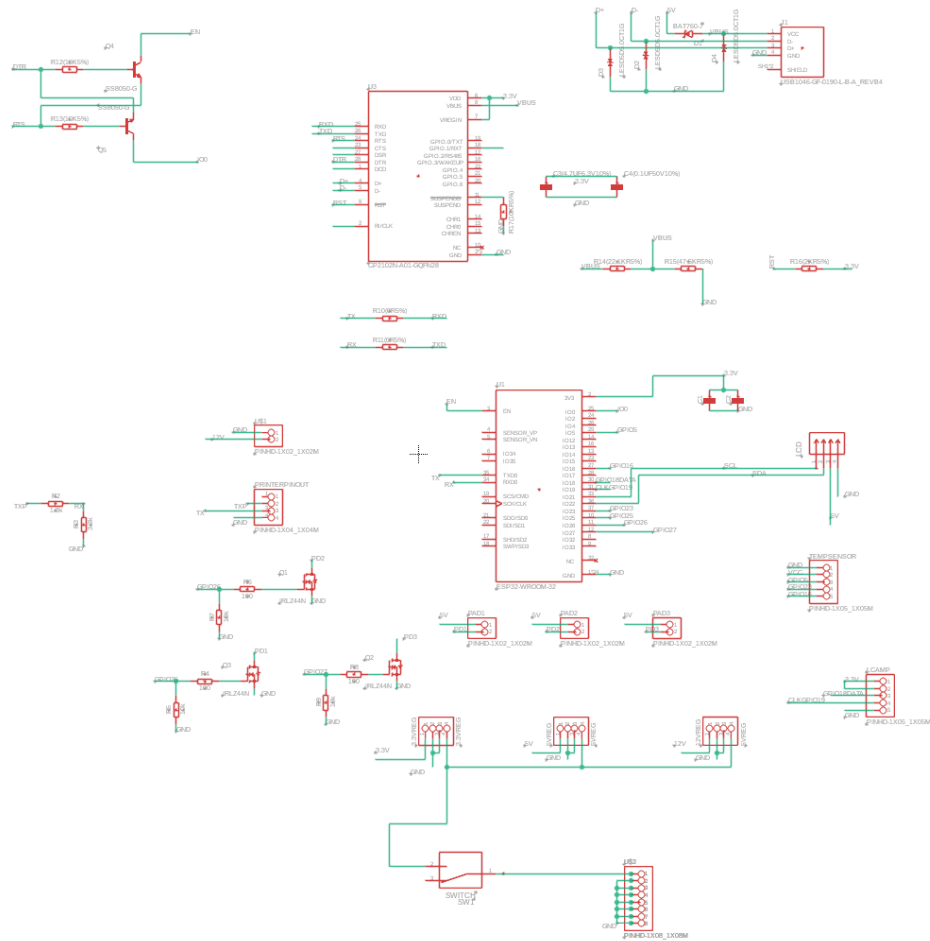


Figure 6.9 - MCU Schematic

This schematic is for the design of the MCU to show how the MCU will communicate with the other components. [43]

Table 6.1 - Hardware Components

Component	Part Number	Price	Voltage
Power Supply	AC-DC Wall adapter	\$5 - \$50	120V - 220V

Thermocouple with MAX6675 Amplifier	MAX 6675 + K type Thermocouple	\$12	3.3V - 5.0V
Load Cell with HX711 Amplifier	TAL220B + HX711 Amplifier	\$11.95 per unit	3V - 10V
LCD	HD44780	\$3 - \$10	3.3V - 5V
Thermal Printer	PRIMUZ Micro Thermal Printer	\$45 - \$65	12V - 24V
Heater	Electric Heating Pad 14cm x 5cm by Adafruit	\$6	5V
MCU	ESP32	Low \$\$\$	3.3V

Chapter 7 - Software Design:

The focus of this chapter is on providing an overview of the elements that make up the software development process for our project. To accomplish this, each section incorporates a diagram that represents the software's design and coding architectures that, when put together, form our software's system.

7.1: Use Case Diagram

The use case diagram is a UML (Unified Modeling Language) diagram that provides a visual representation of the interactions between users (actors) and a system. This diagram provides an easy to understand overview of the various functions of a system that the user can interact with, as well as how these functions can interact with each other. Our use case diagram focuses on the different functions of our device that a user directly interacts with, such as weighing the milk bag, heating the bag, and printing the label with the appropriate information.

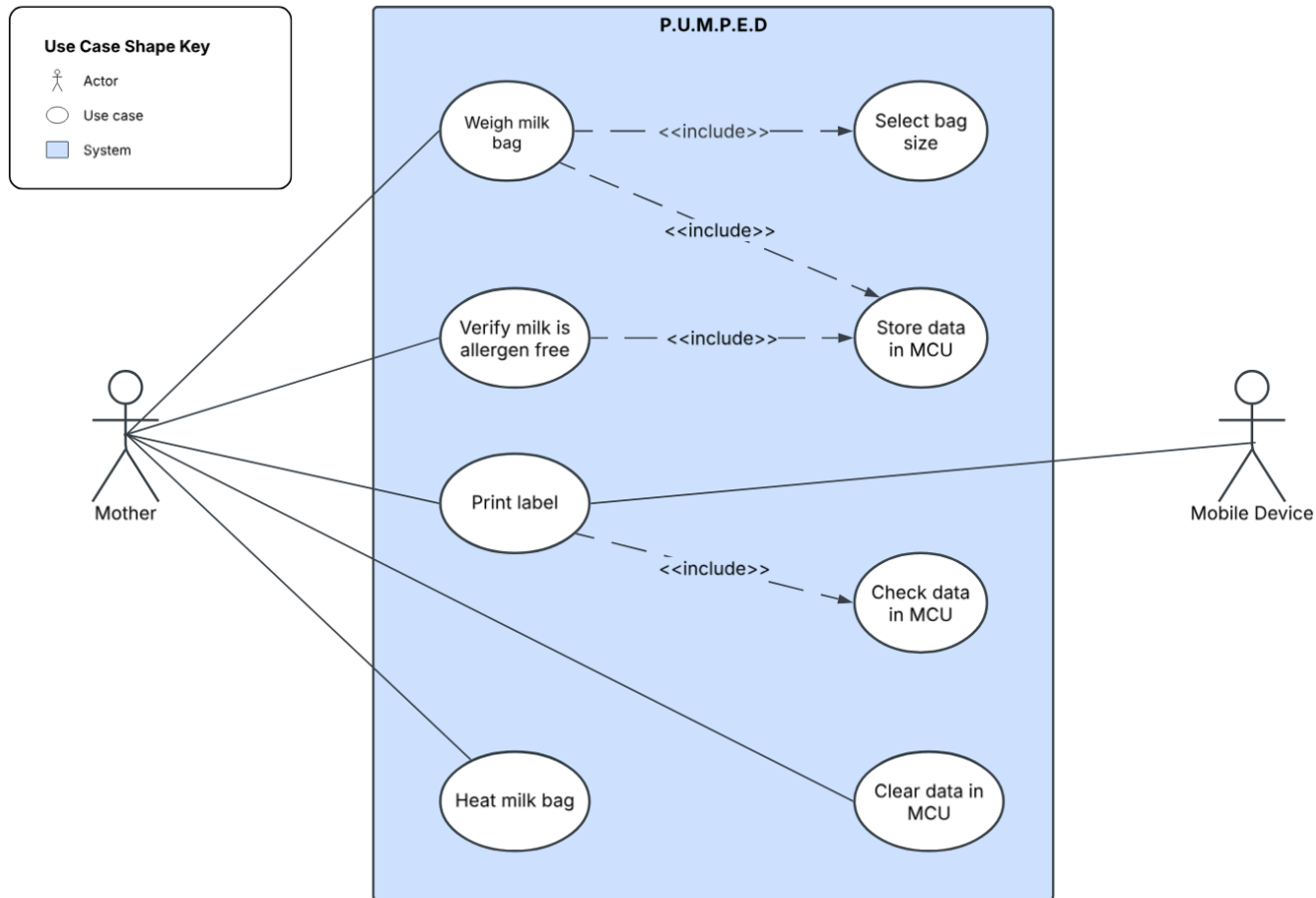


Figure 7.1 - Software Use Case Diagram

7.2: State (Activity) Diagram

The state (activity) diagram is also a UML (Unified Modeling Language) diagram that provides a representation on the condition of the entire system, or parts of the system, at certain instances of time or changes caused by external stimuli (user interactions). This diagram shows the transitions of states that occur within the system that are triggered by certain conditions or interactions. Our state diagram is mainly focused around the idle state, where the device will spend most of its time, until the user interacts directly with the device (clicking the appropriate button). Although there are various composite states, which represent states with internal activities, it's important to note that our state

diagram shows each of them transitioning back to the idle state. This is important because our device is meant to be continuously used and store/rewrite additional data to be printed out as a label. Alternatively, the device can also be used to heat up a milk bag completely independent of the other functions of the device.

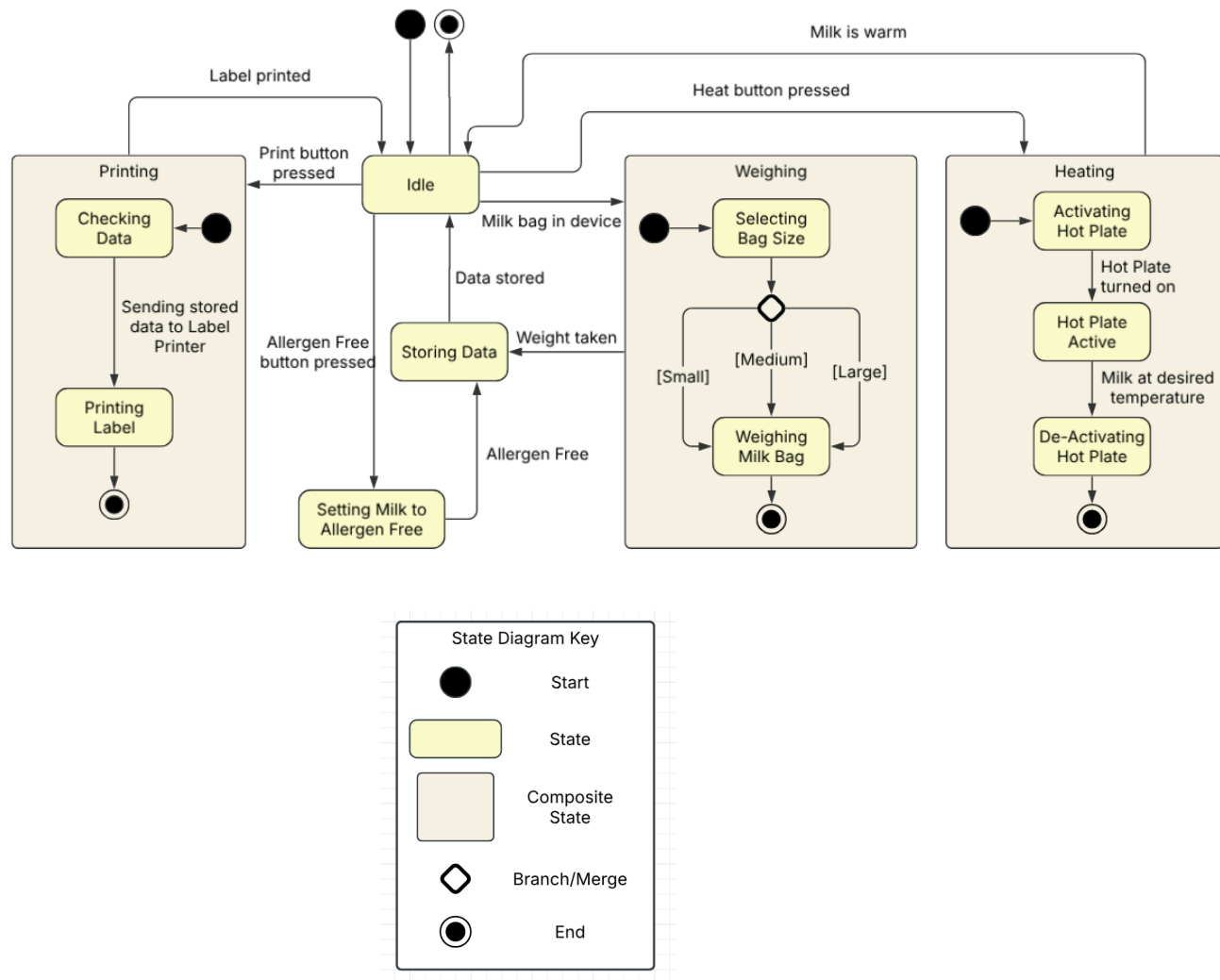


Figure 7.2 - Software State Diagram

7.3: Class Diagram

The class diagram is a UML (Unified Modeling Language) diagram that provides a visual representation of the structure of a system and the relationships between its classes, attributes and methods. Unlike the previous UML diagrams, the class diagram provides an overview of the object-oriented system design and can be used as a representation of the software development for our system. Our class diagram incorporates three classes that make up our system, with the Milk class being the whole (container) class composed of the other two part (contained) classes. There is a difference between the two part classes, with the Weight class representing a composition relationship with the Milk class and being unable to exist independently of its whole class. However, the Heat class represents an aggregation relationship with the Milk class and is able to exist independently of its whole class.

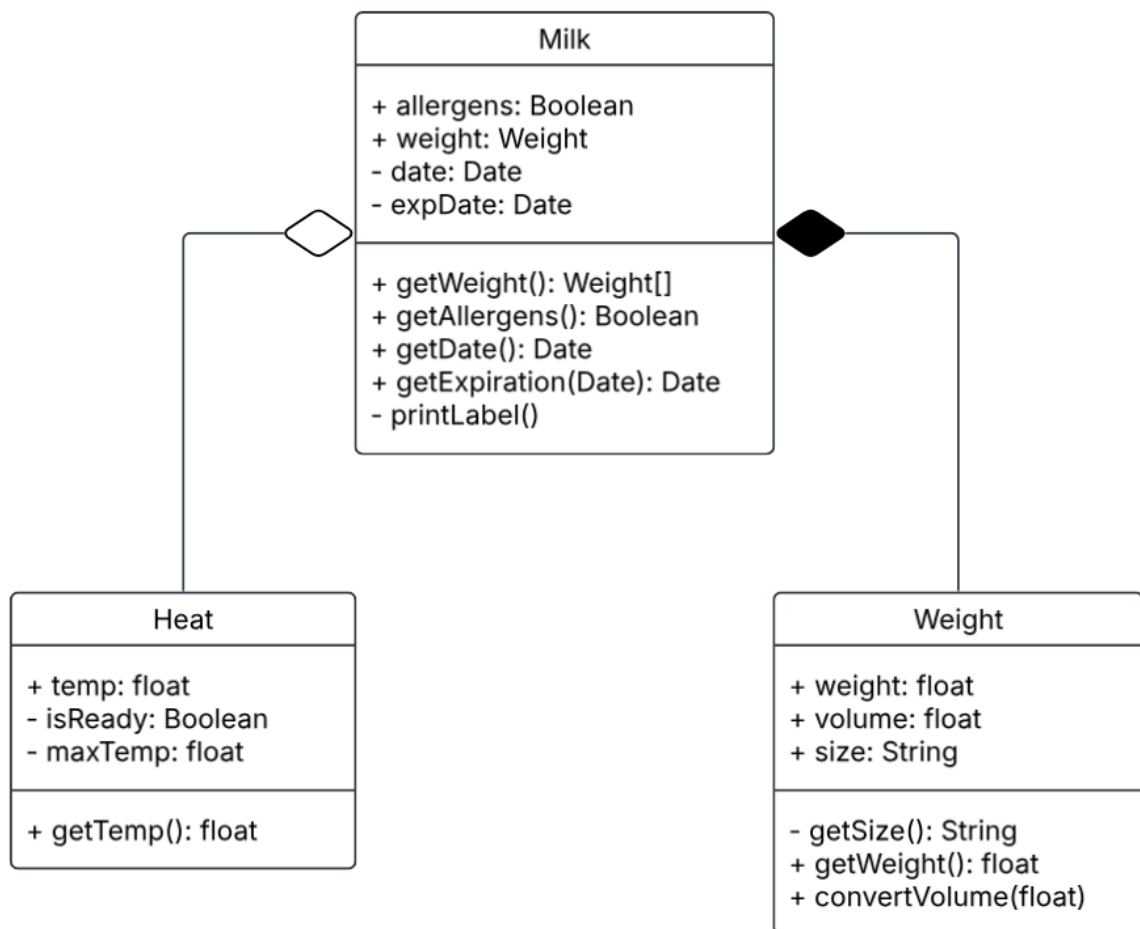


Figure 7.3 - Software Class Diagram

7.4: Current User-Interface (UI)

The current state of the mobile application can be observed below. Figure 7.4, 7.5, 7.6, shows the current login screen, Register Screen, and Home screen Respectively. Each screen is connected to a JavaScript backend API accessing a PostgreSQL database. The homescreen demonstrates measurement retrieval of sample data. Currently there is functionality to add your own measurement with the current date and time. Upon completion the data loaded in the home screen will be retrieved via bluetooth from the ESP32. In the case of an emergency or being away from the PUMPED device, manual data input will be kept in the mobile app for the user's ease of access. Additional UI and frontend components will be fine tuned in the future.

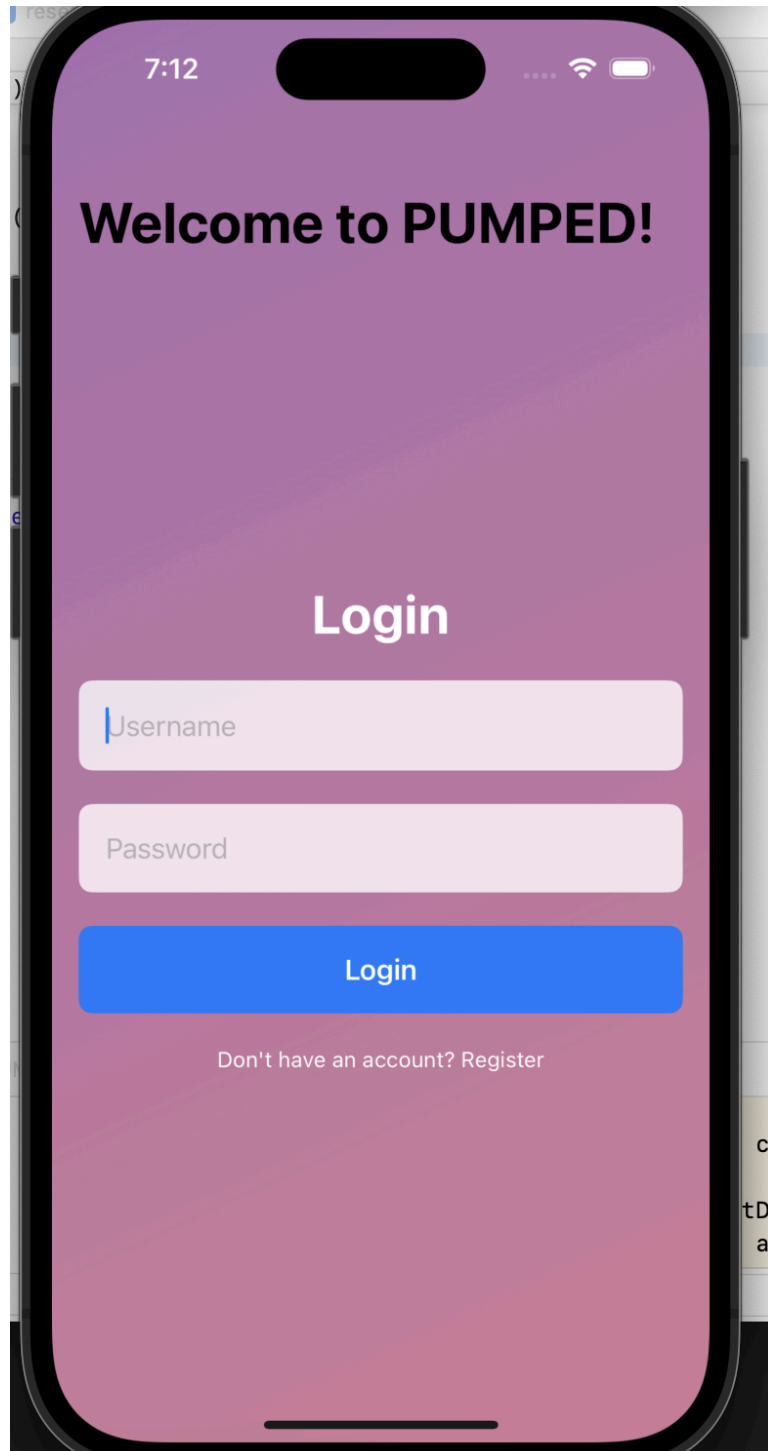


Figure 7.4 - Login Screen

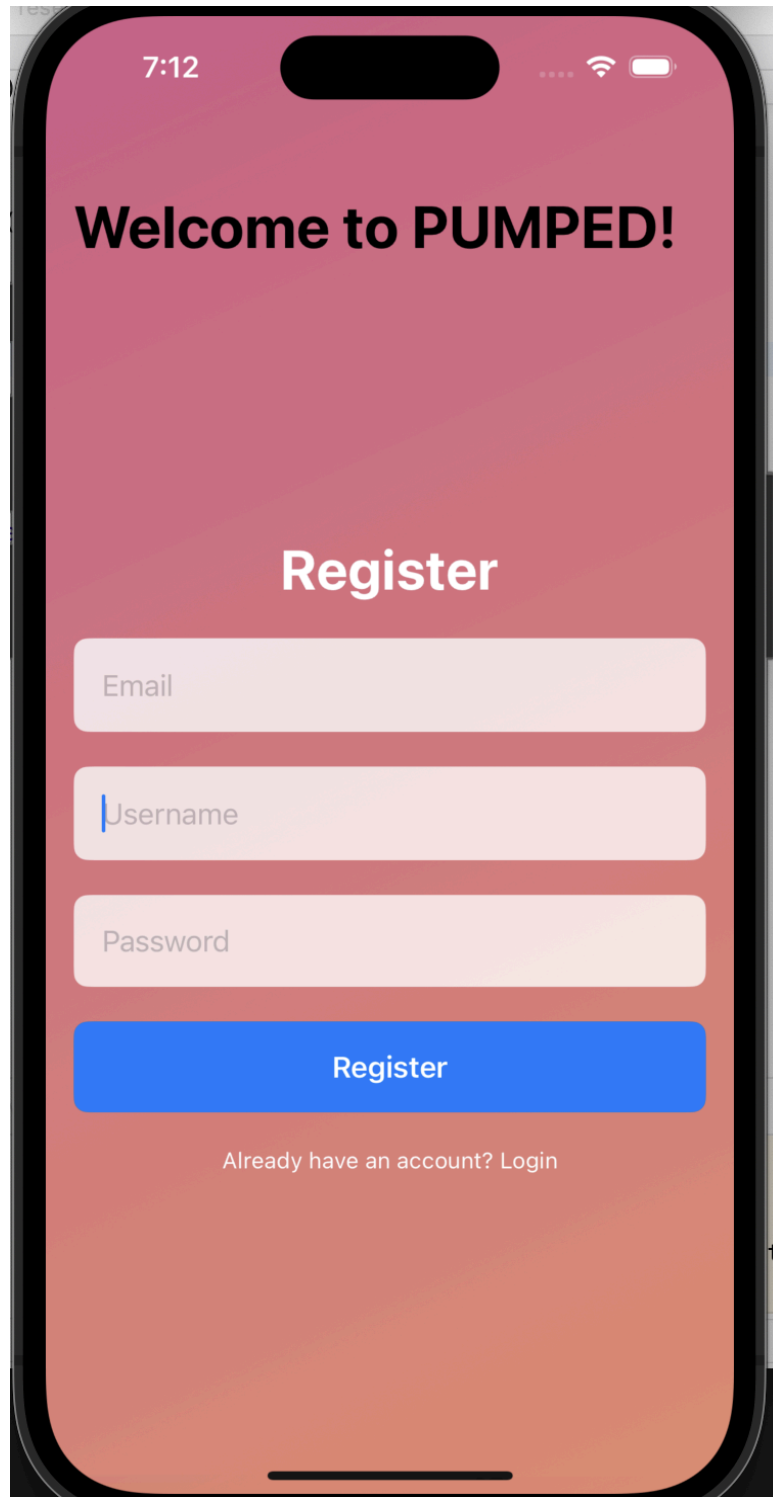


Figure 7.5 - Register Screen

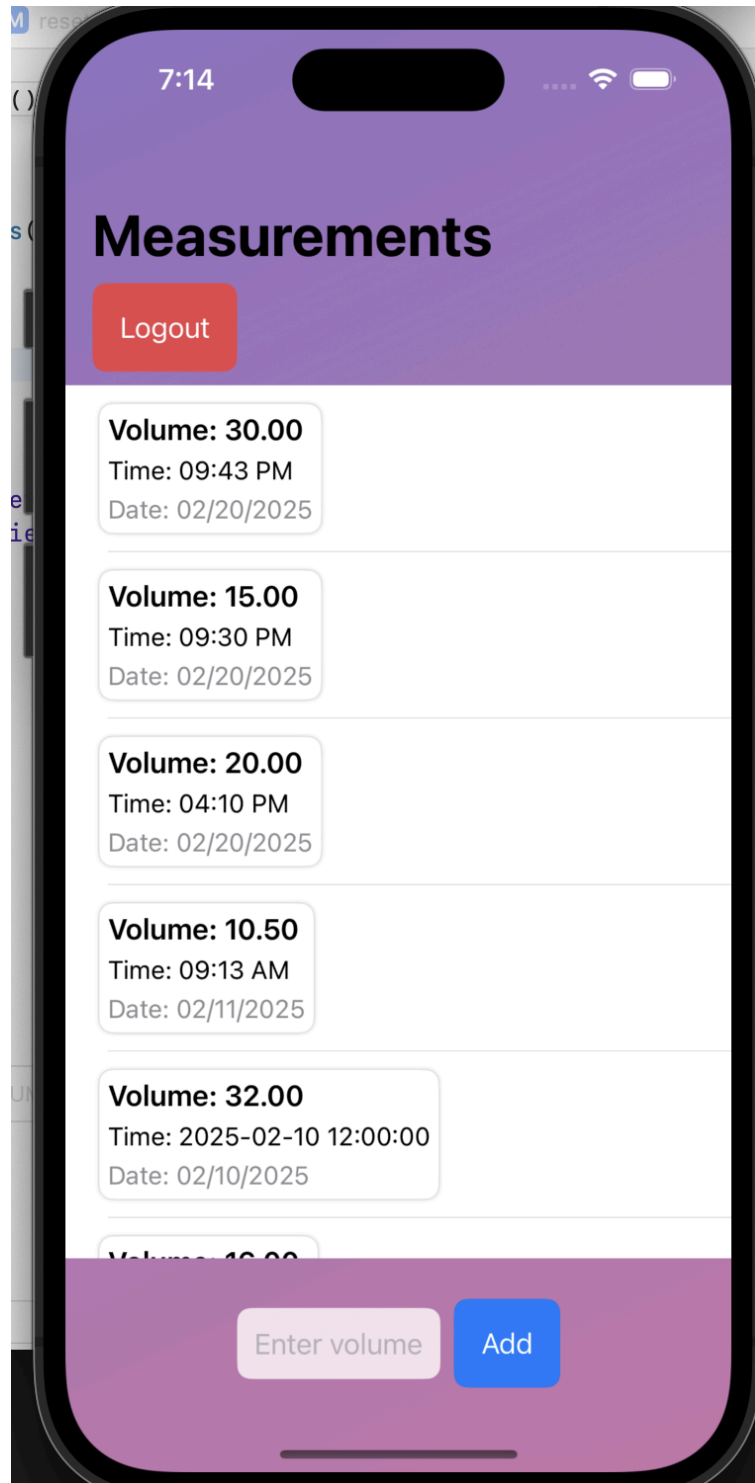


Figure 7.6 - Home Screen

7.5: Custom Icon Integration

Figure 7.7 shows our custom app icon for our PUMPED device that will appear in the users iPhone Screen. The icon represents a scale, highlighting the biggest feature of our product, the storage of weighed, pumped breastmilk. Customers scrolling the app store should be able to understand the functionality of the app due to its icon and description in the apple store.



Figure 7.7 - Custom App Icon

Chapter 8 - System Fabrication/Prototype Construction:

Chapter 8 is dedicated to the physical design of the PCBs for our project based on the research and schematics done in previous chapters. As stated, this chapter will include all PCB designs done in Fusion 360, details of construction for the device enclosure, as well as modifications or additions necessary in order to make the design function properly.

8.1: Guidelines for PCB Design

For our project, there were 6 individual PCB designs that we needed to consider in order for our project to be fully functional. Of the 6 designs, 5 were relatively simple and likely will not change during the testing and development of the project unless there are major component or significant project scope changes. Furthermore, the discussion of each individual PCB design will follow within the chapter to discuss why each PCB was designed in the way it was and if there were any particular challenges associated with that PCB. All designs are based on schematics used previously and provided in the appendix, and will be evaluated by the course professors before being ordered. All designs are subject to change as the project progresses and the scope evolves.

8.2: Regulators

The following designs are of our Buck-Regulators in order from lowest output voltage to largest output voltage. For our regulators, the design makes little modifications to what the datasheet recommends. The only significant difference between all designs are the values of the components used in order to alter the output current necessary to power all components properly. As the design of our device progresses, we will seek approval of board design prior to ordering. A potential design change could come up in the addition of decoupling capacitors for each board. Any further changes to PCB design will be made at the recommendation of any of the mentors for the course in order to ensure proper functionality.

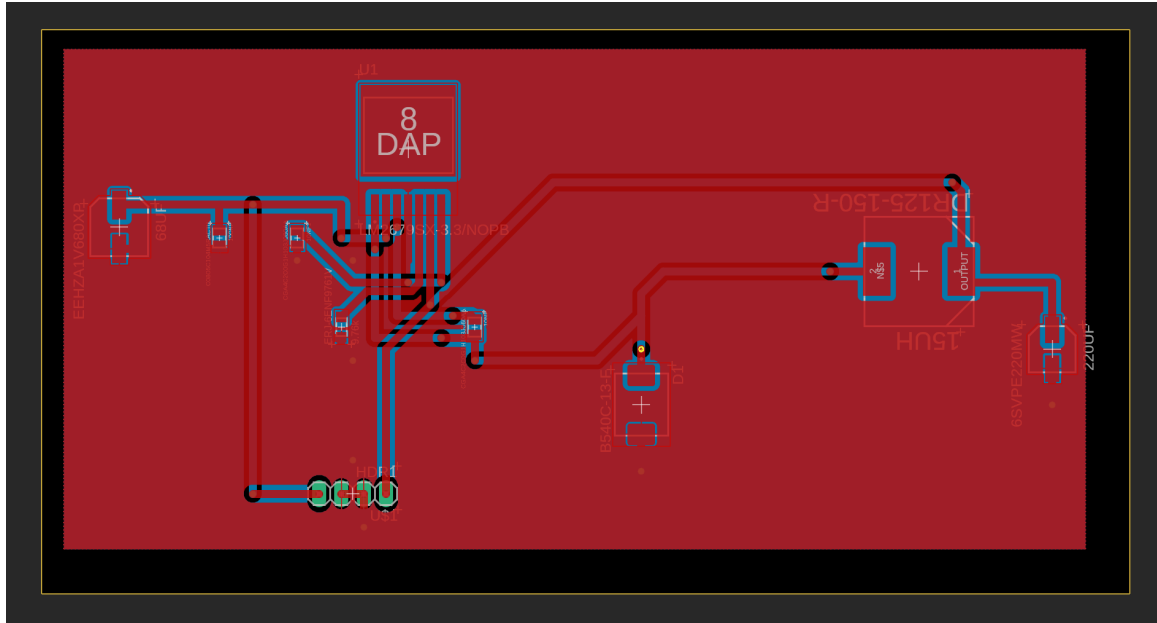


Figure 8.1 - 3.3V Regulator PCB Layout

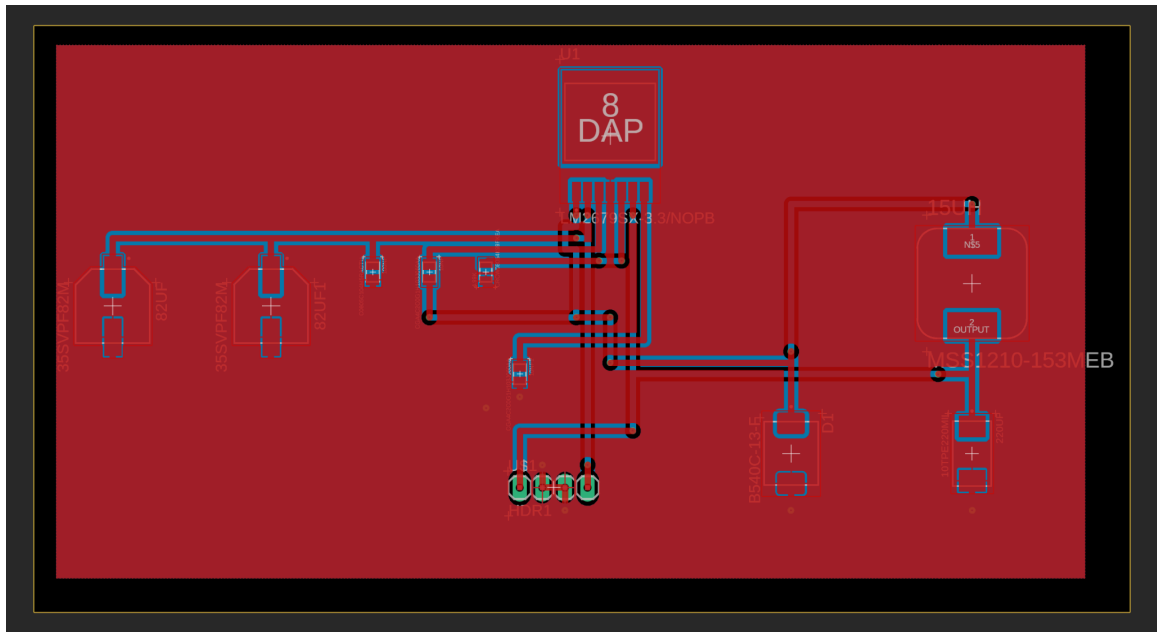


Figure 8.2 - 5V Regulator PCB Layout

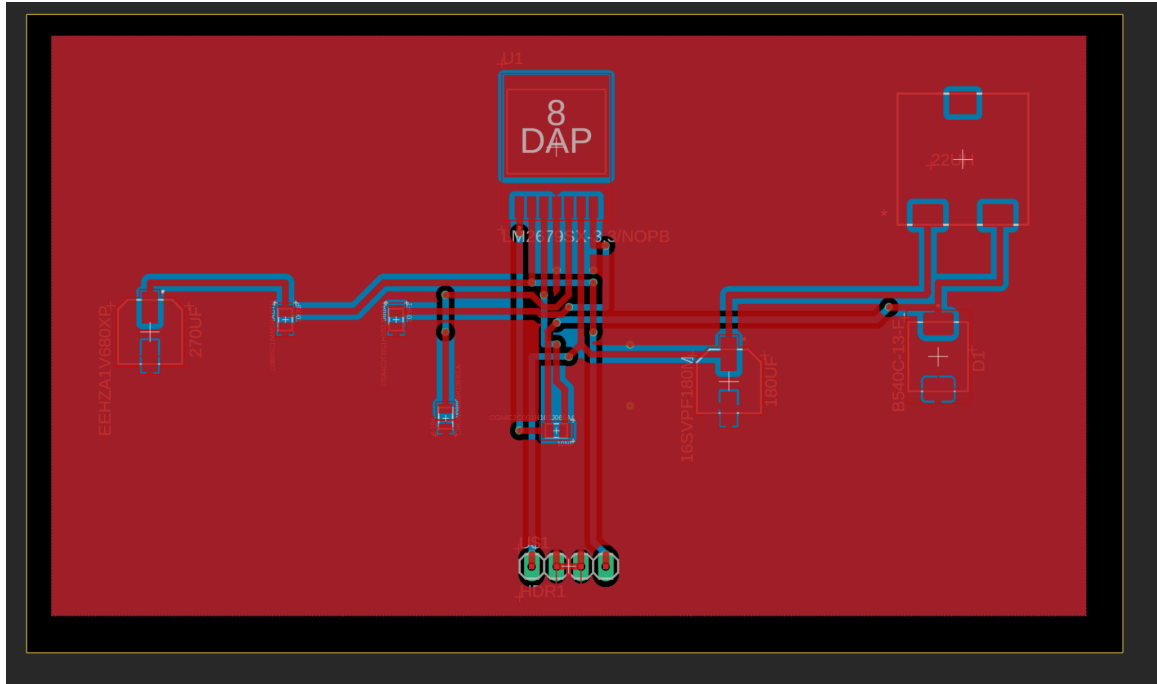


Figure 8.3 - 12V Regulator PCB Layout

8.3: Rectifier

For the design of the rectification, our project needs to have the rectification be separate from the primary PCB in order to make repairs and modifications as efficient as possible. We took after the regulator design by making a daughter board that would be more effective in potential scenarios where any design element malfunctions. Additionally, the signal transformer that feeds the input for the rectifier will be significantly larger than many of the components in the rest of the design. Keeping this element separate from the rest of the PCBs will reduce the overall size by allowing us to stack the PCBs atop each other.

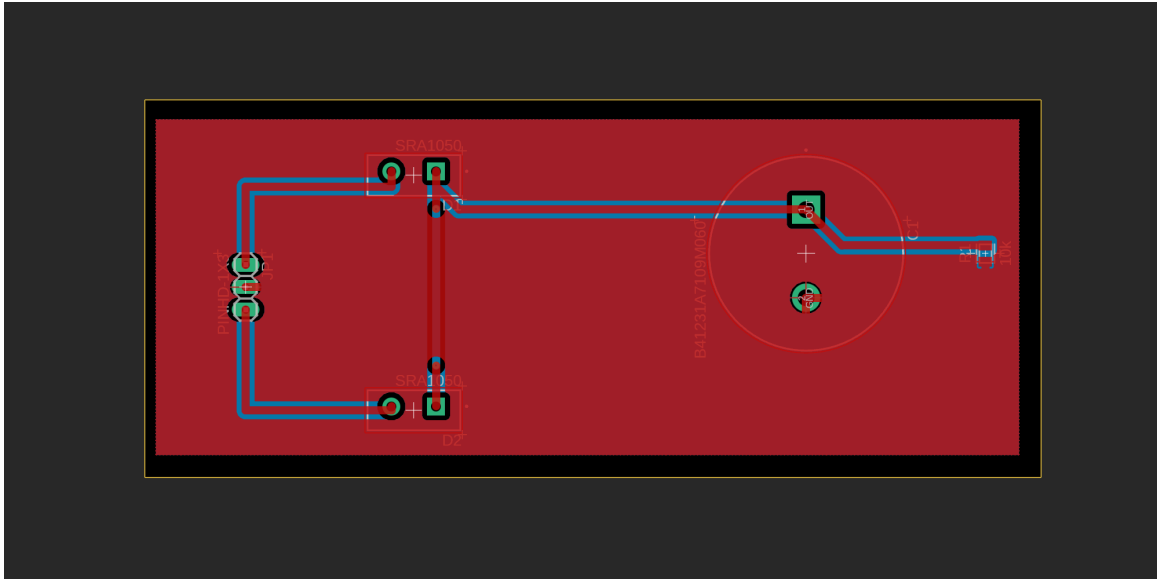


Figure 8.4 - Rectifier PCB Layout

8.4: Load Cell Amplifier

For the design of the load cell, we stuck to the schematic recommendations just as we did for the regulators. Using the design for the amplifier, as used in the schematic from the load cell manufacturer, was the most effective option as it ensures that the signal from the Strain-Gauge is amplified to a detectable amount in the MCU. This saved us time when potentially finding a separate amplifier from a different manufacturer that may or may not function as intended for our specific peripheral component. The design for this daughter board will likely not change significantly unless the method for measuring weight changes within the scope of the project itself.

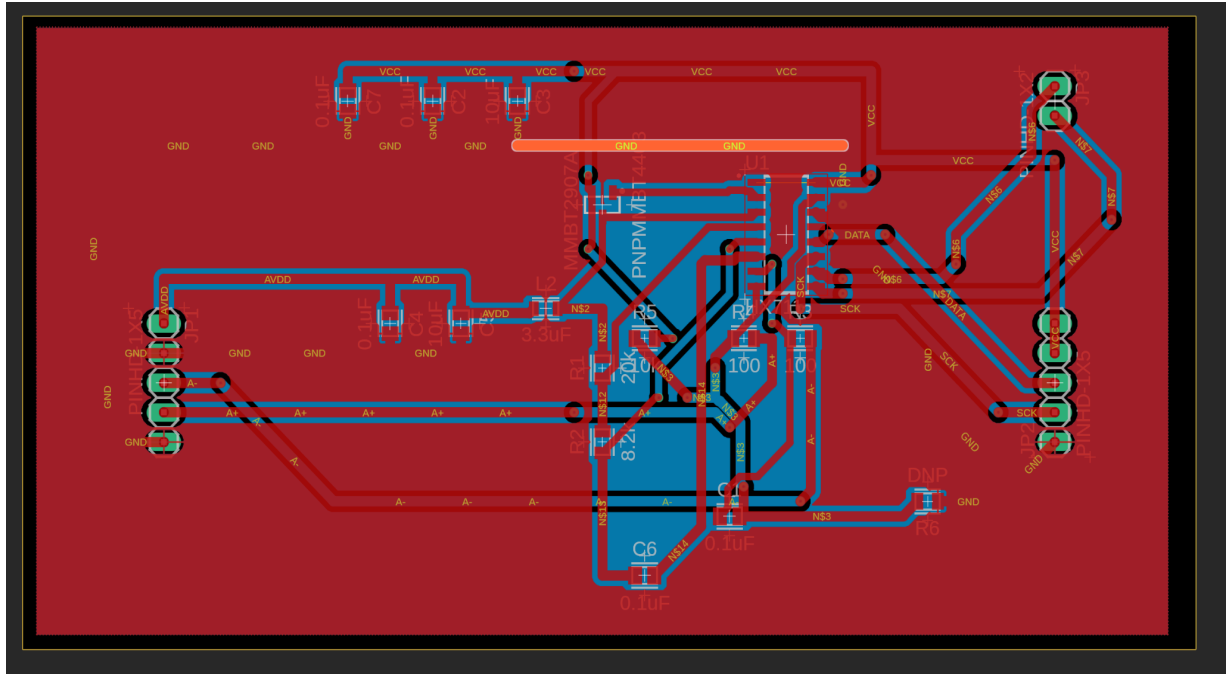


Figure 8.5 - Load Cell Amplifier PCB Layout

8.5: MCU/ Main PCB Layout

The main PCB Layout is a culmination of multiple parts put together. The primary function is to direct and control data to and from peripheral devices. This PCB is the most likely to change out of all of the PCBs discussed in this chapter for several reasons. First of which is that in testing our peripheral devices it could show that a component is not feasible, and may need to be replaced. If that were to occur, then the method for which the component is recognized by the MCU potentially needs to be changed, thus changing the PCB layout. As we test and evaluate our project solutions, this PCB will be subjected to the most change. From those needed changes we will be able to determine the efficacy of design choices within the Main MCU board.

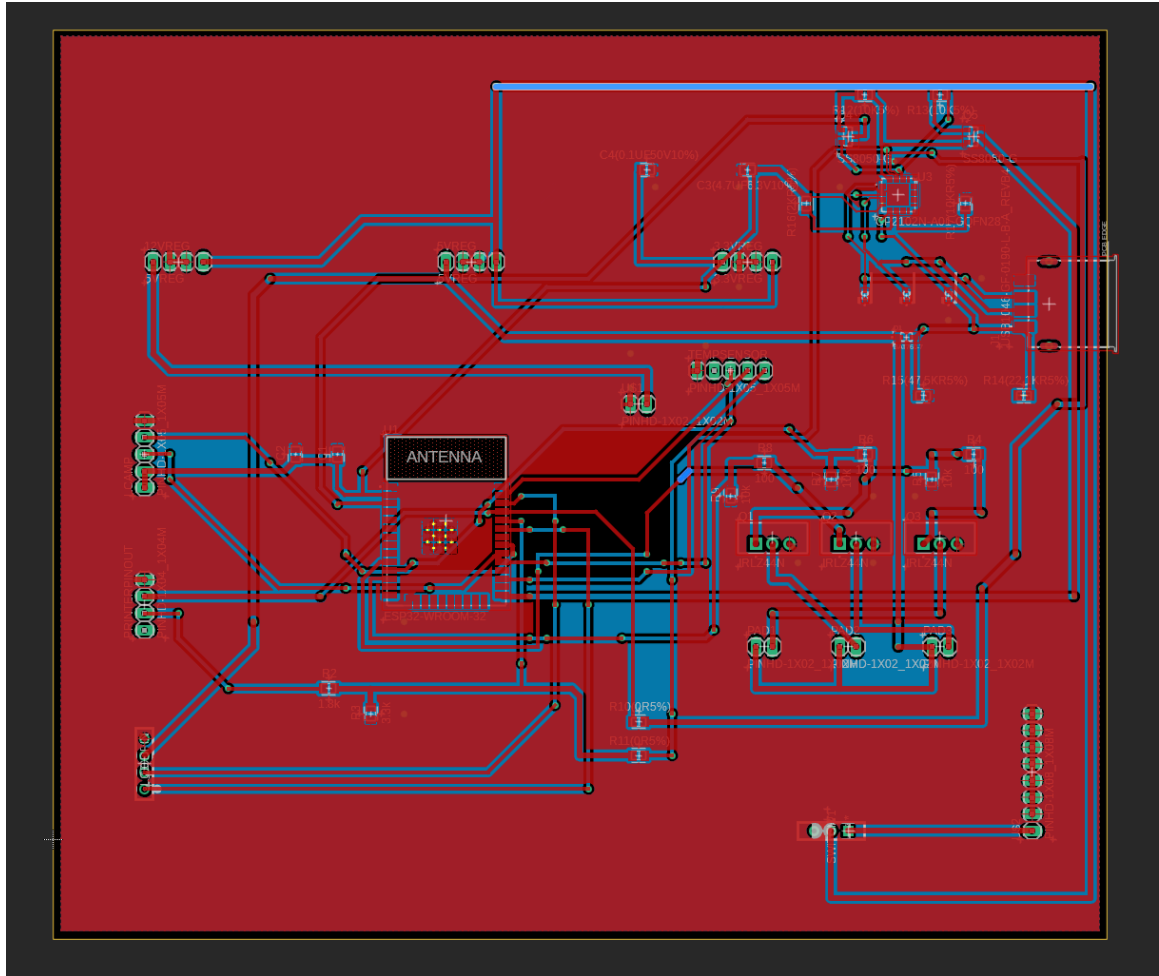


Figure 8.6 - MCU/Main PCB Layout

Chapter 9 - System Testing & Evaluation:

In this chapter, we discuss the plans for testing and evaluating the efficacy of the design of our project, which is one of the most important steps. In particular, we will go over the methods we will utilize to determine how effective the solutions we have found in initial research are to the ultimate final design. Both hardware and software need to be thoroughly scrutinized in order to ensure that our system functions completely as intended.

9.1: Hardware Testing

While this specific section is in regards to the hardware elements, ultimately, testing will need to be evaluated on a software level as well. We need to be able to ensure that the sensors for weight and temperature are implemented and calibrated correctly to ensure accurate readings for the interfaces in our system. Equally as important is evaluating the method for which we are going to heat the breast milk in our design.

9.1.1: ESP32-DevKit v1 (38-pin, WROOM-32)

Initial bring-up focused on validating the microcontroller module that anchors every other subsystem. The board was powered from a laptop USB-C port (5 V). On connection the on-board status LED illuminated and the USB-serial bridge enumerated reliably at 115 200 baud—baseline indicators that the 5 V rail, 3 V3 LDO, and CP210x interface were healthy.

For convenience and signal clarity all peripherals were assembled on a single 400-tie solderless breadboard. The ESP32 straddles the power rails so that 5 V can feed the LCD while 3 V3 services logic-level devices (HX711, MAX6675, I²C pull-ups). *Figure 9.1* (photo placeholder) depicts the complete wiring harness. Table 9.1 lists the definitive pin map now locked into the schematic:

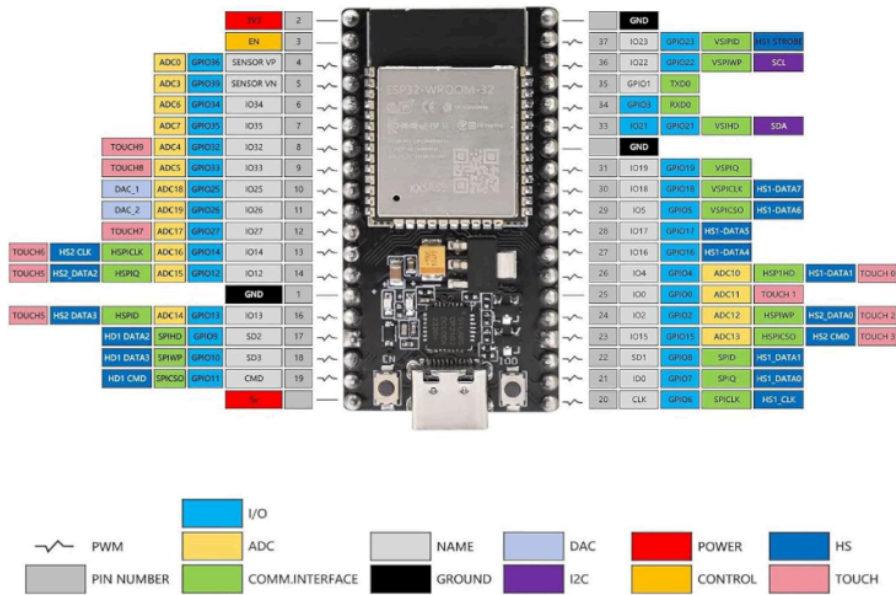


Figure 9.1 - ESP32 Pin Layout

Table 9.1 - Pin Usage

Peripheral	ESP32 Pin	Function
HX711 DT	GPIO16	Digital-In
HX711 SCK	GPIO4	Digital-Out
MAX6675 SO	GPIO19	SPI MISO
MAX6675 CS	GPIO5	SPI CS
MAX6675 SCK	GPIO18	SPI CLK
I ² C SDA (LCD)	GPIO21	LCD Backpack
I ² C SCL (LCD)	GPIO22	LCD Backpack
Load Cell Button	GPIO0	Tare Weight

9.1.2: 5 kg Load Cell with HX711 Amplifier

The single-point load cell was bonded to an HX711 breakout, whose differential input rejects common-mode noise from the shared ground rail. After an initial tare the firmware's calibration constant (-7050) was dialled-in using a 100 g laboratory mass. Each increment updated the LCD within two seconds and displayed a stable value free of noticeable drift—qualitative proof that the Wheatstone bridge, amplifier, and sampling code form a coherent chain.

A short endurance run left the scale sampling continuously for thirty minutes. Visual inspection confirmed that readings held steady, suggesting that thermal variation on the bench did not meaningfully influence the strain gauge during typical use spans.



Figure 9.2 - Lab Mass used for load cell prototyping

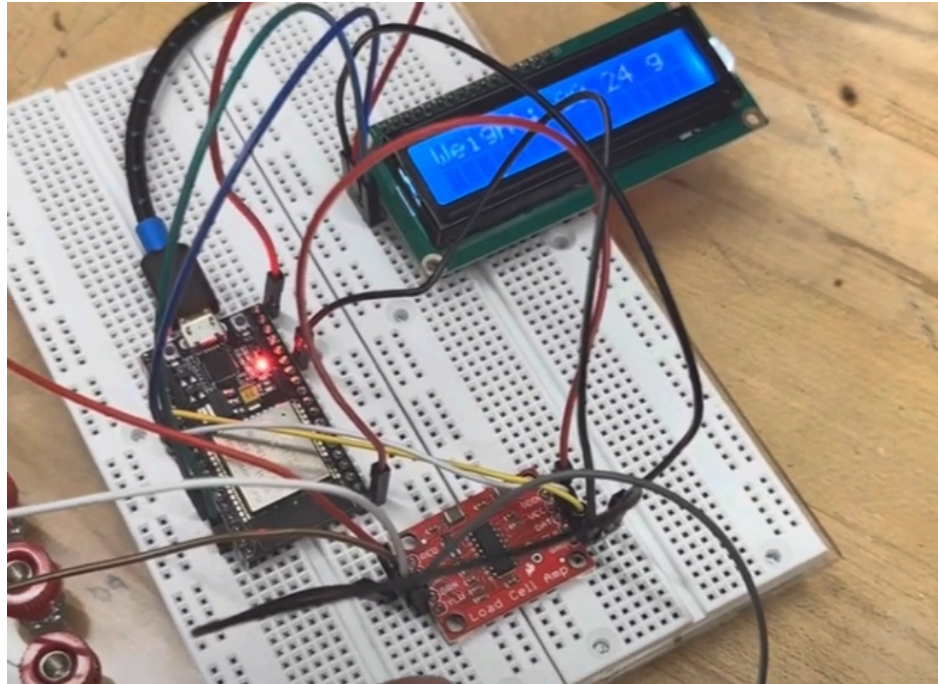


Figure 9.3 - HX711 Breadboard Implementation

9.1.3: Type-K Thermocouple with MAX6675

The MAX6675 breakout communicates over the ESP32's hardware SPI bus. Two practical tests were performed:

The rapid drop confirms correct wiring, cold-junction compensation, and library timing. Although the equilibrium plateau was slightly above the 32 °F theoretical reference, the deviation is reasonable given ice-water mixture entrained with air. *Figure 9.4* (placeholder) illustrates the serial temperature trace captured during the transition.

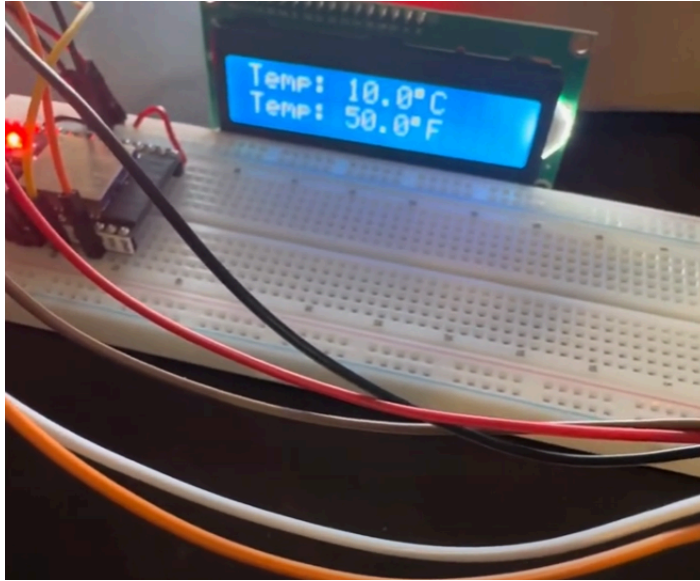


Figure 9.4 - LCD Reading of Thermocouple In Ice

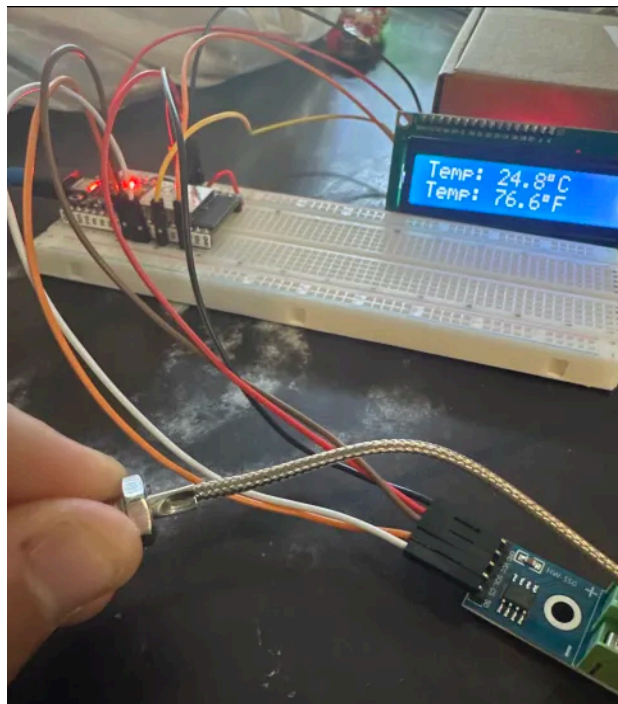


Figure 9.5 - Thermocouple & MAX6675 Breadboard Implementation

9.1.4: Resistive Heating Element

An Electric Heating Pad 14cm x 5cm by Adafruit—destined to be PWM-driven in the final build—was exercised in open-loop fashion from a 10 V bench supply. The heater rose to 76 °C in roughly ten minutes while attached to a 10v supply. The test verified that available wattage is sufficient for milk-thaw workloads without yet invoking closed-loop control. An infrared snapshot (*Figure 9.7*, placeholder) shows uniform surface temperature, an encouraging sign that localized scorching is unlikely when PID control is added later.

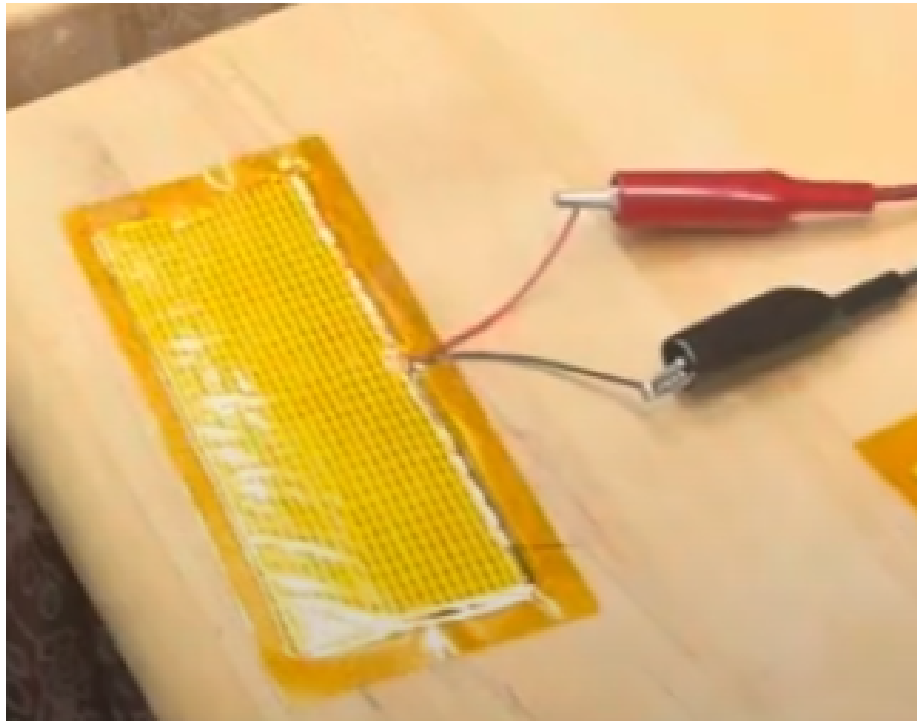


Figure 9.6 - Resistive Heating Element

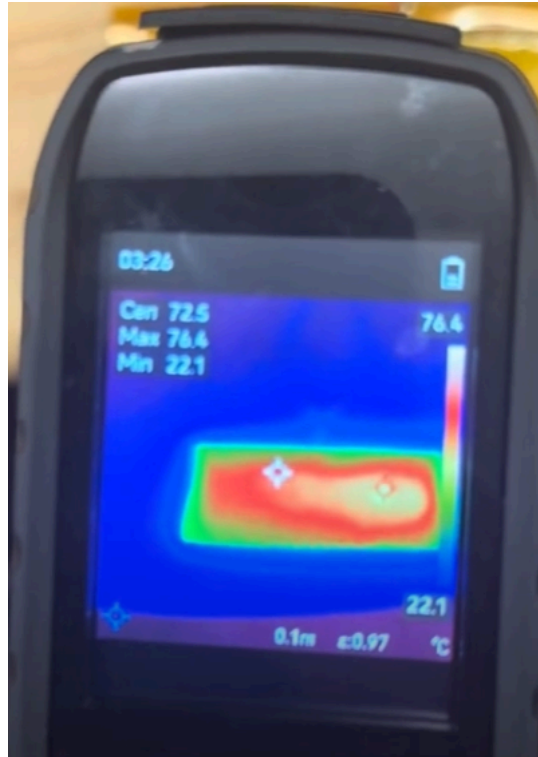


Figure 9.7 - Thermal Reading

9.1.5: I²C 16 × 2 Character LCD

Because the LCD's PCF8574 backpack tolerates 5 V logic, its data lines remain at 3 V3 but power is drawn from the breadboard's 5 V rail shared with the ESP32. Address 0x27 was auto-detected, and the display immediately rendered the temperature while using the thermal coupler, and the weight when using the load cell on first boot, confirming bus integrity. Scrolling text and degree-symbol printing validated the complete character map. Backlight current (~30 mA) is well within the system power budget.



Figure 9.8 - LCD Temperature Display



Figure 9.9 - LCD Weight Display

9.1.6: Breadboard Integration

To streamline debugging, we verified each subsystem on the breadboard in isolation before integrating them with the main firmware. The type-K thermocouple was paired with a MAX6675 cold-junction-compensated amplifier, while the 5 kg load cell was coupled to an HX711 24-bit ADC. Once reliable serial output was confirmed for both sensors, their live readings were redirected to the I²C 16 × 2 LCD, demonstrating that the display interface and data paths were functioning correctly. The resistive heating element required more power than the ESP32's 3.3 V rail could provide, so it was tested separately on a

laboratory bench supply at 10 V. This arrangement prevented brown-outs and allowed us to characterize warm-up behavior without stressing the microcontroller. In the final design, a dedicated step-up regulator and MOSFET driver will let the ESP32 switch the heater safely, enabling closed-loop temperature control while keeping the element electrically isolated from the logic rails.

9.2: Embedded Software Testing

Embedded firmware forms a very important bridge between our hardware and user interface, so extreme testing measures are essential. In this section, we describe our multi-stage testing methodology, which begins with verifying the pin mapping and libraries needed for each part implementation. From there it is important that the firmware illustrates correct pin usage in order to ensure all parts are connected. The following section shows what went in to the development of each sketch, and the status of all of our part integration.

9.2.1: Firmware Build and Flash

All embedded code resides in a PlatformIO project under Git version control, targeting the Arduino framework for the ESP32. A single command (`pio run --target upload`) compiles against the `arduino-esp32` framework and flashes the binary via `esptool.py`. An M2 Macbook air was used connecting via `microusb-usb c` on the MCU. Serial output was observed at a baud rate of 115200 before testing the LCD. Typical cycle time from Save to Running Firmware is under 25 seconds, accelerating iterative development. Boot messages report free heap and print a banner that includes firmware version and build timestamp for easy field identification.

9.2.2: Weight-Display Sketch

The load-cell program is dedicated to the HX711 amplifier and the I2C LCD. The amplifier's DT and SCK lines connect to GPIO16 and GPIO4, while the display uses the default SDA and SCL lines on GPIO21 and GPIO22. After a two-point bench calibration, a scale factor of -7050 is fixed in code. Pressing the on-board BOOT button toggles the readout between live weight and a tared zero value, and a readiness check reports "HX711 missing!" if the module fails to respond.

Values first stream through the serial monitor; once verified, the same readings refresh the LCD every two seconds, demonstrating agreement between both output paths. The scale factor is not 100% calibrated and is prone to inaccurate weight measurements.

9.2.3: MAX6675 Temperature-Display Sketch

A separate sketch measures temperature with the MAX6675. The thermocouple amplifier's SO, CS, and SCK pins are wired to GPIO19, GPIO5, and GPIO18. The loop reads the sensor once per second—well beyond the required 250 millisecond conversion time—and formats both Celsius and Fahrenheit on the 16 × 2 display, appending a degree symbol and clearing any leftover characters. During an ice-bath test the console trace showed the probe cool from 72 °F to about 40 °F in under a minute, confirming proper cold-junction compensation. An explicit handler for an open thermocouple will be added when the temperature and weight codebases are merged.

9.2.4: Debugging Workflow

Each sketch follows the same debugging pattern. Initial runs rely solely on USB serial output until sensor readings stabilize. Once the data are trusted, identical values are routed to the LCD, validating I2C transactions and on-screen formatting. This sequence isolates hardware issues from display logic and avoids the confusion of multiple simultaneous faults.

9.2.5: Firmware Roadmap

During Senior Design 2 the two sketches will be consolidated into a single firmware image. The combined program will add MOSFET-driven heater control, a simple LCD menu, and Bluetooth Low Energy characteristics that broadcast weight and temperature data. The Swift mobile application, now populated with placeholder PostgreSQL records, will subscribe to those BLE updates to display live readings. New error handlers will also be introduced so that events such as open thermocouples or HX711 timeouts appear both on the local display and in

transmitted packets, completing the real-time data loop between the embedded system and the iOS app.

9.3: Future Integration

The next firmware milestone will focus on completing the features that transform the prototype into a production-ready appliance. First, the resistive heating element will be driven through a step-up regulator and logic-level MOSFET, then closed-loop PID control will be tuned against the MAX6675 feedback so the bath reaches its target temperature faster, holds it within a narrow band, and shuts down automatically if any over-temperature fault is detected. A compact UART thermal printer will be added to generate adhesive labels that record the milk bag's measured weight together with the current date and time, eliminating manual handwriting and supporting first-in-first-out rotation. Finally, additional panel buttons will be mapped to dedicated GPIOs and debounced in software, providing the user with a simple way to cycle between Measure, Warm, and Settings modes while displaying clear prompts on the LCD. These enhancements will be developed in parallel with the BLE data path so that every hardware action—heating, weighing, or printing—creates a corresponding event in the mobile application and in the database.

Table 9.2 - Part Integration Status

Component	Category	Status	Notes
ESP32 -DevKit v1(WROOM 38 Pin)	Hardware	Integrated	Breadboard-mounted, USB-C powered
5kg Load Cell + HX711 amplifier	Hardware	Integrated	Reads & displays weight, not yet fully calibrated
Type-K Thermocouple + MAX6675	Hardware	Integrated	Ambient & ice-bath tested

Resistive Heating Element	Hardware	Integrated	Reaches 76 °C in ~10 min on 10 V supply
16 × 2 I ² C LCD	Hardware	Integrated	Displays weight, temp; 0x27 address
Button Controls	Hardware	Pending	Tare implemented on GPIO, still need full button functionality to be implemented
UART Thermal Printer	Hardware	Pending	Wiring & driver code to be added
MOSFET Driver & PID Closed-Loop Control	Hardware	Pending	Allows for control of resistive heating element
Custom PCB (all hardware)	Hardware	Pending	Migration from breadboard
Completed Embedded code with Full Implementation	Firmware	Pending	Firmware currently implemented separately, still need full part implementation
iOS App – Login/Register Screen	Mobile-app	Integrated	Active and using API endpoint
iOS App – Home Screen (sample data list)	Mobile-app	Integrated	Active, retrieving sample data from database
iOS App – Live BLE → Database syn	Mobile-app/Firmware	Pending	Ingest real-time readings via BLE

iOS App – Inventory Charts & Alerts	Mobile App	Pending	Visualization of trends & expiration warnings
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Chapter 10 - Administrative Content:

This chapter discusses the necessary content for the engineering management of our project. This chapter will include and discuss budget estimates, work distribution, and expected milestones. This section is subject to change as the semesters unfold and we continue to progress towards our final designs.

10.1: Budget Estimates

The sponsor for our project has graciously allowed us an \$800 budget for the materials and any services necessary to accomplish the project. The most costly aspect of the project is going to be the electrical hardware ordering. As it currently stands, prices for exporting PCBs and components are ever increasing, so it is difficult to accurately determine how much this aspect is going to cost. In Table 10.1, we have included rough estimates of how much we anticipate items to cost.

Table 10.1 - Bill of Materials

<u>Component</u>	<u>Estimated Cost (USD)</u>
Microcontroller Esp 32 Wroom	\$10 - \$30
Load Cell	\$10 - \$20
LCD Display	\$10 - \$20
Thermal Label Printer	\$20 - \$50
Power Supply	\$15 - \$40
PCB & Prototype Materials	\$80 - \$200
Misc. (cables, connectors, adhesives, buttons)	\$10 - \$20

Temperature Sensor	\$4 - \$30
Heating Element(s)	\$20 - \$50
Enclosure Design Cost (i.e. 3D printing, welding, etc.)	\$40 - \$100
Total (Approx.)	\$219 - \$560

10.2: Work Distribution

The following table shows the engineer responsible for each of the systems within the project, as well as the engineer that will provide support. The roles are not strictly binding, and we fully expect every group member to collaborate with each other as needed.

Table 10.2 - Work Distribution

System/Task	Primary Engineer	Secondary Engineer
Administrative	Zachary Celentano	Jason Devito
Power Supply	Zachary Celentano	Jamieson Foley
Sensor Integration	Jamieson Foley	Zachary Celentano
Thermodynamic Evaluation	Jamieson Foley	Zachary Celentano
Mobile App Development	Jason Devito	Isaiah Robinson
MCU Programming	Isaiah Robinson	Jason Devito
Enclosure Construction	Jason Devito	Isaiah Robinson

10.3: Project Milestones

Weeks 1–2 (Jan 6 – Jan 19)

- Requirements Gathering & Research
 - Finalize project scope with sponsor/mentor.
 - Conduct feasibility analysis for hardware (scale, printer, LCD, etc.) and mobile app integration.
 - Develop initial problem statements and identify key user needs.

Weeks 3–5 (Jan 20 – Feb 9)

- System-Level Design
 - Create and review the hardware block diagram and software flowchart.
 - Draft House of Quality to correlate customer requirements with engineering specs.
 - Establish measurable specs (weight accuracy, label printing speed, etc.).
 - Research Power Supply.

Weeks 6–7 (Feb 10 – Feb 23)

- Component Selection & Ordering
 - Research and select load cell, ADC module, microcontroller, label printer, heater, and LCD screen.
 - Confirm and design power requirements .
 - Order all long-lead-time components to ensure timely delivery.

Weeks 8–10 (Feb 24 – Mar 16)

- Prototype Assembly (Hardware)
 - Assemble and mount the load cell onto a stable platform.
 - Mount heater to the load cell and insulate accordingly.
 - Begin integrating microcontroller, printer, and LCD.
 - Perform initial tests for power distribution and device safety.

Weeks 11–13 (Mar 17 – Apr 6)

- Firmware & Software Development (Phase I)
 - Write code for reading the load cell (via ADC), converting weight to weight, and displaying values on the LCD.
 - Integrate Real-Time Clock (RTC) or system time to record date/time.
 - Begin label printing code and basic user interface logic.

Weeks 14–16 (Apr 7 – Apr 27)

- Firmware & Software Development (Phase II)
 - Refine user interaction (button press to print, error handling, calibration routines).
 - Optimize label formatting and printing speed.
 - Conduct intermediate testing (accuracy, response time, label clarity).

Weeks 17–19 (Apr 28 – May 18)

- Mobile App Integration (Phase I)
 - Set up basic iOS app structure (user accounts, data model).
 - Implement Bluetooth or Wi-Fi communication to sync weight/weight data.
 - Test data transfer for speed and reliability.

Weeks 20–22 (May 19 – Jun 8)

- Mobile App Integration (Phase II)
 - Implement advanced app features (inventory tracking, expiration date alerts, portioning).
 - Conduct usability testing with mock data.
 - Ensure synchronization logic handles offline mode (caching measurements on device).

Weeks 23–25 (Jun 9 – Jun 29)

- System-Level Testing & Validation
 - Perform end-to-end tests (scale -> label -> app).
 - Perform additional tests on the temperature sensor and heater.
 - Validate accuracy, label content, and data consistency.
 - Gather feedback from peers or target users; iterate as needed.

Weeks 26–27 (Jun 30 – Jul 13)

- Final Adjustments & Optimization
 - Refine mechanical design (enclosure, cable management, ease of cleaning).
 - Optimize firmware/app for performance.
 - Prepare documentation for final demonstration (user manual, technical specs).

Weeks 28–29 (Jul 14 – Jul 31)

- Final Presentation & Demonstration
 - Complete final project report, design website, and any required submission materials.
 - Conduct a polished demonstration of the working device (hardware + mobile app).
 - Receive and integrate final feedback from the sponsor and review committee.

Chapter 11 - Conclusion:

PUMPED began as an ambitious vision to streamline every step of breast-milk handling, from pumping to feeding, through an integrated hardware-and-software platform. Over the course of Senior Design 1, that vision has moved from concept to a working bench-top prototype. Core subsystems—mass measurement, thermal monitoring and control, user display, and resistive heating—now operate in concert, validating the design's fundamental architecture and confirming that the project's goals are technically attainable.

Key milestones include successful integration of the load-cell weighing platform, thermocouple-based temperature sensing, closed-loop heating elements, and a user-friendly LCD interface with tactile controls. These achievements establish the reliable data pathways and feedback loops at the heart of the system. While the companion mobile application is still under active development, the groundwork for secure wireless synchronization and inventory tracking has been laid, and interface mock-ups have been tested for usability.

The project therefore enters Senior Design 2 with a stable hardware foundation and a clear roadmap for completion. Upcoming tasks will focus on final enclosure design, extended reliability and safety testing, firmware refinement, and full integration of the iOS application. Equally important will be iterative user-experience trials that ensure the final product meets the everyday needs of new parents.

By maintaining the same collaborative discipline that carried the team through initial prototyping, PUMPED is on track to emerge from Senior Design 2 as a fully realized, user-ready device—demonstrating both the technical competence of its creators and the tangible impact that thoughtful engineering can have on family health and well-being.

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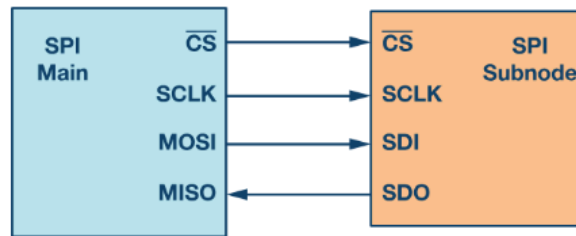


Figure 1. SPI configuration with main and a subnode.

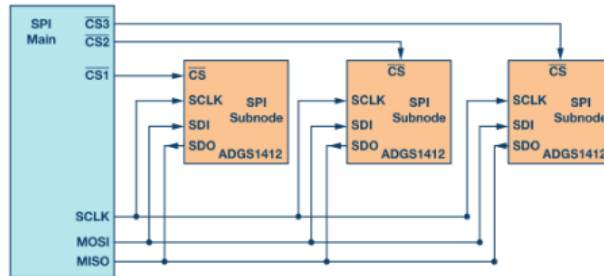


Figure 6. Multi-subnode SPI configuration.

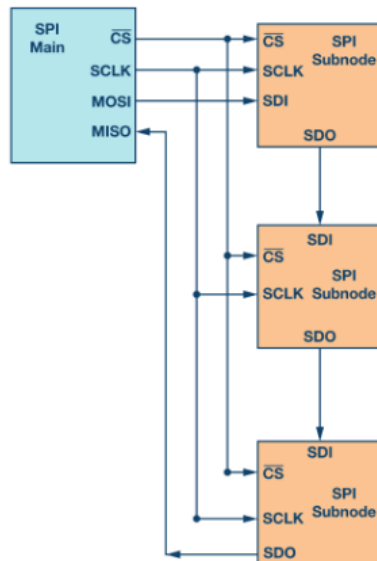


Figure 7. Multi-subnode SPI daisy-chain configuration.

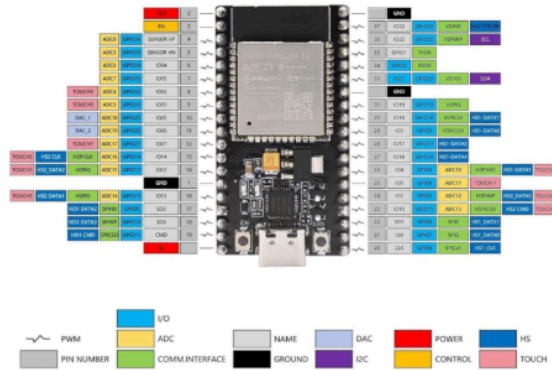
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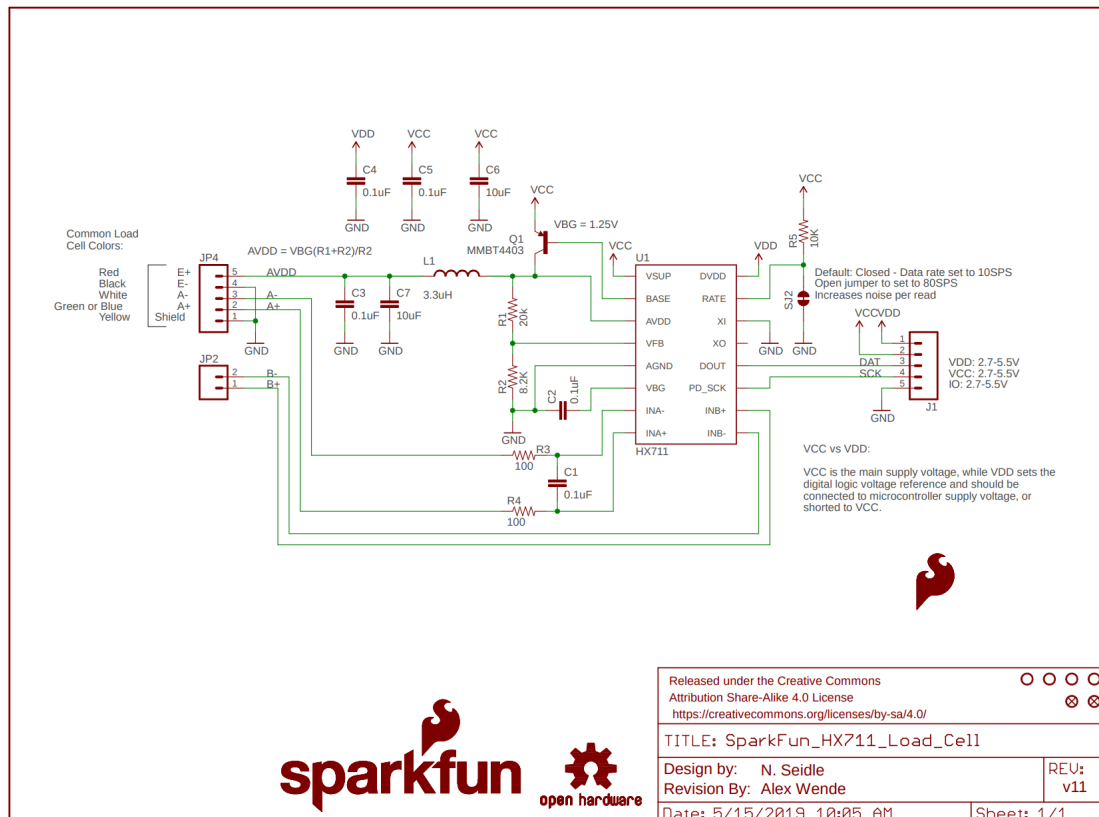


Jason Devito <jasondevito1029@gmail.com>
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Appendix C - Data Sheet:



Load Cell Amplifier Schematic

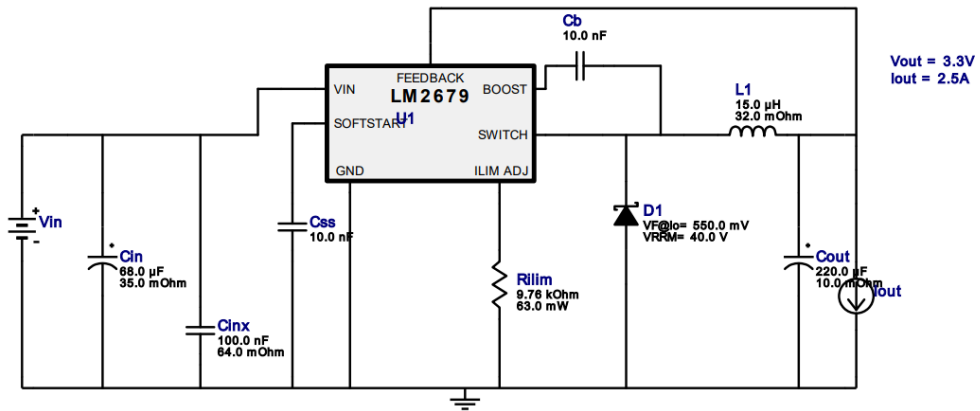


WEBENCH[®] Design Report

Design : 17 LM2679SX-3.3/NOPB
LM2679SX-3.3/NOPB 11V-25V to 3.30V @ 2.5A

VinMin = 11.0V
VinMax = 25.0V
Vout = 3.3V
Iout = 2.5A

Device = LM2679SX-3.3/NOPB
Topology = Buck
Created = 2025-04-03 16:10:20.716
BOM Cost = \$4.36
BOM Count = 9
Total Pd = 1.44W



3.3V PSU Webench Schematic from Texas Instruments

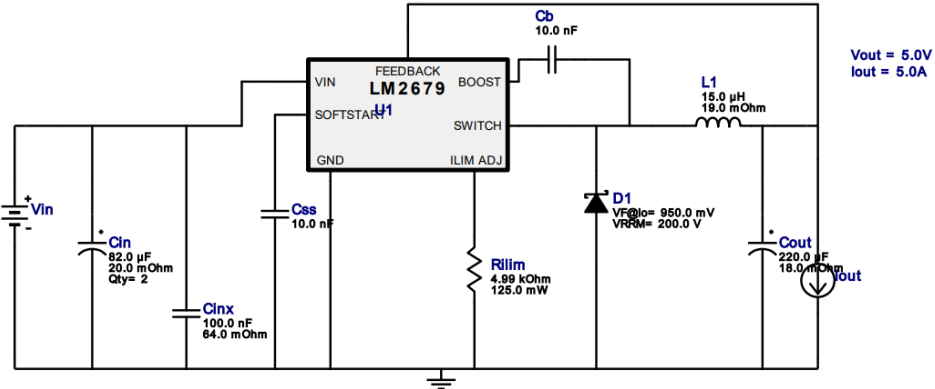


WEBENCH[®] Design Report

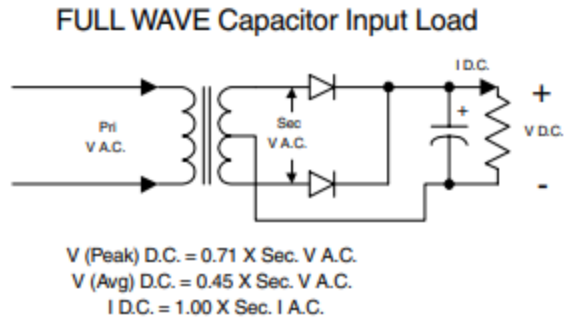
Design : 19 LM2679SX-5.0/NOPB
LM2679SX-5.0/NOPB 11V-25V to 5.00V @ 5A

VinMin = 11.0V
VinMax = 25.0V
Vout = 5.0V
Iout = 5.0A

Device = LM2679SX-5.0/NOPB
Topology = Buck
Created = 2025-04-03 17:30:11.345
BOM Cost = \$6.76
BOM Count = 10
Total Pd = 5.52W



5V PSU Webench Schematic from Texas Instruments



Schematic for Full Wave Rectification

Appendix D - Software Code:

Thermocouple with MAX6675 Embedded Code

```
#include "max6675.h"
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Arduino.h>

int thermoSO = 19;
int thermoCS = 5;
int thermoCLK = 18;
// I²C LCD: SDA=21, SCL=22, address=0x27, size=16x2
LiquidCrystal_I2C lcd(0x27, 16, 2);

MAX6675 thermocouple(thermoCLK, thermoCS, thermoSO);

void setup() {
  Serial.begin(115200);

  Serial.println("MAX6675 test");
  // wait for MAX chip to stabilize
  delay(500);
  Wire.begin(21, 22);
  lcd.init();
  lcd.backlight();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("LCD OK");
}

void loop() {
  // basic readout test, just print the current temp
  double c = thermocouple.readCelsius();
  double f = thermocouple.readFahrenheit();
```

```

Serial.print("C = ");
Serial.println(c);
Serial.print("F = ");
Serial.println(f);

lcd.setCursor(0, 0);           // first row
lcd.print("Temp: ");
lcd.print(c, 1);               // one decimal place
lcd.print((char)223);          // degree symbol
lcd.print("C  ");              // pad to clear leftovers

lcd.setCursor(0, 1);          // second row
lcd.print("Temp: ");
lcd.print(f, 1);
lcd.print((char)223);
lcd.print("F  ");

// For the MAX6675 to update, you must delay AT LEAST 250 ms between reads!
delay(1000);
}

```

Load Cell with HX711 Amplifier Code

```

#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Arduino.h>
#include <HX711.h>

// HX711 pins
#define DOUT_PIN 16
#define SCK_PIN 4

// Button pin (BOOT button on ESP32 DevKit v1)
#define BUTTON_PIN 0

// I²C LCD: SDA=21, SCL=22, address=0x27, size=16x2
LiquidCrystal_I2C lcd(0x27, 16, 2);

// HX711 instance & calibration
HX711 scale;
float calibration_factor = -7050.0f;

```

```

// State variables
bool buttonPrev = false;

void setup() {
  Wire.begin(21, 22);
  lcd.init();
  lcd.backlight();

  pinMode(BUTTON_PIN, INPUT_PULLUP);

  scale.begin(DOUT_PIN, SCK_PIN);
  scale.set_scale(calibration_factor);
  scale.tare(); // initial zero

  lcd.clear();
  lcd.print("Ready");
  delay(1000);
  lcd.clear();
}

void loop() {
  // --- 1) Handle button press to tare ---
  bool buttonNow = (digitalRead(BUTTON_PIN) == LOW);
  if (buttonNow && !buttonPrev) {
    scale.tare(); // actually zero the scale
    lcd.clear();
    lcd.print("Tared");
    delay(500);
    lcd.clear();
  }
  buttonPrev = buttonNow;

  // --- 2) Always show live weight ---
  if (!scale.is_ready()) {
    lcd.setCursor(0, 0);
    lcd.print("HX711 missing!");
  } else {
    float weight = scale.get_units(10);
    lcd.setCursor(0, 0);
    lcd.print("Weight:      ");
    lcd.setCursor(8, 0);
    lcd.print(weight, 2);
    lcd.print(" g");
  }

  // Update every 2 s
  delay(2000);
}

```

Swift Mobile App Implementation

```
import SwiftUI
// MARK: - Animated Gradient Background
struct AnimatedGradient: View {
    @State private var startColors: [Color] = [Color.blue, Color.purple]
    @State private var endColors: [Color] = [Color.pink, Color.orange]

    // We'll alternate between these two gradient sets.
    @State private var animate: Bool = false

    var body: some View {
        LinearGradient(
            gradient: Gradient(colors: animate ? endColors : startColors),
            startPoint: .topLeading,
            endPoint: .bottomTrailing
        )
        .ignoresSafeArea()
        .onAppear {
            withAnimation(Animation.linear(duration: 5).repeatForever(autoreverses: true)) {
                animate.toggle()
            }
        }
    }
}

struct ContentView: View {

    // Toggle between authentication modes
    enum AuthMode {
        case login, register
    }

    // MARK: - Authentication States
    @State private var authMode: AuthMode = .login
    @State private var email: String = ""
    @State private var username: String = ""
    @State private var password: String = ""
    @State private var authMessage: String = ""
    @State private var isLoggedIn: Bool = false

    // MARK: - Measurements States
    @State private var measurements: [Measurement] = []
    @State private var volumeInput: String = ""
    @State private var measurementError: String?

    var body: some View {
        NavigationView {
            ZStack {
                // Animated Gradient Background
            }
        }
    }
}
```

```

        AnimatedGradient()

        // Main content overlay
        if isLoggedIn {
            measurementsView
        } else {
            authenticationView
        }
    }
    .navigationTitle(isLoggedIn ? "Measurements" : "Welcome to PUMPED!")
}
}

// MARK: - Authentication View
var authenticationView: some View {
    VStack(spacing: 20) {
        Text(authMode == .login ? "Login" : "Register")
            .font(.system(size: 32, weight: .bold))
            .foregroundColor(.white) // white text over gradient

        if authMode == .register {
            TextField("Email", text: $email)
                .padding()
                .background(Color.white.opacity(0.8))
                .cornerRadius(8)
                .autocapitalization(.none)
                .disableAutocorrection(true)
        }

        TextField("Username", text: $username)
            .padding()
            .background(Color.white.opacity(0.8))
            .cornerRadius(8)
            .autocapitalization(.none)
            .disableAutocorrection(true)

        SecureField("Password", text: $password)
            .padding()
            .background(Color.white.opacity(0.8))
            .cornerRadius(8)

        if !authMessage.isEmpty {
            Text(authMessage)
                .foregroundColor(.yellow)
                .multilineTextAlignment(.center)
        }

        Button(action: {
            if authMode == .login {
                login()
            } else {

```

```

        register()
    }
}) {
    Text(authMode == .login ? "Login" : "Register")
        .font(.headline)
        .padding()
        .frame(maxWidth: .infinity)
        .background(Color.blue)
        .foregroundColor(.white)
        .cornerRadius(8)
    }

    Button(action: {
        authMode = (authMode == .login) ? .register : .login
        authMessage = ""
    }) {
        Text(authMode == .login ? "Don't have an account? Register" : "Already have an account? Login")
            .font(.footnote)
            .foregroundColor(.white)
    }
}
.padding()
}

// MARK: - Measurements View
var measurementsView: some View {
    VStack {
        // Logout button
        HStack {
            Button("Logout") {
                isLoggedIn = false
                resetAuthFields()
            }
                .padding()
                .background(Color.red.opacity(0.8))
                .foregroundColor(.white)
                .cornerRadius(8)
            Spacer()
        }
        .padding(.horizontal)

        if let error = measurementError {
            Text(error)
                .foregroundColor(.yellow)
                .padding(.horizontal)
        }

        List(measurements) { measurement in
            VStack(alignment: .leading, spacing: 5) {
                Text("Volume: \(measurement.volume, specifier: "%.2f")")
                    .font(.headline)
            }
        }
    }
}

```

```

        Text("Time: \\\(measurement.time)")
            .font(.subheadline)
        Text("Date: \\\(measurement.date)")
            .font(.subheadline)
            .foregroundColor(.gray)
    }
    .padding(5)
    .background(Color.white)
    .cornerRadius(8)
    .shadow(radius: 1)
}
.listStyle(PlainListStyle())
.background(Color.white.opacity(0.5))

HStack {
    TextField("Enter volume", text: $volumeInput)
        .keyboardType(.decimalPad)
        .padding(10)
        .background(Color.white.opacity(0.8))
        .cornerRadius(8)
        .frame(width: 120)

    Button("Add") {
        addMeasurement()
    }
    .padding()
    .background(Color.blue)
    .foregroundColor(.white)
    .cornerRadius(8)
}
.padding()
}
}

// MARK: - Authentication Functions
private func register() {
    NetworkManager.shared.register(email: email, username: username, password: password) { result in
        DispatchQueue.main.async {
            switch result {
            case .success(let responseMessage):
                authMessage = responseMessage
            case .failure(let error):
                authMessage = error.localizedDescription
            }
        }
    }
}

private func login() {
    NetworkManager.shared.login(username: username, password: password) { result in
        DispatchQueue.main.async {

```

```

        switch result {
        case .success(let responseMessage):
            authMessage = responseMessage
            if responseMessage == "Login successful" {
                isLoggedIn = true
                loadMeasurements()
            }
        case .failure(let error):
            authMessage = error.localizedDescription
        }
    }
}

// MARK: - Measurements Functions
private func loadMeasurements() {
    NetworkManager.shared.fetchMeasurements { result in
        DispatchQueue.main.async {
            switch result {
            case .success(let fetchedMeasurements):
                self.measurements = fetchedMeasurements
            case .failure(let error):
                self.measurementError = "Error: \(error.localizedDescription)"
            }
        }
    }
}

private func addMeasurement() {
    guard let volumeValue = Double(volumeInput) else { return }
    NetworkManager.shared.createMeasurement(volume: volumeValue) { result in
        DispatchQueue.main.async {
            switch result {
            case .success(let newMeasurement):
                self.measurements.insert(newMeasurement, at: 0)
                self.volumeInput = ""
            case .failure(let error):
                self.measurementError = "Error: \(error.localizedDescription)"
            }
        }
    }
}

private func resetAuthFields() {
    email = ""
    username = ""
    password = ""
    authMessage = ""
}
}

struct ContentView_Previews: PreviewProvider {

```

```

    static var previews: some View {
        ContentView()
    }
}

```

Frontend Client Connection

```

import Foundation
// MARK: - Data Model (Measurement)
struct Measurement: Codable, Identifiable {

    let id = UUID()
    let volume: Double
    let time: String
    let date: String

    private enum CodingKeys: String, CodingKey {
        case volume, time, date
    }
}
// MARK: - API Manager
class NetworkManager {
    static let shared = NetworkManager() // Singleton instance for easy access
    private let baseURL = "http://localhost:5001"

    // MARK: - Measurements Endpoints

    // GET /measurements
    func fetchMeasurements(completion: @escaping (Result<[Measurement], Error>) -> Void) {
        guard let url = URL(string: "\{baseURL}/measurements") else {
            return completion(.failure(NSError(domain: "BadURL", code: 0)))
        }

        URLSession.shared.dataTask(with: url) { data, _, error in
            if let error = error {
                return completion(.failure(error))
            }
            guard let data = data else {
                return completion(.failure(NSError(domain: "NoData", code: 0)))
            }
            do {
                let measurements = try JSONDecoder().decode([Measurement].self, from: data)
                completion(.success(measurements))
            } catch {
                completion(.failure(error))
            }
        }.resume()
    }
}

```

```

// POST /measurements
func createMeasurement(volume: Double, completion: @escaping (Result<Measurement, Error>) ->
Void) {
    guard let url = URL(string: "\(baseUrl)/measurements") else {
        return completion(.failure(NSError(domain: "BadURL", code: 0)))
    }

    var request = URLRequest(url: url)
    request.httpMethod = "POST"
    request.setValue("application/json", forHTTPHeaderField: "Content-Type")

    let body = ["volume": volume]
    do {
        request.httpBody = try JSONSerialization.data(withJSONObject: body, options: [])
    } catch {
        return completion(.failure(error))
    }

    URLSession.shared.dataTask(with: request) { data, _, error in
        if let error = error {
            return completion(.failure(error))
        }
        guard let data = data else {
            return completion(.failure(NSError(domain: "NoData", code: 0)))
        }
        do {
            let newMeasurement = try JSONDecoder().decode(Measurement.self, from: data)
            completion(.success(newMeasurement))
        } catch {
            completion(.failure(error))
        }
    }.resume()
}

// MARK: - Authentication Endpoints

// POST /auth/register
// Expects a JSON body with email, username, and password.
// Returns a success message or error.
func register(email: String, username: String, password: String, completion: @escaping (Result<String,
Error>) -> Void) {
    guard let url = URL(string: "\(baseUrl)/auth/register") else {
        return completion(.failure(NSError(domain: "BadURL", code: 0)))
    }

    let body: [String: Any] = [
        "email": email,
        "username": username,
        "password": password
    ]

```

```

var request = URLRequest(url: url)
request.httpMethod = "POST"
request.setValue("application/json", forHTTPHeaderField: "Content-Type")

do {
    request.httpBody = try JSONSerialization.data(withJSONObject: body, options: [])
} catch {
    return completion(.failure(error))
}

URLSession.shared.dataTask(with: request) { data, __, error in
    if let error = error {
        return completion(.failure(error))
    }
    guard let data = data else {
        return completion(.failure(NSError(domain: "NoData", code: 0)))
    }
    do {
        // Here we assume the API returns JSON with a "message" key on success or "error" key on
failure.
        if let json = try JSONSerialization.jsonObject(with: data) as? [String: Any],
            let message = json["message"] as? String {
            completion(.success(message))
        } else if let json = try JSONSerialization.jsonObject(with: data) as? [String: Any],
            let errorMessage = json["error"] as? String {
            completion(.failure(NSError(domain: "", code: 0, userInfo: [NSLocalizedDescriptionKey:
errorMessage])))
        } else {
            completion(.failure(NSError(domain: "InvalidResponse", code: 0)))
        }
    } catch {
        completion(.failure(error))
    }
}.resume()
}

// POST /auth/login
// Expects a JSON body with username and password.
// Returns a success message on valid credentials.
func login(username: String, password: String, completion: @escaping (Result<String, Error>) -> Void) {
    guard let url = URL(string: "\(baseUrl)/auth/login") else {
        return completion(.failure(NSError(domain: "BadURL", code: 0)))
    }

    let body: [String: Any] = [
        "username": username,
        "password": password
    ]

    var request = URLRequest(url: url)
    request.httpMethod = "POST"

```

```

request.setValue("application/json", forHTTPHeaderField: "Content-Type")

do {
    request.httpBody = try JSONSerialization.data(withJSONObject: body, options: [])
} catch {
    return completion(.failure(error))
}

URLSession.shared.dataTask(with: request) { data, _, error in
    if let error = error {
        return completion(.failure(error))
    }
    guard let data = data else {
        return completion(.failure(NSError(domain: "NoData", code: 0)))
    }
    do {
        if let json = try JSONSerialization.jsonObject(with: data) as? [String: Any],
            let message = json["message"] as? String {
            completion(.success(message))
        } else if let json = try JSONSerialization.jsonObject(with: data) as? [String: Any],
            let errorMessage = json["error"] as? String {
            completion(.failure(NSError(domain: "", code: 0, userInfo: [NSLocalizedDescriptionKey:
errorMessage])))
        } else {
            completion(.failure(NSError(domain: "InvalidResponse", code: 0)))
        }
    } catch {
        completion(.failure(error))
    }
}.resume()
}
}

```

Backend Server Code For Swift Mobile App

```

require('dotenv').config();
const express = require('express');
const cors = require('cors');
const bodyParser = require('body-parser');
const { Pool } = require('pg');
const bcrypt = require('bcrypt'); // for hashing passwords

const app = express();
const port = process.env.PORT || 5001;

// Middleware
app.use(cors());

```

```

app.use(bodyParser.json());

// PostgreSQL Connection
const pool = new Pool({
  connectionString: process.env.DATABASE_URL ||
  "postgres://jasondevito@localhost:5432/pumped_app",
});

// Test API Route
app.get('/', (req, res) => {
  res.send('Pumped App Backend is running!');
});

// =====
//   REGISTRATION ENDPOINT (POST /auth/register)
// =====
app.post('/auth/register', async (req, res) => {
  try {
    const { email, username, password } = req.body;

    // Basic validation
    if (!email || !username || !password) {
      return res.status(400).json({ error: 'All fields (email, username, password) are
required' });
    }

    // Check if user already exists (by email or username)
    const userCheck = await pool.query(
      "SELECT id FROM users WHERE email = $1 OR username = $2",
      [email, username]
    );

    if (userCheck.rows.length > 0) {
      return res.status(400).json({ error: 'Email or username already taken' });
    }

    // Hash the password
    const saltRounds = 10;
    const hashedPassword = await bcrypt.hash(password, saltRounds);

    // Insert new user
    await pool.query(
      "INSERT INTO users (email, username, hashed_password) VALUES ($1, $2, $3)",
      [email, username, hashedPassword]
    );

    return res.status(201).json({ message: 'User registered successfully' });
  } catch (error) {
    console.error(error);
  }
});

```

```

        return res.status(500).json({ error: 'Server Error' });
    }
});

// =====
// LOGIN ENDPOINT (POST /auth/login)
// =====
app.post('/auth/login', async (req, res) => {
    try {
        const { username, password } = req.body;

        // Basic validation
        if (!username || !password) {
            return res.status(400).json({ error: 'Username and password are required' });
        }

        // Find user by username
        const userResult = await pool.query(
            "SELECT username, hashed_password FROM users WHERE username = $1",
            [username]
        );

        if (userResult.rows.length === 0) {
            // User not found
            return res.status(401).json({ error: 'Invalid credentials' });
        }

        const { hashed_password } = userResult.rows[0];

        // Compare the provided password with the stored hashed password
        const isMatch = await bcrypt.compare(password, hashed_password);
        if (!isMatch) {
            // Password mismatch
            return res.status(401).json({ error: 'Invalid credentials' });
        }

        // If valid, return success (no token, just a success message)
        return res.json({ message: 'Login successful' });
    } catch (error) {
        console.error(error);
        return res.status(500).json({ error: 'Server Error' });
    }
});

// =====
// SAVE MEASUREMENT (POST /measurements)
// =====
app.post('/measurements', async (req, res) => {
    const { volume } = req.body;

```

```

// Get current time and date
const now = new Date();
const formattedTime = now.toLocaleTimeString('en-US', {
  hour: '2-digit',
  minute: '2-digit',
  hour12: true
});
const formattedDate = now.toLocaleDateString('en-US', {
  month: '2-digit',
  day: '2-digit',
  year: 'numeric'
});

try {
  const newMeasurement = await pool.query(
    "INSERT INTO measurements (volume, time, date) VALUES ($1, $2, $3) RETURNING *",
    [volume, formattedTime, formattedDate]
  );
  res.json(newMeasurement.rows[0]);
} catch (error) {
  console.error(error.message);
  res.status(500).send('Server Error');
}
});

// =====
//   RETRIEVE MEASUREMENTS (GET /measurements)
// =====
app.get('/measurements', async (req, res) => {
  try {
    const results = await pool.query("SELECT volume, time, date FROM measurements ORDER BY
date DESC, time DESC");
    res.json(results.rows);
  } catch (error) {
    console.error(error.message);
    res.status(500).send('Server Error');
  }
});

// Start Server
app.listen(port, () => {
  console.log(`Server running on port ${port}`);
});

```

Appendix E - ChatGPT Prompts & Outcomes:

ChatGPT 4o mini ▾

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give me three power sources to power a small device less than 60 watts

Here are three power sources you can use to power a small device consuming less than 60 watts:

1. Lithium-ion Battery Pack

- Voltage: 3.7V (single cell) or higher (packs with multiple cells)
- Capacity: Varies (e.g., 10,000mAh can provide ~37Wh at 3.7V)
- Pros: Rechargeable, portable, high energy density
- Cons: Requires a proper battery management system (BMS) for safe operation

2. AC-DC Power Adapter (Wall Adapter)

- Output: 5V, 12V, or 24V depending on device requirements
- Power Rating: 60W or lower
- Pros: Reliable, continuous power supply
- Cons: Not portable, depends on an electrical outlet

3. Small Solar Panel with Battery Storage

- Solar Panel: 10W-60W output, depending on sunlight conditions
- Battery Storage: Li-ion or Lead-acid battery for continuous power
- Pros: Renewable energy source, great for outdoor applications
- Cons: Dependent on sunlight, requires an energy storage system for nighttime use

Would you like recommendations based on a specific application?

no i need three temperature sensors that i can use in a device

Here are three temperature sensors you can use in a device:

1. LM35 (Analog Temperature Sensor)

The LM35 is a popular analog temperature sensor that provides a linear voltage output proportional to temperature. It operates within a range of **-55°C to 150°C** with an accuracy of **±0.5°C** at room temperature. Since it outputs **10mV per °C**, it's easy to interface with microcontrollers using an **ADC (Analog-to-Digital Converter)**. This sensor is ideal for battery-powered applications because it consumes very little power (less than 60µA). However, it requires proper calibration and an ADC input to read temperature values accurately.

2. DS18B20 (Digital Temperature Sensor - 1-Wire Protocol)

The DS18B20 is a **digital** temperature sensor that communicates using the **1-Wire protocol**, which allows multiple sensors to be connected to a single microcontroller pin. It operates within **-55°C to 125°C** with an accuracy of **±0.5°C** over most of its range. Since it provides a **direct digital output**, it does not require an ADC, making it easy to integrate with microcontrollers like **Arduino, ESP32, or MSP430**. It also supports **parasitic power mode**, meaning it can draw power from the data line, reducing wiring complexity.

3. BME280 (Temperature, Humidity, and Pressure Sensor - I2C/SPI Protocol)

The BME280 is an advanced sensor that not only measures **temperature** but also **humidity** and **pressure**, making it ideal for weather monitoring and IoT applications. It communicates via **I2C** or **SPI**, allowing easy integration with various microcontrollers. It has a temperature range of **-40°C to 85°C** with an accuracy of **±1°C**. The BME280 is commonly used in **smart home devices, environmental monitoring systems, and wearable electronics** because of its low power consumption and high precision.

Would you like recommendations based on a specific type of device you're building?

Can you give me three LCD display screens that i can use to display practical data and has a display time of less than 1 second

Here are three LCD display options that can show practical data with an update time of less than 1 second for your water heater project:

1. 16x2 Character LCD (HD44780 - I2C or Parallel Interface)

The 16x2 LCD is a widely used display that can show two lines of 16 characters each. It uses the HD44780 driver, which allows easy interfacing with microcontrollers like MSP430, Arduino, and ESP32. You can connect it using a parallel 4-bit/8-bit interface or an I2C module for simplified wiring. The refresh rate is very fast (milliseconds range), ensuring an update time well below 1 second. This display is great for showing temperature readings, system status, and basic control options in a water heater system.

2. 128x64 Monochrome LCD (ST7920 - SPI/I2C/Parallel Interface)

The 128x64 graphical LCD provides more flexibility than a character LCD, allowing you to display numbers, text, and simple graphics such as temperature graphs or heating status indicators. The ST7920 driver supports SPI, I2C, and parallel communication, making it easy to interface with microcontrollers. The update speed is fast (typically under 100ms per full screen refresh), ensuring real-time data display. This type of screen is useful if you need more detailed information or a better user experience compared to a simple character display.

3. 2.8-inch TFT LCD (ILI9341 - SPI Interface, Full Color)

If you need a more advanced and visually appealing display, the 2.8-inch TFT LCD with the ILI9341 driver is a great choice. It offers a 320x240 pixel resolution with full-color support, allowing you to create a graphical user interface (GUI) with buttons, charts, and real-time temperature readings. This display communicates via SPI, ensuring fast updates (typically 50-200ms per refresh, depending on the complexity of the graphics). It is ideal for a touchscreen-based control panel for a smart water heater system.

Which One Should You Choose?

- For a simple, easy-to-read display, the 16x2 LCD is a great option.
- For more detailed information and better visuals, the 128x64 LCD is a good choice.
- For a modern, touchscreen-based interface, the 2.8-inch TFT LCD is the best option.

Would you like help integrating one of these displays into your system?

g) Skip to content al printers i can implement into my water heating device, that will allow me to print needed data on 2" x 1" thermal paper

Here are three thermal printers that can be integrated into your water heating device to print data on 2" x 1" thermal paper:

1. MUNBYN IMP001 58mm Thermal Printer (Serial/UART & USB)

The MUNBYN IMP001 is a compact 58mm (2.28 inches) thermal printer, making it well-suited for printing small labels or receipts. It supports serial (UART) and USB communication, allowing easy interfacing with microcontrollers like MSP430, Arduino, and Raspberry Pi. The printer offers fast printing speeds (90mm/s) and high resolution for clear text and simple graphics. It is ideal for printing temperature logs, timestamps, and heater status updates. Additionally, it operates on DC 5V-9V, making it adaptable to embedded systems.

2. Adafruit Mini Thermal Printer (TTL Serial/UART)

The Adafruit Mini Thermal Printer is a small and efficient 2-inch thermal printer designed for embedded applications. It communicates using TTL Serial/UART, making it easy to integrate with microcontrollers. This printer supports thermal label paper sizes of at least 2 inches wide, which can be cut to 1-inch length as needed. It prints at a speed of 50mm/s and supports basic text and graphics. Since it operates at 5V-9V, it is well-suited for low-power applications like a water heater system where periodic data printing is required.

3. PeriPage A6 Mini Thermal Printer (Bluetooth & USB - Custom Paper Size)

The PeriPage A6 Mini Thermal Printer is a small, lightweight, and versatile thermal printer that supports Bluetooth and USB communication. While it is primarily designed for mobile printing, it can be adapted for embedded applications via USB. It supports custom-sized thermal paper, including 2-inch width with variable length, making it ideal for printing temperature readings, error logs, and maintenance alerts. This printer is powered by a rechargeable battery or USB, making it a flexible choice for integration into a water heater system.

Which One Should You Choose?

- For direct microcontroller integration (TTL Serial/UART), the Adafruit Mini Thermal Printer is the best option.
- For high-speed printing and reliable data logs, the MUNBYN IMP001 is a solid choice.
- For a flexible, wireless solution with USB/Bluetooth options, the PeriPage A6 is a great fit.

Would you like help with integrating one of these printers into your system?

Give me three components

give me three components that can heat water and be controlled by and connected to a pcb board. I need you to include Electric Heating Pad - 14cm x 5cm by Adafruit but find me two more components

Here are three components that can heat water and be controlled by a PCB:

1. **Electric Heating Pad - 14cm x 5cm (Adafruit)**
 - Voltage: 5V-12V
 - Power: ~5W at 12V
 - Thin and flexible, easy to mount on surfaces
 - Can be controlled via MOSFETs or relays connected to the PCB
2. **Cartridge Heater - 12V 40W**
 - Voltage: 12V
 - Power: 40W
 - Small cylindrical heater, often used in 3D printers
 - Can be controlled via a MOSFET or relay for precise heating
3. **Silicone Heating Pad - 12V 10W**
 - Voltage: 12V
 - Power: 10W
 - Thin and flexible, suitable for heating liquids or surfaces
 - Can be controlled using a relay or MOSFET

These components can be easily integrated into your PCB-based water heating system using relays or MOSFETs to regulate temperature via a microcontroller. Let me know if you need help choosing control circuits!

now also give me comparisons for cost, implementation, and maintenance

Here's a comparison of the three heating components based on cost, implementation, and maintenance:

Component	Cost	Implementation Complexity	Maintenance
Electric Heating Pad (14cm x 5cm) - Adafruit	~\$5-\$10	Easy - Thin and flexible, can be attached directly to a surface with adhesive. Requires MOSFET or relay for control.	Low
Cartridge Heater - 12V 40W	~\$5-\$15	Moderate - Requires a hole or slot to be inserted into a heating block or water container. Needs a MOSFET or relay for switching.	Moderate
Silicone Heating Pad - 12V 10W	~\$10-\$20	Easy - Flexible and can be attached to surfaces using adhesive. Requires a relay or MOSFET for control.	Low

Summary

- If you need a **low-cost and simple solution**, the **Adafruit Electric Heating Pad** is ideal.
- If you need **higher power and more efficient heating**, the **Cartridge Heater** is a better choice but requires more complex mounting.
- If you need **flexibility and moderate power**, the **Silicone Heating Pad** is a solid option but slightly more expensive.

Would you like recommendations on which one to use based on your specific needs?

Okay take the electric heating pad by adafruit, Silicone heating pad by meccanixity, and the cartridge heater by makertechstore and give me information about their power, and a basic overview on how they would work

Here's a detailed breakdown of the three heating components, including their power ratings and how they function in a PCB-controlled water heating system:

1. Electric Heating Pad (14cm x 5cm) – Adafruit

- **Power:** ~5W at 12V
- **How It Works:**
 - This heating pad is a flexible, thin film that generates heat when voltage is applied.
 - It can be mounted on a surface using adhesive and is ideal for low-power heating applications.
 - Control can be achieved using a **MOSFET** or **relay** connected to a microcontroller.
 - A **temperature sensor** (such as a thermistor) can be used to monitor the heat output and regulate the temperature dynamically.
- **Best Use Case:** Maintaining mild warmth over a surface or heating small amounts of water in insulated conditions.

2. Silicone Heating Pad – Meccanixity

- **Power:** 10W at 12V
- **How It Works:**
 - This is a flexible **silicone-based heating element** that distributes heat evenly over its surface.
 - It is often attached directly to a metal or plastic container using adhesive backing.
 - Like the Adafruit heating pad, it requires a **MOSFET** or **relay** to control power from a PCB.
 - A **thermistor** or **temperature sensor** can be added for real-time temperature regulation.
- **Best Use Case:** Heating water or maintaining a steady temperature for small-scale applications such as lab equipment or pre-heating surfaces.

3. Cartridge Heater – MakerTechStore

- **Power:** 40W at 12V
- **How It Works:**
 - This is a **metal cylindrical heater** designed to be inserted into a **metal block** or **water reservoir**.
 - It heats up rapidly and can provide **high-temperature heating** for more demanding applications.
 - Requires a **MOSFET, relay, or solid-state relay (SSR)** to handle the higher current draw.
 - A **heat sink** or **proper mounting** is necessary to prevent overheating.
 - Temperature control is best handled with a **thermocouple** or **high-temperature thermistor** to avoid overheating or inefficiency.
- **Best Use Case:** Direct water heating in metal enclosures or heating metal surfaces that transfer heat to water.

Comparison & Selection Guide

Component	Power	Installation	Best For	Control Type
Adafruit Electric Heating Pad	5W	Adhesive to a surface	Mild heating, insulation-based applications	MOSFET or Relay
Meccanixity Silicone Heating Pad	10W	Adhesive, flexible placement	Even heat distribution, low-power water heating	MOSFET or Relay
MakerTechStore Cartridge Heater	40W	Inserted into a block/container	Direct water heating, high heat output	MOSFET, Relay, or SSR

give me three components, in the nature of load of something such as a load cell, that i can implement in a pcb design to measure the weight of something

Here are three types of load-measuring components you can integrate into a PCB design:

1. Load Cell (Strain Gauge-Based)
- A strain gauge load cell consists of a Wheatstone bridge circuit that changes resistance based on applied force.
 - Requires an **amplifier** (e.g., HX711) for signal conditioning before interfacing with a microcontroller.
 - Suitable for precision weight measurement.
2. Piezoelectric Force Sensor
- Uses the **piezoelectric effect** to generate voltage when force is applied.
 - Provides high sensitivity and is ideal for dynamic force measurement.
 - Requires a **charge amplifier** (e.g., AD620) to convert the signal into a usable voltage.
3. Capacitive Force Sensor
- Measures weight by detecting changes in capacitance due to deformation under force.
 - Provides a non-contact way to measure force with high resolution.
 - Can be implemented using a **capacitive sensing IC** like the FDC1004.

Would you like recommendations on specific models for your application?

give me a more in depth analysis of each of these along with specific models, comparing their implementation, cost, and maintenance

Here's a detailed analysis of each weight-measuring component, including specific models, implementation complexity, cost, and maintenance considerations.

1. Load Cell (Strain Gauge-Based)

How It Works

- A strain gauge load cell consists of a Wheatstone bridge circuit with resistive strain elements that deform under applied force. This deformation changes the resistance, generating a small differential voltage.
- An amplifier (e.g., HX711 or INA125) is required to boost the signal to a usable level for a microcontroller.

Popular Models

Model	Capacity	Sensitivity	Excitation Voltage	Price (Approx.)
TAL220	1-5kg	1.0 mV/V	5-10V	\$5-10
CZL635	50-200kg	2.0 mV/V	5-12V	\$15-40
Zemic L6D	500-1000kg	2.0 mV/V	5-12V	\$50-150

Implementation

- Pros:**
 - High precision and accuracy.
 - Wide range of weight capacities.
 - Works well for both static and dynamic loads.
- Cons:**
 - Requires signal amplification and ADC conversion.
 - May need temperature compensation.
 - Must be mounted properly for accurate readings.

Cost & Maintenance

- Cost:** Medium (\$5-\$150 depending on weight capacity).
- Maintenance:** Low, but can drift over time and may need recalibration.

2. Piezoelectric Force Sensor

How It Works

- Uses the **piezoelectric effect**, where force on a piezoelectric material generates a small voltage. This voltage is proportional to the force applied.
- Requires a **charge amplifier** (e.g., AD620, OPA129) to convert the small charge into a readable voltage.

Popular Models

Model	Measurement Range	Output Signal	Price (Approx.)
Kistler 9212	0-500N	Charge Output (pC)	\$200+
TE Connectivity 141A	0-100N	Voltage	\$50-100
PCB Piezotronics 208C	0-10kN	Charge Output (pC)	\$500+

Implementation [Skip to content](#)

- **Pros:**
 - Very high sensitivity and fast response.
 - Works well for dynamic force measurements.
- **Cons:**
 - Not ideal for static weight measurements (drift over time).
 - Requires specialized electronics for signal processing.

Cost & Maintenance

- **Cost:** High (\$50-\$500+ depending on accuracy).
- **Maintenance:** Medium to high (sensitive to environmental factors, may need recalibration).

3. Capacitive Force Sensor

How It Works

- Measures force by detecting changes in capacitance when a dielectric (such as air or an elastomer) is compressed.
- Uses a capacitive sensing IC (e.g., FDC1004) to measure capacitance changes.

Popular Models

Model	Measurement Range	Output Signal	Price (Approx.)
TactileLabs CFS100	0-50N	Analog Voltage	\$50
FSR402 (Force-Sensitive Resistor)	0-10kg	Resistance Change	\$10-20
NXP MPXL30025PA	0-25kPa (pressure)	Digital (I2C)	\$20-40

Implementation

- **Pros:**
 - Can be built into compact PCB designs.
 - Lower power consumption.
 - Good for lightweight applications.
- **Cons:**
 - Lower accuracy than strain gauge-based sensors.
 - Requires calibration to achieve high precision.

[Skip to content](#) Cons of the load cell with sources as well if possible

Load cells (strain gauge-based) are widely used for weight measurement due to their high accuracy, but they also have notable drawbacks. Here's an in-depth look at the cons of load cells, along with relevant sources where possible.

1. Requires Signal Amplification & Conditioning

Issue:

- The raw signal from a load cell is very **weak** (in the millivolt range, typically 1-3mV/V).
- To make this signal usable by microcontrollers, it requires an **instrumentation amplifier** (e.g., HX711, INA125).
- Noise interference from the environment can further degrade the signal, requiring filtering and proper PCB design.

Sources:

- "Load cells generate very small signals that require careful amplification and signal conditioning" – Omega Engineering. [\[Source\]](#)

2. Temperature Sensitivity & Drift

Issue:

- The electrical resistance of the strain gauges **changes with temperature**, leading to errors.
- Requires **temperature compensation** to maintain accuracy (often done using compensation resistors or software-based calibration).
- Over time, thermal expansion and contraction can cause **drift**, meaning periodic recalibration is needed.

Sources:

- "Load cells are susceptible to temperature effects, which can lead to signal drift" – National Instruments. [\[Source\]](#)
- "Load cell output is influenced by temperature changes, requiring compensation circuits" – Honeywell Industrial. [\[Source\]](#)

3. Installation & Mounting Sensitivity

Issue:

- Load cells must be **properly mounted and aligned** to avoid errors.
- If the load is not applied precisely at the center of the sensor, it may cause **uneven strain** and inaccurate readings.
- Requires **rigid mechanical design** to prevent unintended force variations.

Sources:

- "Incorrect installation can result in errors due to misalignment or uneven force application" – Mettler Toledo [\[Source\]](#)
- "The accuracy of a load cell depends heavily on proper mechanical installation" – Omega Engineering.

4. Mechanical Fatigue & Long-Term Degradation

Issue:

- Repeated loading and unloading cycles can cause **wear and tear** on the strain gauge material.
- **Creep effect:** Over time, a load cell can experience **slow deformation**, leading to minor permanent shifts in readings.
- **Hysteresis effect:** When force is applied and removed, the load cell might not return to its exact original value.

Sources:

- "Load cells experience mechanical fatigue over time, leading to reduced accuracy and eventual failure" – Interface Inc. [\[Source\]](#)
- "Hysteresis and creep effects can lead to small but cumulative errors in long-term use" – HBM Load Cells. [\[Source\]](#)

5. Environmental Sensitivity (Moisture, Shock, & Vibration)

Issue:

- **Moisture ingress** can lead to corrosion of the strain gauge wiring, requiring **sealed or IP-rated** load cells for outdoor use.
- **Vibrations and shocks** can cause **momentary errors** and, in extreme cases, damage the strain gauge.
- Requires **mechanical dampening or filtering** in high-vibration environments.

Sources:

- "Environmental conditions such as moisture and vibration can affect load cell reliability" – Flintec Load Cells. [\[Source\]](#)

are induction, convection, and conduction all methods to heat water?

Yes, **induction, convection, and conduction** can all be used to heat water, but they work in different ways:

1. **Conduction** – Direct heat transfer through a material.
 - Example: A metal pot on a stovetop heats water as heat transfers from the hot surface of the pot to the water inside.
2. **Convection** – Heat transfer through fluid movement.
 - Example: When water is heated in a pot, hot water rises while cooler water sinks, creating convection currents that distribute heat.
3. **Induction** – Heating through electromagnetic fields.
 - Example: An induction cooktop generates an electromagnetic field that directly heats the pot, which then transfers heat to the water via conduction.

So while **induction itself does not heat the water directly**, it heats the container, which then heats the water through conduction. Convection then helps distribute the heat evenly within the liquid.

Are there any other methods of heating?

Yes! Besides **conduction, convection, and induction**, there are several other methods of heating:

1. Radiation (Infrared Heating)

- Heat is transferred through electromagnetic waves (infrared radiation).
- Example: Infrared heaters or sunlight warming water in a container.

2. Resistive (Joule) Heating

- Electrical energy is converted into heat through resistance.
- Example: Electric kettles or immersion heaters use resistive coils to directly heat water.

3. Microwave Heating

- Uses microwave radiation to excite water molecules, generating heat from within.
- Example: Heating water in a microwave oven.

4. Dielectric Heating

- Uses high-frequency electromagnetic fields to heat materials with polar molecules.
- Example: Industrial RF (radio frequency) heaters used in food processing.

5. Friction Heating

- Heat generated by friction between surfaces.
- Example: Some high-speed industrial mixing processes generate heat through friction.

examples of convection heating

Convection heating occurs when heat is transferred through the movement of a fluid (liquid or gas). Here are some examples of convection heating:

1. Boiling Water

- In a pot on a stove, as the water at the bottom heats up, it rises to the top, while the cooler water sinks. This creates convection currents that help evenly distribute the heat throughout the water.

2. Convection Ovens

- These ovens use a fan to circulate hot air around the food. This ensures more even cooking by transferring heat to the food more effectively through the movement of air (a gas).

3. Radiators

- In home heating systems, radiators heat the air. Warm air rises from the radiator, and cooler air moves in to take its place, creating a convection current that helps heat the room.

4. Air Conditioning Systems

- Air conditioners use convection to cool a room by circulating the cooler air they generate, ensuring the whole space reaches the desired temperature.

5. Forced-Air Heating Systems

- These use a fan to push warm air into a room. As the air warms up, it rises, and cooler air is drawn in from below, creating a convection loop throughout the room.

6. Hot Water Heaters

- In a tank, heated water rises to the top while cooler water sinks, allowing for the efficient circulation of hot water that can be used throughout a house or building.

7. Wind

- On a larger scale, natural convection in the atmosphere causes wind currents. Warm air rises, and cooler air moves in to replace it, helping to redistribute heat around the planet.

In each case, the heating is achieved through the movement of a fluid (air, water, etc.) carrying the heat from one place to another.

how does induction heating work?

Induction heating is a process that uses electromagnetic fields to generate heat directly in a material (usually metal) without needing direct contact with the heat source. Here's how it works:

1. Electromagnetic Induction

- A high-frequency alternating current (AC) is passed through a coil of wire, which creates a changing magnetic field around the coil.
- The magnetic field produced by the coil induces electric currents (called **eddy currents**) in the conductive material (like a metal object) placed inside or near the coil.

2. Eddy Currents and Resistance

- The eddy currents generated inside the material circulate and encounter resistance within the material.
- The resistance causes the material to heat up. This heating is localized to the area of the material where the eddy currents are generated, making induction heating very efficient.

3. Skin Effect

- The heat is concentrated near the surface of the material, because eddy currents tend to flow near the outer surface. This is called the **skin effect**, and it makes induction heating particularly good for surface heating.

4. Control of Heating

- The depth of heating depends on the frequency of the AC current used and the type of material. Higher frequencies create more surface heating, while lower frequencies penetrate deeper into the material.

Applications of Induction Heating:

- **Induction Cooktops** – A coil under the glass surface generates a magnetic field that heats the cookware directly.
- **Metal Hardening** – Induction heating is used in industrial processes to heat metals for hardening or brazing.
- **Forging** – Induction heating can quickly bring metals to the desired temperature for forging.
- **Soldering and Welding** – It's used to heat small areas of metal for joining processes.

Induction heating is efficient because it heats only the material and not the surrounding air or the heating element itself, which reduces energy loss.

The amount of energy used by **induction heating** in a **PCB design** (Printed Circuit Board design) would depend on several factors, such as the specific application, the power requirements, and the components involved. Induction heating on a PCB is usually more relevant for specific tasks like **soldering** or **curing coatings** rather than for general heating.

Here are some key factors that influence energy consumption for induction heating in a PCB design:

1. Power of the Induction Coil

- **Power levels** can vary depending on the application. Small induction heating applications (like PCB soldering) might use around **30-100 W** of power, while larger applications could require several **kilowatts (kW)**.
- The **size of the coil**, the **frequency** of the alternating current (AC), and the **materials** involved (e.g., copper traces on the PCB) all impact the power needed for heating.

2. Duration of Heating

- The **duration** of induction heating will significantly affect energy consumption. For instance, heating a small area of a PCB for a few seconds to melt solder will consume far less energy than using induction to heat larger areas over a longer period.
- Short bursts of heat for specific tasks (like soldering) are typically in the range of **1 to 5 seconds**.

3. Efficiency of Induction Heating

- Induction heating is highly efficient, with **80%-90% of the energy** directly going into heating the target material. However, the efficiency will also depend on factors like the **geometry of the coil**, the **frequency used**, and the **material properties** of the PCB components.

4. Power Supply and Frequency

- The frequency of the AC used in the induction system impacts both the **depth of heating** and the **energy consumption**. **Higher frequencies** (for surface heating) may require less power compared to **lower frequencies** (for deeper heating).
- The power supply unit must be able to provide the necessary voltage and current to generate the required magnetic field. Typically, induction heating circuits are designed to be efficient at the operating frequency.

Example:

For a typical **induction soldering** process on a PCB, the **energy used per cycle** might be calculated using the following basic formula:

Energy (J) = Power (W) × Time (s)

For instance:

- **Power:** 50 W (small induction coil for soldering)
- **Time:** 5 seconds (time to heat a small joint)

Energy = 50 W × 5 s = 250 Joules

Step 1: Organize Components

I'm trying to create my schematic for the PCB design of the MCU board in Fusion 360, and I have several peripherals I need to connect. How do I go about connecting the peripherals?

Great! Sounds like you're at the exciting stage of turning your project into real hardware. Since you're designing your **MCU board schematic** in **Fusion 360 (Electronics)** and want to connect multiple peripherals, here's a step-by-step guide to get you going:

Step 1: Organize Your Components

Start by listing your peripherals and their interfaces. Based on what you told me, here's what you're working with:

Peripheral	Interface	Voltage
ESP32 (MCU)	-	3.3V
HD44780 16x2 LCD (I2C)	I2C (SDA, SCL)	5V (logic tolerant)
DS18B20 Temp Sensor	1-Wire (GPIO)	3.3V or 5V
TAL2208 Load Cell + HX711	HX711 uses I2C-ish	5V (logic)
ASPIRON 58mm Thermal Printer	UART + TTL	5V
Adafruit Heating Pads x3	Power only (MOSFET switching)	5V (high current)

Step 2: Start the Schematic in Fusion 360

1. **Open your schematic editor** in Fusion 360.
2. **Add the ESP32:** If there's no official library, you can use a generic ESP32 module (like DevKitC or WROOM32), or import one from SnapEDA or UltraLibrarian.
3. **Add peripherals:** Use components from libraries or create custom symbols as needed. Common parts like HX711, DS18B20, and LCDs are often available in community libraries.

🔧 Step 3: Connect Power and Ground

- Add 3.3V and 5V power nets as needed.
- Connect all GNDs together.
- Add a **voltage regulator** circuit if you're stepping down from 5V to 3.3V for ESP32.

🔧 Step 4: Connect Peripherals by Signal

1. LCD (I2C)

- SDA → ESP32 GPIO (e.g., GPIO21)
- SCL → ESP32 GPIO (e.g., GPIO22)
- Add 4.7kΩ pull-up resistors if needed
- Power from 5V (most I2C modules tolerate 3.3V logic)

2. DS18B20

- DATA → ESP32 GPIO (e.g., GPIO15)
- Add 4.7kΩ pull-up between DATA and VCC
- Power from 3.3V or 5V (depending on how you're wiring it)

3. HX711 (Load Cell Amplifier)

- DT (Data) → ESP32 GPIO (e.g., GPIO18)
- SCK (Clock) → ESP32 GPIO (e.g., GPIO19)
- Power from 5V

4. Thermal Printer

- TXD → ESP32 RX (use level shifter if printer TX is 5V)
- RXD → ESP32 TX (use level shifter: ESP32 TX to 5V)
- GND shared
- Power from 5V
- Add a **logic level shifter** for safe communication if printer is 5V TTL

5. Heating Pads

- Controlled via MOSFETs
- Gate → ESP32 GPIO (e.g., GPIO23, 25, 26)
- Source to GND, Drain to heating pad negative
- Pad positive to 5V rail
- Add flyback diodes if needed (if inductive, unlikely with resistive pads)

🖼️ Step 5: Label Nets and Use Buses

- Use **Net Labels** to keep your schematic clean.
- For I2C or related signals, you can use **Buses** to group signals logically.

🔧 Step 6: Add Decoupling Capacitors and Protection

- Add 0.1µF decoupling caps close to each IC's VCC pin.
- Add pull-up/pull-down resistors as needed (like for EN or IO0 on ESP32).
- Consider TVS diodes or fuses for protection on power inputs.

📋 Final Checks

- Confirm **voltage compatibility** across all interfaces.
- Assign **unique GPIOs** for each signal line.
- Document which GPIO does what in a table or comment section.
- Add **test pads** for debugging if you have space.

for the printer i am actually using ASPIRON 58mm Embedded Thermal Printer Module (UART & TTL Interface)

Perfect, thanks for clarifying! That printer uses **UART over TTL**, which is great because the ESP32 has multiple UART ports. Since it's TTL, we just need to be careful about **voltage levels**, because:

- The **ESP32 TX** (transmit) is 3.3V
- The **Printer RX** (receive) expects 5V TTL
- The **Printer TX** (transmit) sends 5V signals
- The **ESP32 RX** (receive) expects 3.3V

 Recommended UART Connection Between ESP32 and ASPIRON Printer

Printer Pin	ESP32 Pin	Note
TXD	RX (e.g., GPIO16 / UART2 RX)	Needs level shifting down to 3.3V
RXD	TX (e.g., GPIO17 / UART2 TX)	3.3V should be okay, but safer to shift up
GND	GND	Shared ground
VCC	5V	Printer requires 5V power