Monitoring System for Afridev Hand Pumps

by

Juan D. Luna | jlunaing@calpoly.edu
Ashley Mayer | asmayer@calpoly.edu
Dominic Chmiel | dchmiel@calpoly.edu
Linnea Skinner | lsskinne@calpoly.edu

College of Engineering

California Polytechnic State University

San Luis Obispo

2023

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff, including the students, cannot be held liable for any use or misuse of the project.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The sponsor of this project, CLEAN International, is a non-profit organization based in Ventura, California. They supervise maintenance of water well pumps in developing nations like Ghana, Honduras, and the Democratic Republic of the Congo (DRC) **[1]**. CLEAN International has partnered with a local maintenance team called Habitat Technologies Solutions (HTS) which maintains water wells in the Équateur Province of the DRC **[2]**. They manage teams that are responsible for responding to and repairing failed hand pumps. Each hand pump in this region provides a daily source of water for about 1,300 people, even though they are designed to service only 500. This overuse leads to frequent failure, requiring maintenance by the local repair teams. However, communication difficulties with the local community result in delays or even outright failures to repair broken pumps. Faced with inoperable pump systems, locals usually revert to gathering water from the Congo River, which is far from their homes and a hotspot for pollution because of nearby mining sites. Broken pumps are often scavenged for parts soon after they break, making prompt repair a necessity.

The objectives of the sponsor for this project are to reduce lapses in repairing failed hand pumps and quantify the impact of the water wells they manage. Time between pump failure and repair will be reduced by developing a reliable failure detection measuring system that will inform CLEAN International when pumps need attention from the HTS repair team. The system will collect data on pump usage and water flow rate estimation for CLEAN International to access remotely. By tracking these metrics, they will be able to track the function and community impact of each water well pump they are monitoring in the DRC. In addition, the reduction in hand pump repair time will increase the consistency of well water available to people in the Équateur Province of the DRC.

Project Management

The team consists of four engineering students with different backgrounds working together to design the described system and create a functional prototype. The development of the monitoring system for hand pumps involved several stages. The team had several meetings with the sponsor to translate their needs into engineering requirements. Then, background research on the problem took place and we established goals and milestones for the project. The phases and tasks of the senior design project were planned out in the Gantt Chart (**Appendix G**). Through brainstorming, ideation activities, and iteratively building on top of each other's ideas, the team defined the engineering specifications of the potential solution.

After presenting our ideas to the sponsor through the Project Requirement Document, in November, and receiving feedback, we developed a concept design for the sensor system, formally presented in the Concept Design Report, in December, towards the end of the Fall academic term. At this stage, we received a great amount of feedback from our sponsor and new considerations that caused the direction of our design to change. After iteratively improving our design to better match our sponsor feedback, we arrived at what would soon be the final design. We presented this design as part of the Critical Design Review report, in February. Around this time, we started manufacturing and ordering materials to create a prototype. Members of the team focused on separate aspects of the project, including interfacing with the sensors and satellite system, creating the printed-circuit board (PCB) that would hold the electronics, designing the housing that would protect and enclose the sensor system, and modifying the cover plate of the hand pump. Testing took place as well, with much of the effort being focused on testing the functionality of the electronics on the Afridev hand pump.

We successfully worked towards a functional prototype, which was displayed at the Senior Project Expo, which took place in June. This included a prototype that demonstrated the ability of the monitoring system to provide an estimate of the flow rate out of the pump. This demo included a functional PCB in a 3D-printed housing and visually pleasing demo software. Finally, we described our design, its development and realization, in the current Final Design Report.

The goals presented in the Gantt chart were followed for the most part, with a few setbacks along the way due to the nature of the project and the limited amount of time and expertise on the design of systems of this scale. Some aspects of the project were deprioritized in the service of core prototype functionality. In particular, the time allotted for software development shrank to the point where, while functional, it needs to be significantly revised. Additionally, a few minor mistakes occurred in the development of the PCB due to limited time and complexity of the system. Overall, however, the goals of the project were met, and a functional prototype was successfully developed. Recommendations for future development and improvement are made in the relevant sections of this report.

Chapter 2: Background

Currently, there are no commercially available options for well pump sensors with the capabilities to detect pump function, monitor water flow rate, and transmit data internationally. However, open-source systems of a similar nature have been developed by other organizations. A notable one is Charity: Water, a non-profit serving over 15 million people across 29 developing countries through community water projects and sanitation efforts **[3]**. Their sensors—which can be retrofitted onto the Afridev, Tapstand, and India Mark II hand pump models—are able to collect data on the quantity of water being pumped from a well. The gathered data is transmitted to the cloud weekly via cellular networks, where it is stored, processed, and made viewable by an application running on Amazon Web Services (AWS) **[4].** Extensive documentation for the Afridev and India Mark II models of the sensor is available on GitHub **[5, 6, 7]**. The Afridev model appears to have been developed from 2016 to 2020 by Intelligent Product Solutions (IPS), while the India Mark II sensor was developed in 2021 by TwistThink over the course of at least a year.

Charity: Water's third generation *Afridev Handpump Sensor V-2* expands on its predecessors with the ability to gather GPS, temperature, and device performance information **[8]**. A more recent model, the India Mark II Sensor, adds to these capabilities with additional stroke and humidity sensors. It costs $250 to build and maintain for its battery-limited 10-year lifespan and can collect ten million data points over a 24-hour period. This data is continually analyzed through Charity: Water's Amazon Web Services (AWS) backend, where personalized emails are dispatched to monitoring teams daily **[9]**. More details of all sensor models can be found in the references section **[10].** Design specifications for Charity: Water's sensors are available from open source and will continue to provide references as we design a well pump sensor for CLEAN International.

The Charity: Water sensors all use a similar strategy to measure water flow rate. During a pumping cycle, water is brought into a chamber where its depth is measured by a series of capacitive sensors. From this, the quantity per pump—and therefore average flow rate—can be accurately estimated. While it does work, this method has a few weaknesses. The capacitive sensors are highly sensitive to environmental changes such as temperature variation and require frequent (multiple per hour) automated calibrations to maintain measurement accuracy. Moreover, the sensor has an upper limit on the amount of flow it can measure per pump—any output over the chamber volume cannot be measured. With this setup, Charity: Water claims a 20% tolerance for the calculated flow rate, which was improved to 5% with IPS's help **[11]**.

In addition to the common water sensing strategy, both sensors also feature a cellular module to communicate with Charity: Water's cloud infrastructure, GPS to provide positioning, and battery power of undisclosed capacity. It is claimed that the India Mark II sensor can remain operational for up to ten years. While cellular communication is available in some areas of the DRC, coverage is sparce outside of urban settlements **[12]**. This makes the use of Global System for Mobile Communications (GSM) technology difficult to implement for the pump distribution in the DRC. Satellite communication is a more reliable alternative, with coverage in the DRC by telecommunications infrastructure providers such as Globalstar, Swarm, and Astrocast. Their satellite networks cover the entirety of the DRC, including regions of the Équateur Province where our sensors will be implemented **[13].**

It is important to recognize the standards that products of this nature must adhere to. The RoHS guidelines restrict the use of ten hazardous materials in electrical components. Our primary part supplier, DigiKey, reveals the compliance status of each product in inventory. This status will be checked for each component used in our product and only RoHS compliant parts will be purchased. In addition, testing will verify compliance with IEEE Standards to ensure safe and responsible deployment of the product.

Chapter 3: Design Development

For the initial decision and selection process, we first defined means of achieving each required function of the system through a morphological chart. This involved brainstorming ideas based on our background research on technologies and known solutions, as shown in Table B.1 (**Appendix B**). The functions and means were gathered in Pugh decision matrices to compare methods based on different criteria. These initial matrices are shown in **Appendix B.** From these matrices, we selected the optimal method for achieving each function and began brainstorming ways to combine these components. The different key components of our design include the power management, processing, system enclosure, pump functionality sensing, and wireless communication.

Regarding the system enclosure, our early design considered aluminum as the most suitable option based on durability, waterproofing, and environmental resistance to factors such as UV exposure. Upon further analysis and conceptual integration with our design, we realized that aluminum would inhibit the ability of the system to transmit data. Furthermore, the thermal properties of aluminum could foster an internal temperature inside the enclosure that may not be suitable for component operations. High temperatures within the enclosure and pump could also facilitate evaporation of water inside the pump, resulting in condensation and potential damage within the circuitry. As such, the final version uses 3D-Printed Polycarbonate and Epoxy Seal 9000 to ensure that the electronics are both permanently protected and able to transmit data without an external antenna.

For power generation and storage, we initially planned to pair a solar panel and lithium-ion battery so that we can harvest natural energy and store it within the battery. We continued with this design choice with slight revisions. Power management is driven by the integration of low-power devices and utilizing a sleep or idle mode on the system. This way, we can preserve the limited power for the longest period possible. The only modification from the last design iteration is the switch from the single 18650-sized battery to three small 10440 AAA-sized batteries connected in parallel to minimize the final package height.

To transmit data wirelessly, we determined satellite to be the only feasible option in our region of operation within the DRC, due to the lack of cellular coverage in the Équateur Province. Initially, we selected SWARM as a satellite provider for their pricing and reliable coverage. However, their modem requires a large antenna to communicate with the satellite, which puts the functionality of the device at risk if the antenna were to be damaged or stolen. We aimed to find a new satellite device and provider that offered a small and subtle design that can be fully enclosed within the system. This necessitated a switch to a higher-frequency network that could be used with a smaller antenna. We settled on GlobalStar as a provider, which operates its network at a frequency of 1.6GHz. Their STX3 patch antennae integrates into the final, lower-profile design and can transmit data to the United States using satellite.

Gathering more information about the conditions within the DRC and preferences of our sponsor encouraged the iteration and changes we made to our initial design. During intermediate stages of the design, the sponsor reported that theft was an issue in the region, and when pumps stopped working, they were often taken apart by local Congolese. The speculation is that people will sell any parts that they deem valuable due to extreme poverty in the region. All of this meant that we needed to revisit our initial design and iterate from a viewpoint of system security, ensuring that the sensing module could not be easily accessed and taken apart. Likewise, CLEAN International informed our team that they wanted each device as a single, stand-alone unit. Thus, initial plans for inter-pump communication were discarded in the following iteration of the design. Initial testing proved the concept of using temperature sensing in combination with lidar. However, throughout the course of this project, the design was developed to meet the changing requirements and optimize the system.

Chapter 4: Description of Final Design

Overview of Solid Model

Previously, our team explored different design concepts that effectively fulfilled the product requirements. **Figure 1-2** illustrates the final iteration of the system design. The enclosure of the sensor was designed with subtlety in mind, to discourage theft. The system's low-profile design contributes to its effectiveness in this regard. The unit is securely fastened to the top panel of the Afridev hand pump with fasteners that are hidden from external view. At the bottom surface, the enclosure has dimensions of 90 x 115 mm and is attached to the top panel of the pump, directly over the axis of motion of the plunger, allowing downward clearance for both the time-of-flight and the infrared sensors.

Figure 1. *Monitoring system installed on top of the Afridev hand pump*

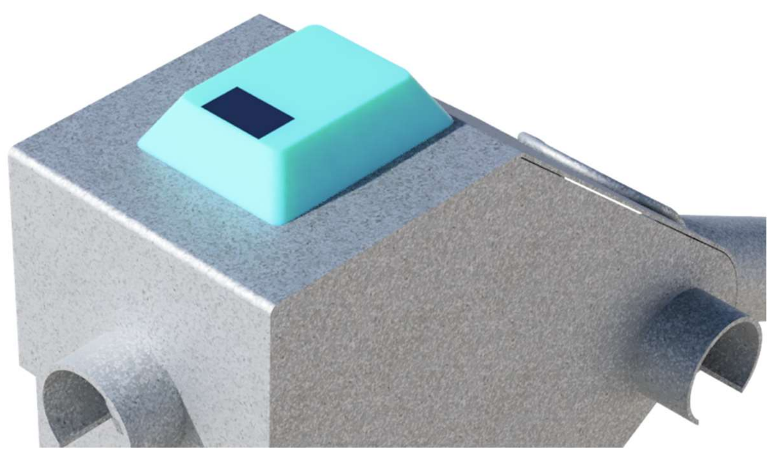


Figure 2*. Close-up view of monitoring system*

A more detailed CAD drawing of the polycarbonate enclosure can be found in **Appendix C.** The mechanical design of the housing features walls at 60-degree angles to dissuade removal of the sensor. The electrical system consists of batteries, a solar cell, charge controller, two sensors, a satellite modem, and a microcontroller. These components, as described in the following sections, are integrated into a printed-circuit board (PCB) which is situated between the bottom and top housing. An exploded and collapsed view of the housing and the PCB is shown below (**Figure 3-4**). More detailed engineering drawings and the detailed electrical circuit schematic can be found in **Appendix C**. The software system that the design will use to process the data is described in the software development plan in **Chapter 5.**

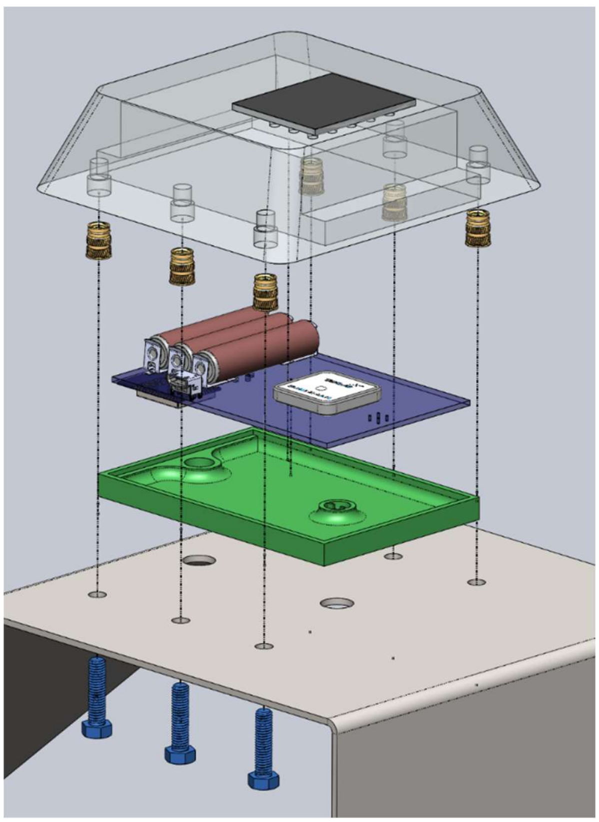


Figure 3. *Exploded view of monitoring system. Colors shown for visual purposes.*

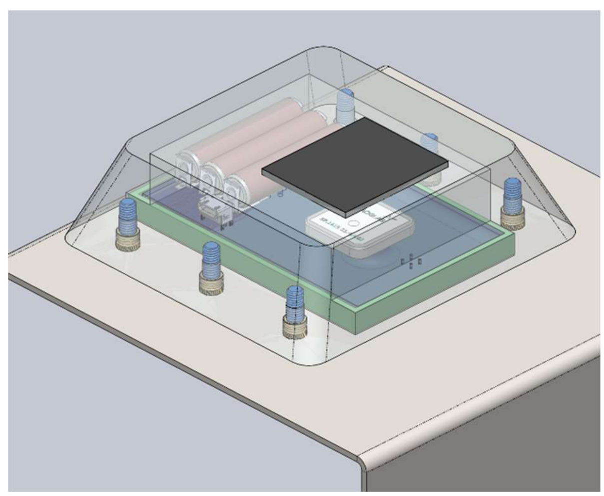


Figure 4. *"Collapsed" exploded view of monitoring system.*

Component Selection

We selected components based on our derived engineering requirements and factors including cost, performance metrics, compatibility and others described earlier in our design development section. To provide power to the sensor system, three 10440 AAA rechargeable lithium-ion phosphate batteries, also known as LiFePO4 batteries, were selected. Compared to traditional alkaline AAA batteries, 10440 LiFePO4 batteries have a higher voltage, energy density, and are rechargeable so they can provide more power and last longer. They also have a more stable chemistry than other lithium-ion alternatives, lasting up to 10 years. Connected in parallel, these batteries will supply 3.2 V of power with a combined capacity of 1200 mAh. The LiFePO4 is a readily available battery, often used in solar garden lights, with a low cost of $2.99 each. Since they will be connected in parallel, charging is balanced between the two batteries. The design also incorporates the SM141K06L monocrystalline solar cell, which will recharge the batteries from solar energy. This specific cell provides a 4.15-V nominal output with 183-mW peak power. Its small size of 35x22 mm and the fact that it is pre-sealed allows for ease of integration into the design **[14]**. To integrate the solar cell and batteries, we will use a shunt charger. This is the simplest type of charger and can be used in this application because the capacity of the batteries far outclasses the maximum output of the solar cell. The solar cell is directly connected to the batteries, and a shunt circuit limits voltage to the battery's max – about 3.6 volts. When the batteries are full, additional power generated by the solar cell is simply wasted as heat through the shunt to keep the battery voltage below its max. The Maximum Power Point (MPP) of the solar cell is specifically selected so that it's near the target voltage of the battery, ensuring efficient power extraction. When charging at around 3.5 volts, the panel will sit at about 3.7 volts after a reverse-bias diode, which is near enough the MPP for efficient operation.

To ensure that the handpump system is working, two sensors are responsible for measurements—specifically, detecting physical pumping action and the presence of water. The VL53L4CD time-of-flight sensor from ST Microelectronics measures the position of the pump plunger as it's moved vertically during pumping. From this displacement and the known cross-sectional area of the plunger, water outflow is estimated. The sensor includes some useful features such as adjustable distance threshold interrupts that can be used to optimize the power draw of the microcontroller. It also features an accuracy of about 5 mm. This component runs on 3.3 V, with a current draw of 19 mA during active mode and 5uA in idle mode **[18].** Likewise, to detect whether water is indeed flowing when pumping action occurs, we have selected the MLX90614 digital infrared temperature sensor from Melexis. By measuring the temperature of a region of the pump that becomes flooded when water is flowing, a temperature drop can be used to directly check that water is present. Its measurement resolution, accuracy, and wide range make it suitable for our purposes. It requires a power supply in the range 2.6-3.6 V to measure temperatures from -40 to 85°C **[19].**

To transmit data back to CLEAN, we have chosen the STX3 satellite modem from Globalstar. It relies on a low-profile 20x20mm patch antenna that is mounted directly to the PCB together with a surrounding 60x60mm ground plane to function. The Global Star network covers the entirety of the DRC and operates at an L-band of 1.6 GHz. Each STX3 Modem comes at an initial cost of $60, with a subscription of $16 per month for data transmission **[17]**.

To interface with the sensor and satellite module as well as control the overall behavior of the electronic system, we have chosen the ESP32-S2 microcontroller (MCU). The ESP32 series of microcontrollers is highly integrated, ubiquitous, and features built-in Wi-Fi. The S2 variant we have chosen also features an ultra-low-power RISC-V co-processor which can be used to run arbitrary code while the main, power hungry, MCU is in deep-sleep. This co-processor has low power consumption at 627uW and – importantly for our application – has access to the I2C peripheral. This enables it to communicate with our various sensors without booting the main MCU. The co-processor also has access to 8kB of SRAM, which is sufficient for our requirements. The primary processor has 1MB of flash and 320kB of SRAM **[22]**. The primary processor has access to additional UART peripherals, which are used to communicate with the satellite transceiver. This system uses the C programming language for developing the code. It integrates into our compact design with dimensions of 18x25mm **[16]**. The extremely rich feature-set of the ESP32-S2 also keeps doors open to additional features like a smartphone-enabled setup.

The MAX77827 buck-boost converter IC was selected to regulate the main 3.3V rail at an efficiency of 96%. It accepts input voltages from 2.3-5.5V and can output a steady 3.3V, regardless of whether the input voltage is above or below the target. This is important for functionality, as during satellite transmission, peak current draws may cause battery voltages to dip below 3.3v, making a standard step-down only converter inadequate.

To monitor battery voltage, the system uses the MCP3425A0T ADC. This component supports I2C serial interface and runs within the range of power supplied by the previously mentioned buck converter. It has up to 16-bit resolution in a SOT-23-6 package and can use its internal 2V reference to sense the entire battery range without needing a voltage divider. An external ADC is used instead of the ESP32's built-in ADC to manage quiescent current. The ESP32's ADC is notoriously poor and has a relatively low impedance – meaning it will waste power if used.

To preserve the Lithium-ion batteries, the XB8358D0 has been integrated. This battery management IC is contained in a small SOT23-5 package and runs on low current, switching between operation mode (2.8µA) and power-down mode (1.5µA). This IC will extend battery life by protecting against overcharging, over discharging, overcurrent, load short circuiting, and reverse polarity. While not *strictly* necessary if the batteries are never replaced, it is included under the assumption that batteries should be serviceable by laypeople.

For more technical specifications of components, see the datasheets in **Appendix C**. Additional components, included only for testing and validation on the prototype, include the CP2102 USB-serial converter, the BQ25170DSGR Li-ion charger, and the LM66200DRLR power switch. These components should not be populated for production versions of the device.

Cost Breakdown

The final cost per sensor unit came out to be $156. A specific requirement was not given at the start of this project, and the sponsor seems satisfied with this outcome. The manufactured PCB – including the soldered components and satellite transmitter – accounts for about 80% of this cost. A more detailed breakdown of the budget for this product development and the final prototype can be found in **Appendix D.**

System Integration

These components are assembled into a printed circuit board (PCB) and the board is placed inside the polycarbonate housing. A circuit schematic showing the connections between the components is shown in **Appendix C**.

The PCB is mounted into a tray, where an electrical potting compound is used to permanently seal the sensors. The two holes surrounding the LIDAR and Temperature sensors are designed to prevent the potting epoxy from leaking onto the sensors and causing issues.

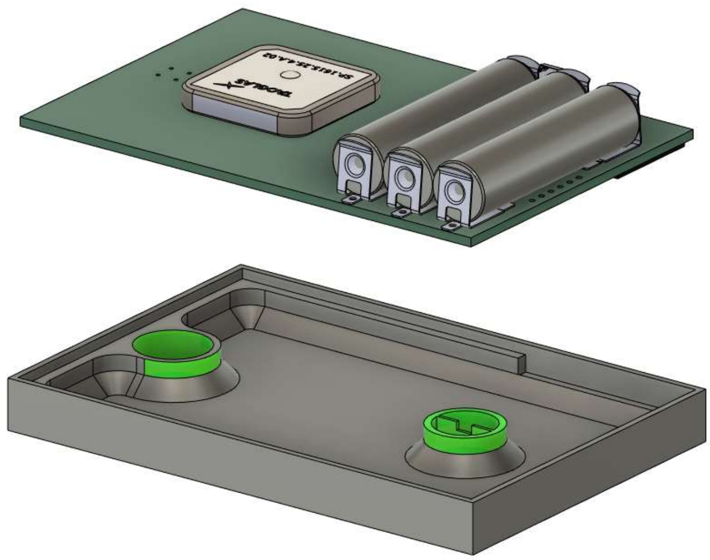


Figure 5. *The PCB and associated tray, with sensor holes highlighted.*

The solar panel is mounted in much the same way, with the perforations beneath it designed to allow epoxy to hold it in place effectively.

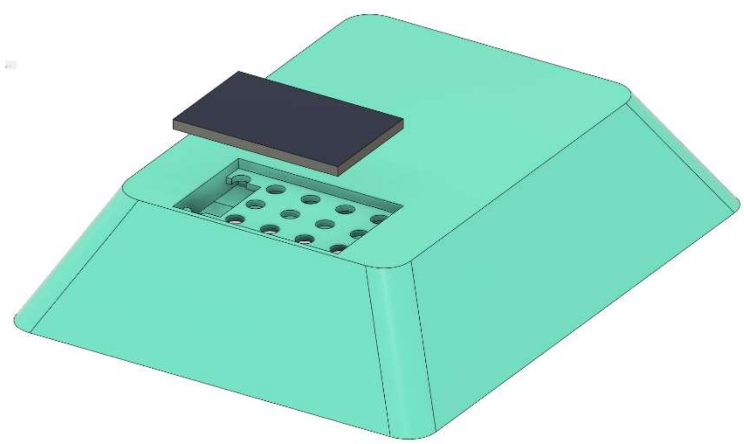


Figure 6. *The solar panel and its associated perforations.*

During assembly, the bottom tray is sealed into the enclosure with a thin epoxy seal, which is designed to be cut should the outer enclosure or batteries need to be replaced.

Epoxy Seal 9000 has high temperature and impact resistance and keeps moisture out of the enclosure. This product is RoHS Compliant and can be purchased easily online for $0.08 per fluid ounce **[20].** Potting the important components secures the design against component theft and water damage. The potted enclosure is mounted on top of the Afridev pump using M3 screws with heat-set inserts. Combined with slightly undersized holes, these heat-set inserts produce a locking effect like nylon locknuts. The trade-off for the added security from potting and locking screws is that only the replacement of the solar panel and batteries is possible. Therefore, extensive testing should be completed to ensure longevity of each component and the system will be deployed as a single unit that will require replacement approximately every 10 years.

Safety and Sustainability Considerations

Throughout our design process, we have managed to incorporate several principles of design for the environment, although it has been a challenge to prioritize sustainability while fulfilling the sponsor's requests. Energy efficiency is a priority in our design to conserve battery life and extend the lifespan of the product. We have also minimized the presence of hazardous materials in the design by verifying that the electronic components ordered from suppliers are RoHS compliant. In addition, the sealed housing will prevent contact between the sensor system and water coming through the pump. The safety of this technology needs to be investigated further to ensure that the integration of this sensor will not pose any danger to communities in the DRC.

Two of the biggest barriers preventing us from designing a more sustainable sensor system are the risks of theft and water damage from high humidity. Unfortunately, our designed solution to the sponsor's specifications will produce waste from various electronic components at the end of their life. Our design aims to reduce waste by allowing for partial disassembly. The epoxy seal can be cut around the perimeter to remove the bottom and top housing, exposing the batteries and solar panel. Once a sensor is out of commission, it can be removed from the pump, taken to a repair location, and partially refurbished. Because the sensor will contain various synthetic materials and electrical components, salvaging components for re-use will be crucial to minimizing the environmental impact of this product. Recommendations regarding the sustainability of this product will be discussed further in **Chapter 7**.

Assembly

As the prototype is intended to act only as a demonstration of the final design concept, we decided not to take the permanent steps involved in assembly. After drilling holes through the top shell of the Afridev pump, the enclosure was fastened with M3 screws and heat-set inserts. The epoxy seal was not used for the prototype to maintain accessibility and viewability of the design. A full assembly guide for the sensor prototype can be found in **Appendix J.**

Chapter 5: Product Realization

Software Development

The software required to create a fully functioning system needs to be able to perform data collection, translation, and transmission, as well as transitioning a system between idle and active mode. The software is programmed and processed on a microcontroller unit (MCU) that acts as the central controller for the entire system. The finite state diagram for the software is shown in **Figure 7.**

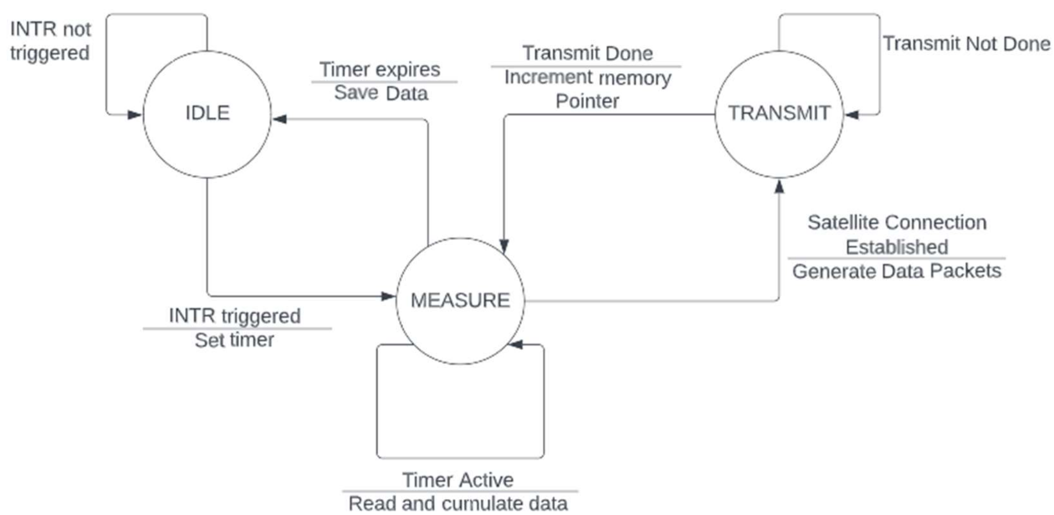


***Figure** 7. Finite state machine driving the microcontroller unit.*

For data collection, the temperature and distance (ToF) sensor work in tandem to detect if the pump is working. The head of these data collections will be the distance sensor that is used to detect if the handle is being pumped. This communicates with the MCU using the I^2C protocol and provides accurate measurements. When the sensor reads that the pump is pulled up, the sensor triggers an interrupt (*INTR* in diagram) in the MCU to come out of standby mode **[21]**. The MCU will then turn on the temperature sensor, which takes measurements on the ambient and object temperature. The object of interest for the temperature sensor is the bottom of the pump where water should appear, and measured data will be sent to the MCU through I^2C communication as well. A temperature difference between the two, or change in temperature of the object, denotes the presence of water within the pump, as described in the earlier section. The MCU makes use of a timer, that is set when the interrupt is triggered, to minimize the data collection when the pump is not being used.

For data translation, the system must be able to translate measured data values into volumetric measurements of water being pumped. The MCU will use the displacement of the pump handle mechanism to estimate the volume of water displaced by the plunger. This relationship will be determined from testing with the Afridev pump. The temperature sensor will determine if water is present at the time of pumping. These measurements will be calculated and translated to the number of liters output by the pump and detect if the pump has failed or not.

For data transmission, the MCU communicates directly with the satellite antenna, and uses satellite to send the data internationally. The MCU prepares the data packets to send, which will include the pump number, failure status, a checksum, and number of liters pumped over the course of a day. The pump number is a numerical representation of a pump station that can be mapped to the physical location of the pump. The failure status will display if a pump has failed or is still active. The checksum is a calculated value that is sent with the data packet to be checked at the receiving end, to ensure that data has not been corrupted during transmission. The number of liters will be stored and displayed within the external database that will be accessible to CLEAN international.

To work efficiently with a minimal power supply, the device must be able to conserve as much power as possible. To do this, we have selected low-power components with idle and active modes, which can be triggered by a pin interrupt from our distance sensor.

Finally, for data storage and display, we will use Grafana to create the user-facing dashboard, and Prometheus to store data. Grafana is an open-source analytics and interactive visualization web application that can be used to create attractive online dashboards and is suitable for this application. Prometheus is a database focused on the storage of timescale data, which fits this application well. The two are designed to interoperate, which will simplify the setup. To connect the Prometheus database to the satellite provider's API, we will likely need to write a custom translation service that will constantly listen for pump data and insert it into the database.

Due to unforeseen challenges, the software of the prototype does not display all the planned functionality. The final prototype utilizes the distance sensor and temperature sensor to report an active or inactive pump and generate an estimated flow rate. The finite state machine of the device is still accurate to the design, but the transmit state of the device was not seen into fruition. Nonetheless, we were able to build software that quickly and accurately responds to movement in the pump system and provides estimates of the flow rate.

Manufacturing

Manufacturing was completed very quickly for the prototype. Most components came pre-populated on the board, as we utilized JLCPCB's assembly service. This had the benefits of saving us time and money, as the components they have open for selection are often orders of magnitude cheaper than what can be found on Mouser or Digikey. Components that could not be found in their vast library for assembly were manually ordered from Mouser and Digikey then assembled by hand. The demonstration enclosure was printed on a group member's 3D printer out of PETG.

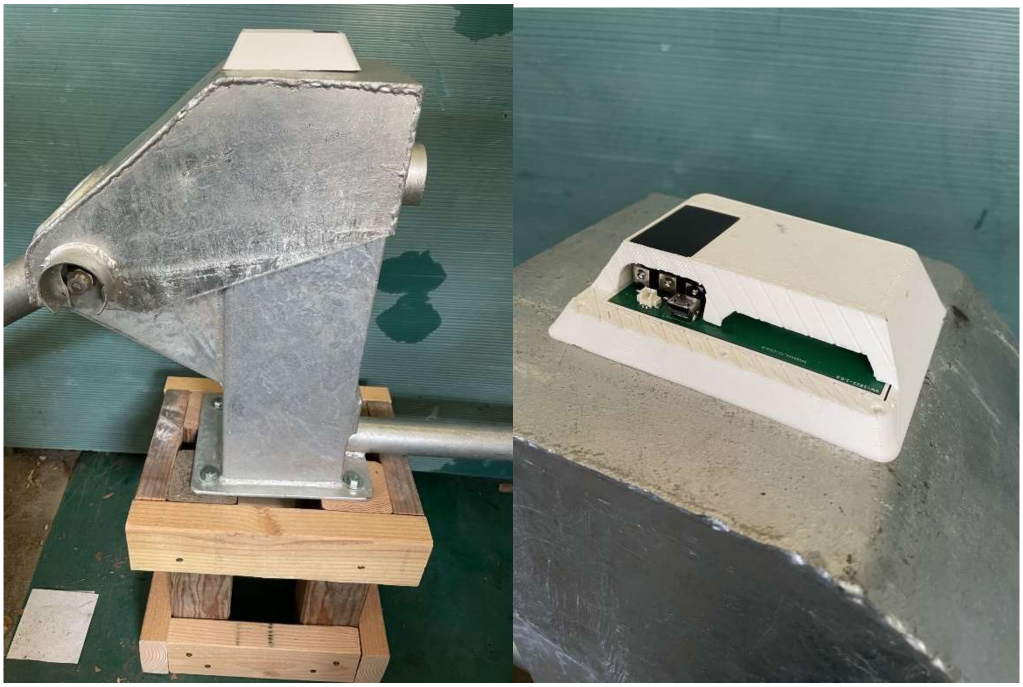


Figure 8. *(a) Model Afridev hand pump on stand. (b) Open sensor prototype on pump.*

Potential Improvements

To improve the accuracy of our device in detecting the functionality of the pump, a few changes in the components may be considered. A PIR motion sensor could be considered to replace the temperature sensor, to detect motion at the bottom of the pump instead of a change in temperature. Possible difficulties arise in this replacement, as the sensor must be configured to measure the bottom of the pump without interference from the moving lever. Any movement registered from the pump mechanism itself and not running water at the base of the pump would provide inaccurate results. Another improvement to consider is using a flow sensor, which would provide more accurate results of flow rate and degradation of the pump. These sensors, however, must be placed in the route of the flowing water. With our design sitting as a single unit at the top of the pump frame, this may bring need for two separate device units on the pump. This approach may complicate the integration of the device onto the pumps, whereas our current design aims for simple integration as a single unit.

Prototype Errata

Given the broad scope of the project and limited actual development time, we have multiple recommendations to fix identified weaknesses with the prototype. The manufactured PCBs had a few mistakes that meant full functionality was unable to be tested. Firstly, the power switch IC (LM66200) had an incorrect footprint, meaning that both prototype PCBs are bodged to work only with USB power. Secondly, a last-minute addition of a diode to the solar charging circuit – and a failure to re-flow the upper ground plane – resulted in the solar charging circuit being nonfunctional. Finally, the serial lines going from the USB-serial converter to the MCU were flipped. This mistake has been bodged into functionality on both prototypes. **These errors are fixed in the EDA files provided as a part of the deliverables.**

Further Development

We have multiple recommendations for the further development of this project. During development, we identified multiple areas where costs can be potentially cut, if desired. In particular, the MLX90614 temperature sensor – which represents a significant cost – can likely be replaced with a standard Passive Infrared (PIR) element like those from Zilog. This is possible because it only needs to effectively detect the temperature *difference* caused by flowing water, not the temperature itself. Additionally, the satellite transceiver should – once coverage expands to the USA in 2024 – likely be replaced with the Astronode series of transceivers from Astrocast. These modules are both more fully featured and cheaper to buy and operate than the Globalstar offering we integrated into the prototype.

Because of time constraints on the project, the dashboard for viewing data was not able to be completed. However, we highly recommend using Grafana because of the project's good documentation and integration with existing time-series databases.

Chapter 6: Design Verification

The design required verification of both basic functionality and longevity to ensure a high-quality deliverable. To verify functionality, the sensor was mounted and tested on an Afridev hand pump provided by CLEAN international. Using this model set-up, measurement obtainment, processing, and translation could be demonstrated. The course of prototype testing was marked by a combination of achievements and unforeseen obstacles, resulting in the realization of only some of the necessary verification tests. Tests of basic functionality were conducted in controlled environments with the resources available to us.

The verification process of the distance sensor involved rigorous testing and evaluation to ensure its accuracy and reliability. Initially, the sensor is subjected to calibration procedures to establish a baseline measurement reference. These preliminary trials, shown in **Figure 7**, allowed us to establish the baseline functionality. It is then tested against known distances to validate its measurement accuracy. Results of these tests are displayed in **Appendix I,** showing a strong relation between the set distance and the sensor's measurement (R squared value = 0.985)**.** Various environmental factors such as temperature, humidity, and ambient light are also considered to assess the sensor's performance under different conditions. Additionally, the sensor's response time and repeatability are examined to ensure consistent and timely distance readings. Finally, the sensor is mounted to the Afridev Hand pump with drilled placement holes to verify its reliability in application designed. From these tests, we were able to determine the sensor performs as expected, and measure the distance range between the sensor and the target pump lever. Through this comprehensive verification process, any discrepancies or issues with the distance sensor can be identified and addressed, guaranteeing its suitability for accurate distance measurement in real-world applications.

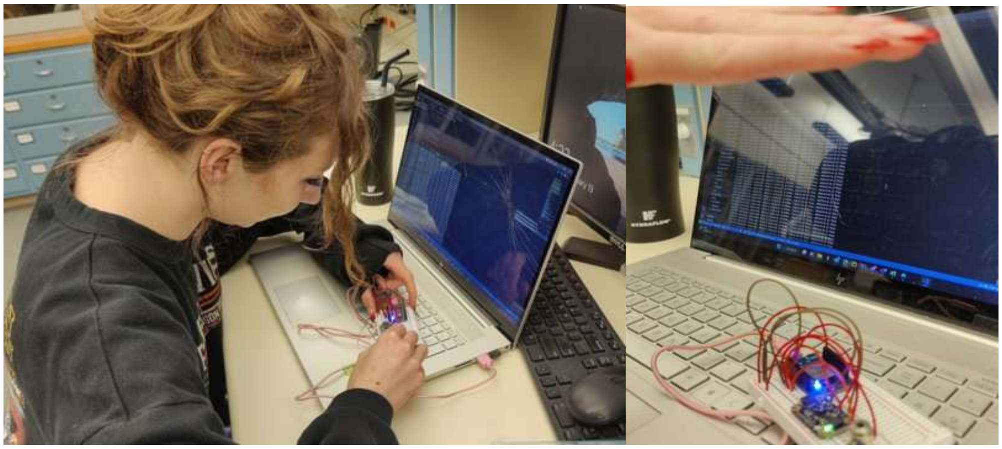


Figure 7. *Initial Testing of Time-of-Flight Sensor*

Much like the ToF Sensor, the verification process of the temperature sensor consisted of stand-alone calibration and functionality testing, and then integrated testing with the system. Because we did not have a thermometer, nor access to a temperature chamber, getting exact measurements of the temperature proved to be rather arbitrary. Instead, we focused our testing on detecting the change in temperature readings when directed at different objects. A complete list of our findings is shown in **Appendix I**. From these results, we can see a clear differentiation between the object temperature and the ambient temperature. A strong assumption of our system is that the water coming from the underground well will be a different temperature than the temperature of the aluminum pump. A major roadblock in the verification of this behavior is that the pump delivered to us did not have the plunger component. Without this piece, complete testing of our system was limited to the assumptions we had made prior, as any testing on the pump would not reflect the true environment and system interaction.

Verification of the satellite communication capabilities consisted of a short-lived round of test transmissions. Our sample message was transmitted correctly and displayed in the STX database, with a latency of about 20 minutes. However, once the system was ready to integrate the satellite chip, our development trial expired, and we would have to purchase a year-long subscription to resume the service. The verification of proper sending and receiving of test packets was deemed substantial enough evidence of a working module, and we carried on with the implementation of the system.

Tests regarding the power consumption of the device and lifespan of the device were not performed in this stage of prototyping due to a series of roadblocks. Due to a broken solar panel charger and the satellite module trial expiring, we verified our testing and prototyping results through UART communication, with a computer display of our results. The connection to the computer provided power to the device, making our external power sources obsolete in our testing. The theoretical calculations of lifespan and functionality of the rechargeable batteries still stand, however. We also know that the satellite gains connection at least once a day and can be detected by the module, so our specification of regular updates is highly likely to be met. The specification checklist of our testing is shown in **Table 1**.

Table 1: Specification Verification Checklist

Spec. #	Parameter Description	Target	Tolerance	Spec. Validation Method	Pass?
1	Active power	2 W	Max	Discharge Test	N/A
2	Rechargeable Battery	1.4 Wh	Min	Charge test	N/A
3	Permissible TX Power	1 W	Max	RF power meter	N/A
4	Regular Updates	1 tx/wk	Min	DC power measurement + analysis	N/A
5	Memory/Storage	256 kB	Min	H2testw capacity test	Y
6	Frequency of Data Measurements	10 Hz	Min	Read selected sensors at full speed	Y
7	Flow Rate Estimation	L/s	+/- 30%	On-pump test	Y
8	Lifespan	1 year	Min	DC power measurement + analysis	N/A

Chapter 7: Conclusions and Recommendations

Throughout the course of this design project, our team designed a monitoring system for the Afridev hand pump as per the specifications of CLEAN International. This sensor system is a proof-of-concept design for detecting pump failure and estimating water flow by utilizing the ToF and IR sensors. The system is powered by a solar unit and rechargeable batteries. Further testing and design development and optimization are necessary prior to implementing this sensor in the field or any remote locations of the DRC. The next steps will be to test the integrated system, including power consumption, regular transmission of data packages, and lifespan.

Longevity testing should include high heat, high humidity conditions to mimic the climate in the DRC and test for component degradation.

Following the initial design process of this project, our team has several recommendations for the pursuit of this product realization. Planning for the refurbishment and end-of-life disposal of these sensors is critical to their impact on communities in the Democratic Republic of the Congo. Africa has been inundated with E-waste, which is often scavenged for valuables or incinerated, posing serious threats to human health. Contributing to this issue are solar-powered products that, ironically, aim to help people in Africa. CLEAN International must consider the entire lifecycle of this product to ensure that this technology is in the best interest of the communities for which it intends to improve access to well water. The global context of this project can be explored further through lenses such as the one of "Community Participation in Development" by the Oxford Press **[23].** This perspective suggests that the communities' needs be prioritized, and their voices valued in the development and integration of technology as a potential solution to increase their access to well water.

Acknowledgements

We would like to express gratitude toward our sponsor, CLEAN International, for proposing this project and providing us access to a hand pump for testing, and Grace Silver, Director of WASH Sustainability and Engagement for CLEAN International, for her support and feedback throughout the year-long project. We would also like to thank our senior project advisor, Vladimir Prodanov, for his guidance and technical assistance.

Appendices

A. References
B. QFD, Decision Matrices
C. Technical Details
    I. Circuit Schematic
    II. Printed-Circuit Board Schematic
    III. Software Diagrams
    IV. Code
    V. Assembly and Part Drawings
D. Bill of Materials
E. List of Vendors, Contact Information, and Pricing
F. Vendor-Supplied Component Specifications and Data Sheets
G. Gantt Chart
H. Safety Check List
I. Verification Results
J. User Assembly Guide

Appendix A References

[1] CLEAN International.

[2] "Our Model". https://htscongo.org/

[3] https://www.charitywater.org/

[4] Charity: Water Sensor Location Map. https://sensors-data.charitywater.org/public/dashboards/MQwmyOCdpgJaqbDIZYPValhOAyLV2EiU8oXc6NVp?org_slug=default

[5] Charity: Water – India Mark II. https://github.com/charitywater/india-mark-ii-sensor

[6] https://github.com/orgs/charitywater/repositories?type=all

[7] https://github.com/charitywater/afridev2-sensor

[8] Afridev Sensor AFD-2 Datasheet. https://s3.amazonaws.com/maji-assets/assets/static-pages/sensors/Afridev-DataSheet_V2.pdf

[9] https://assets.ctfassets.net/2w85ks0ylymt/5KVx3rWmfau6QVy7wwWM97/625fa9b251b4dc44869134fa27592ac8/IndiaMarkII_Brochure_May2021_updated_v5.pdf

[10] "Our Work". Charity Water. https://www.charitywater.org/our-work/sensors

[11] https://github.com/charitywater/afridev2-sensor/blob/master/software/architecture%20and%20analysis/charity%20water%20AfriDev%20sensor%20algorithm%20v.2.pdf

[12] https://www.gsma.com/coverage/#88

[13] Satellite Data Transmitter & Coverage Map STX3 | Satellite Modem | Globalstar US

[14] https://www.digikey.com/en/products/detail/anysolar-ltd/SM940K12L/9990451

[15] https://www.digikey.com/en/product-highlight/t/texas-instruments/bq24650-controller-solar-battery-charger?utm_adgroup=Texas%20Instruments&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search_EN_Focus%20Suppliers&utm_term=&utm_content=Texas%20Instruments&gclid=Cj0KCQiAutyfBhCMARIsAMgcRJSg1smQ1mFlMM_zFjVkBFurk7TbDys_aW9Me2WPgR_fRChHjxPYT6saAvffEALw_wcB

[16] https://www.digikey.com/en/products/detail/analog-devices-inc-maxim-integrated/MAX32660-EVSYS/9666375?utm_adgroup=Analog%20Devices&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search_EN_Focus%20Suppliers&utm_term=&utm_content=Anal

og%20Devices&gclid=Cj0KCQiA3eGfBhCeARIsACpJNU-49YoB7sAqtS9UuBvUOc9qdWFvfAYJvwmPHul0VFCSWkiYnIVMqlgaAu83EALw_wcB

[17] https://www.globalstar.com/en-us/products/iot/stx3

[18] https://www.digikey.com/en/products/detail/adafruit-industries-llc/5425/16499347

[19] https://www.digikey.com/en/products/detail/melexis-technologies-nv/MLX90614ESF-BAA-000-SP/5414793

[20] https://www.theepoxyresinstore.com/products/epoxyseal-9000-2-to-1-electronic-grade-potting-epoxy-resin-48oz-kit

[21] A guide to using the VL53L4CX Time-of-Flight sensor with extended distance measurement - User manual

[22] esp32-s2_technical_reference_manual_en.pdf (espressif.com)

[23] Botes, L. & Rensburg, D. "Community participation in development: nine plagues and twelve commandments". Oxford University Press. 2000.

Appendix B QFD, decision matrices etc.

Table B.1. Morphological Chart for design development

Functions	Means
Measure flow rate	▫ Monitor internal capacitance ▫ Flow meter/sensor ▫ Water wheel
Convert mechanical energy to electrical energy	▫ Inductor array ▫ Magnets and coil
Translate electrical energy	▫ Convert analog to digital ▫ Memory to transmit package ▫ Convert to correct units
Transmit data	▫ Satellite ▫ Cellular
Conserve battery life	▫ Solar panel ▫ Capacitor array
Protect from external environment	▫ Epoxy resin enclosure ▫ Sensor box inserted inside well ▫ Sensor box inserted between metal well components ▫ Polycarbonate housing

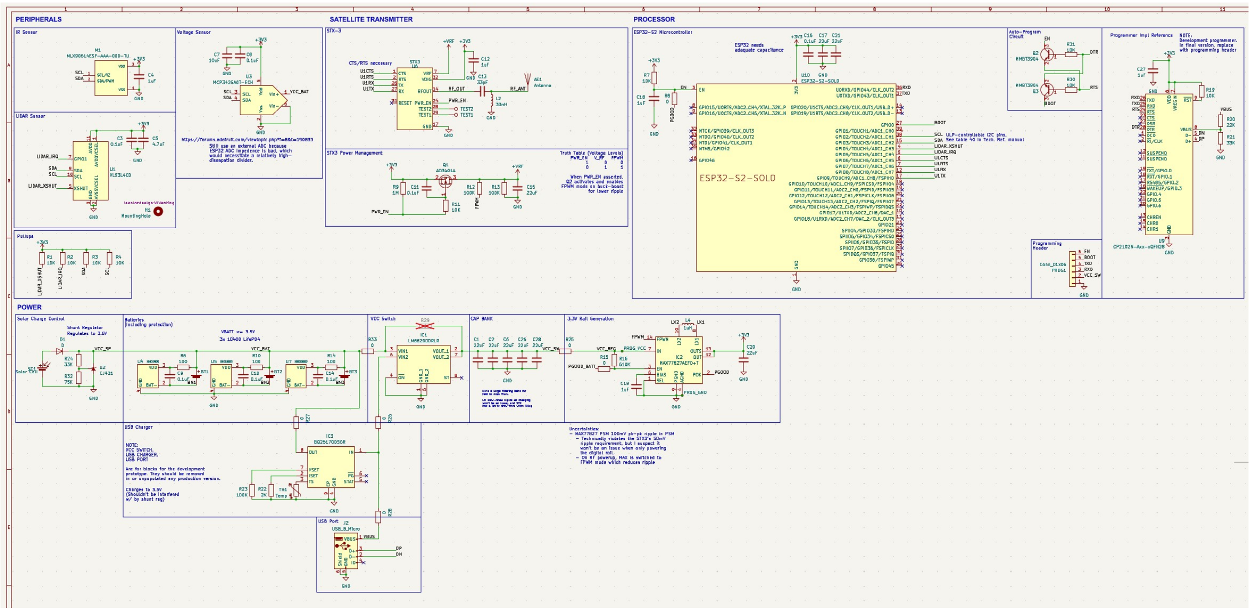
Table B.2. Detailed engineering specifications for sensor design.

Spec. #	Parameter Description	Target	Tolerance	Risk	Compliance	Spec. Validation Method
1	Active power	2 W	Max	M	I	Discharge Test
2	Rechargeable Battery	1.4 Wh	Min	L	S, T	Charge test
3	Permissible TX Power	1 W	Max	H	S, A	RF power meter
4	Regular Updates	1 tx/wk	Min	L	A	DC power measurement + analysis
5	Memory/Storage	256 kB	Min	L	S, A	H2testw capacity test
6	Frequency of Data Measurements	10 Hz	Min	L	T	Read selected sensors at full speed
7	Flow Rate Estimation	L/s	+/- 30%	L	S, A, T	On-pump test
8	Lifespan	1 year	Min	L	A	DC power measurement + analysis

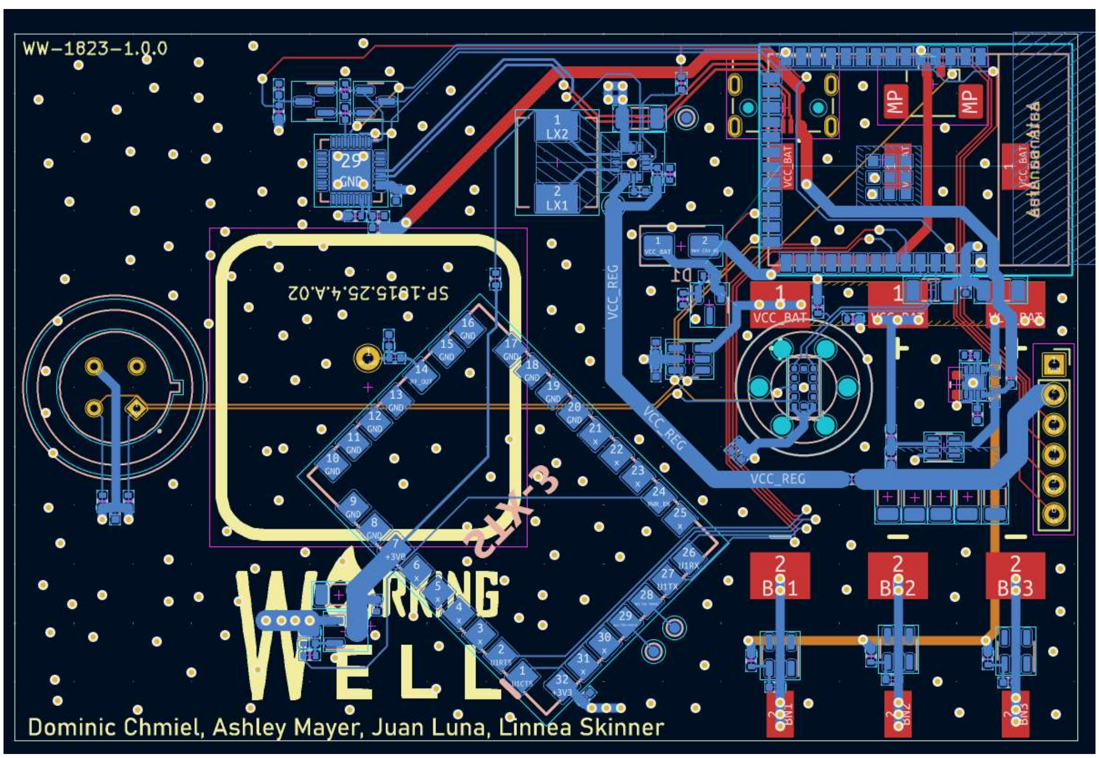
Appendix C Final Drawings (schematics, software diagrams, code, part drawings)

Note: Full-resolution PDFs, together with the source EDA can be found in the documentation package under the Electrical folder.

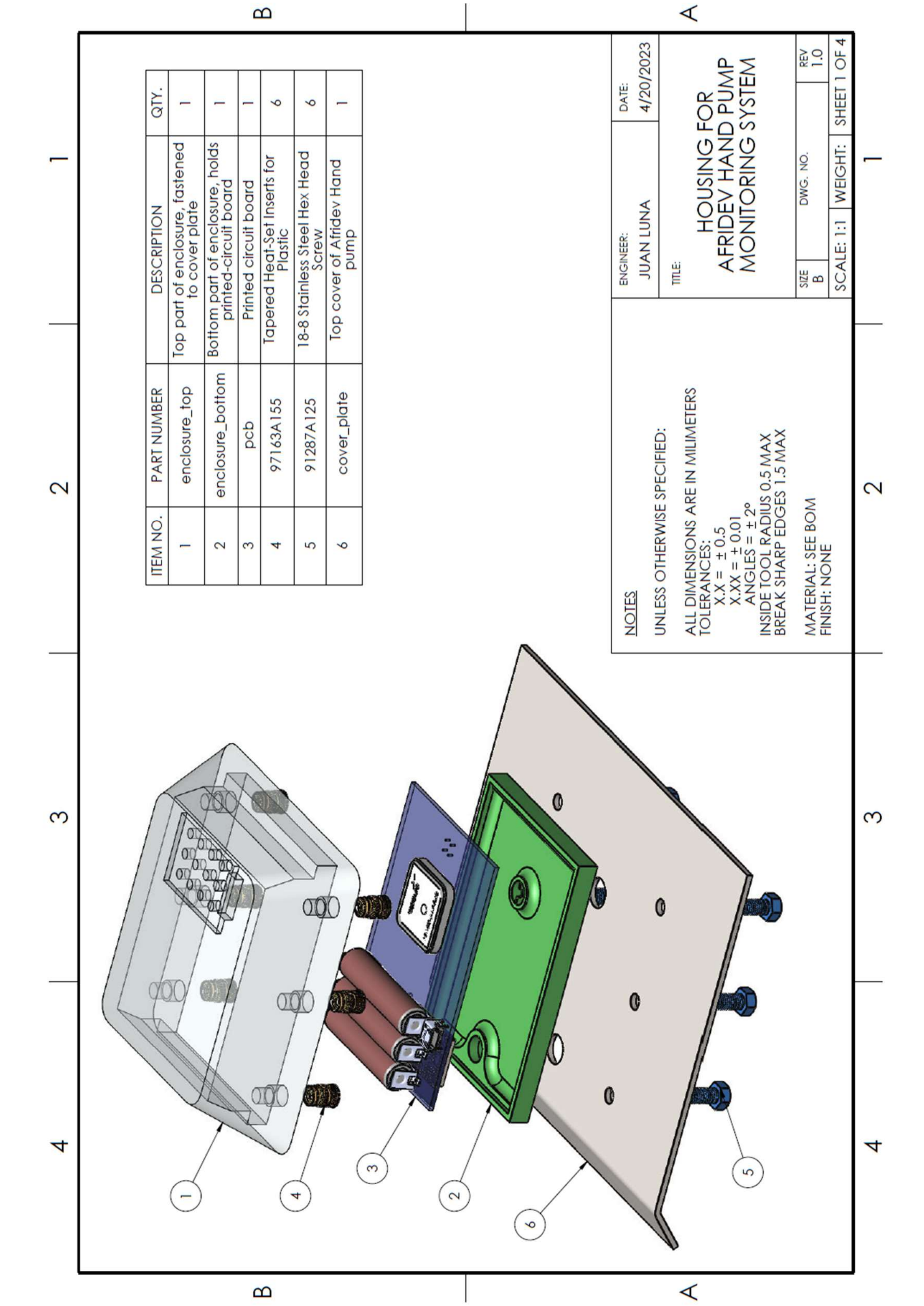
Schematic



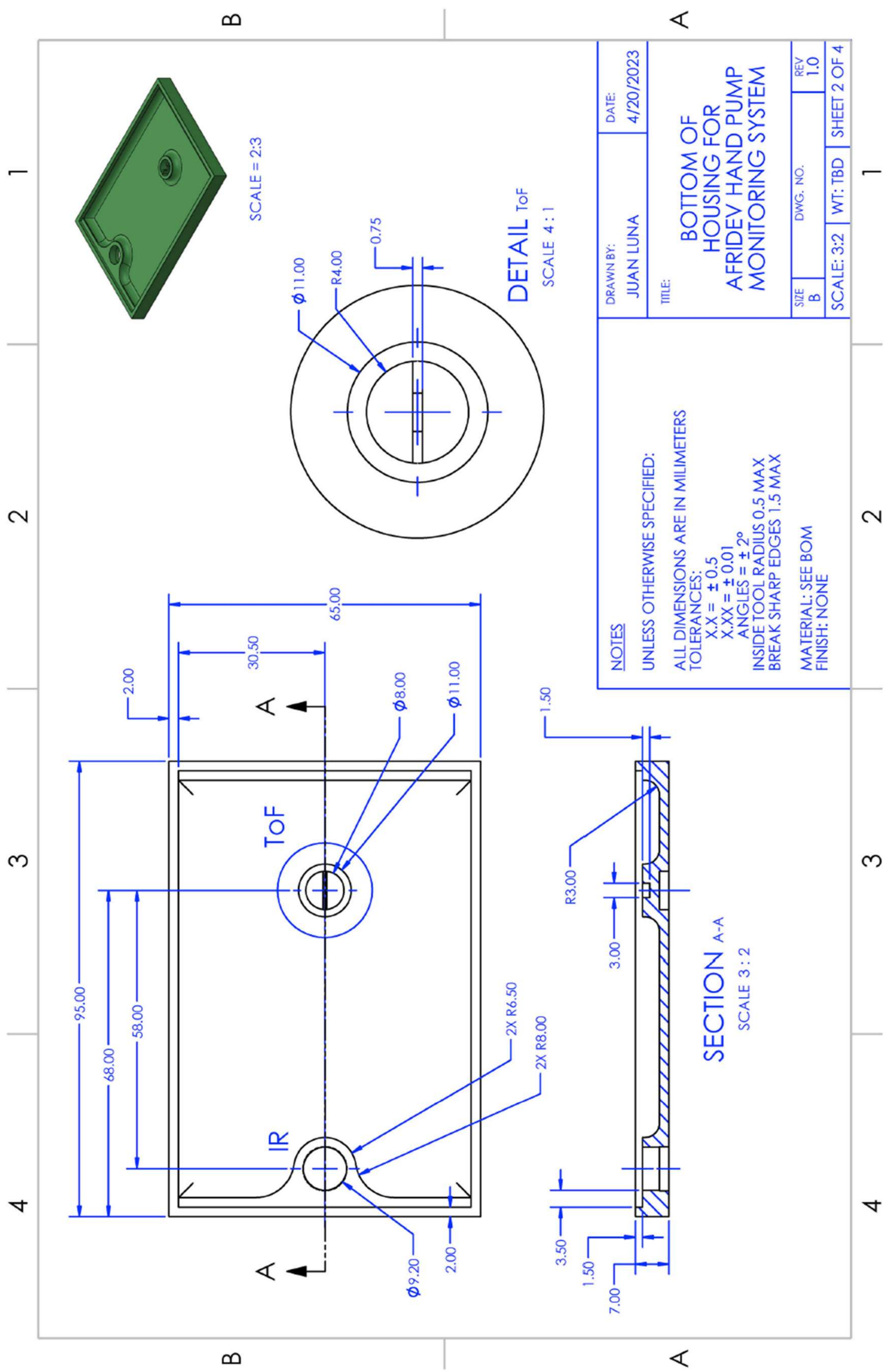
Board Layout

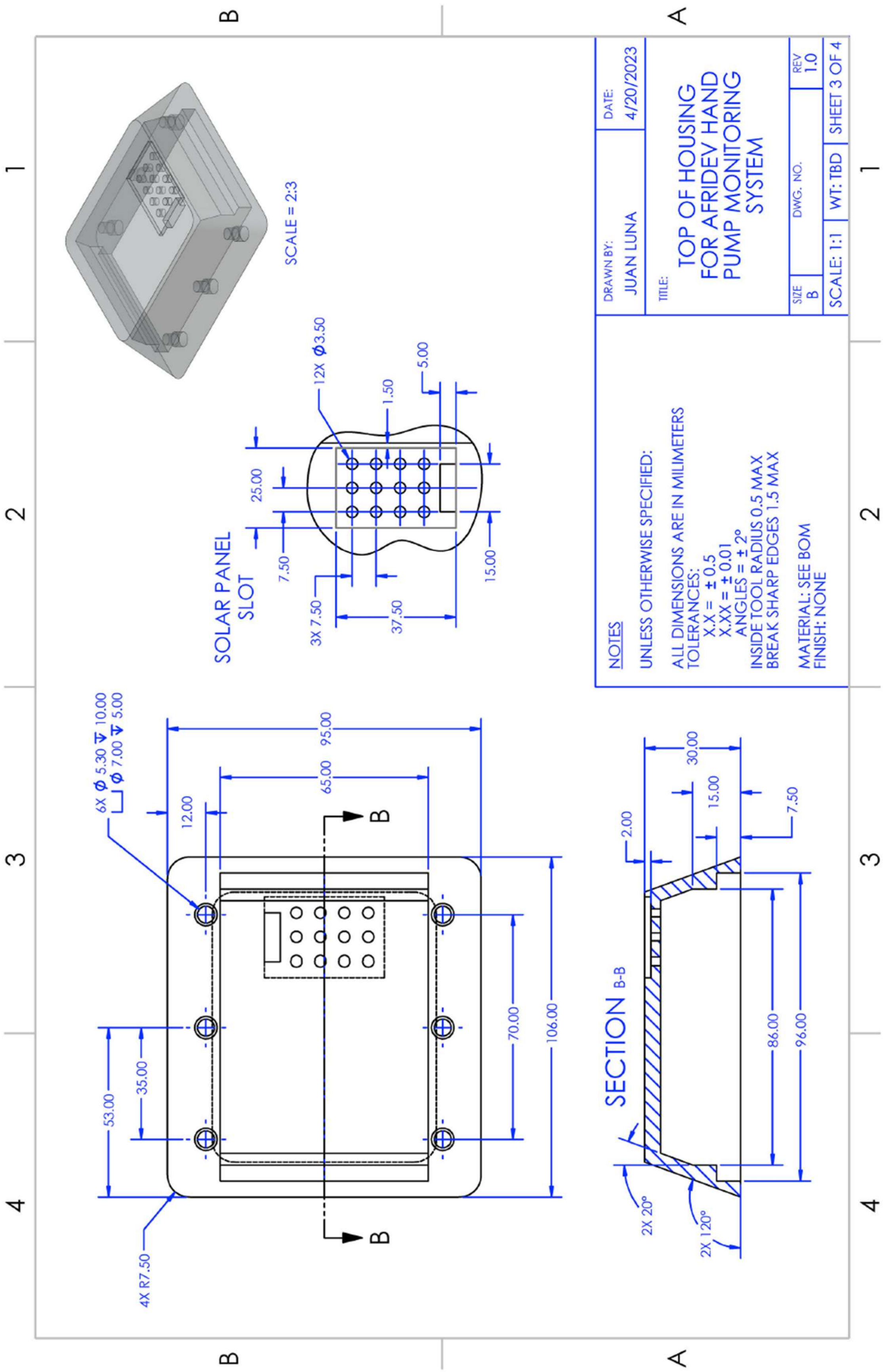


Enclosure Drawings

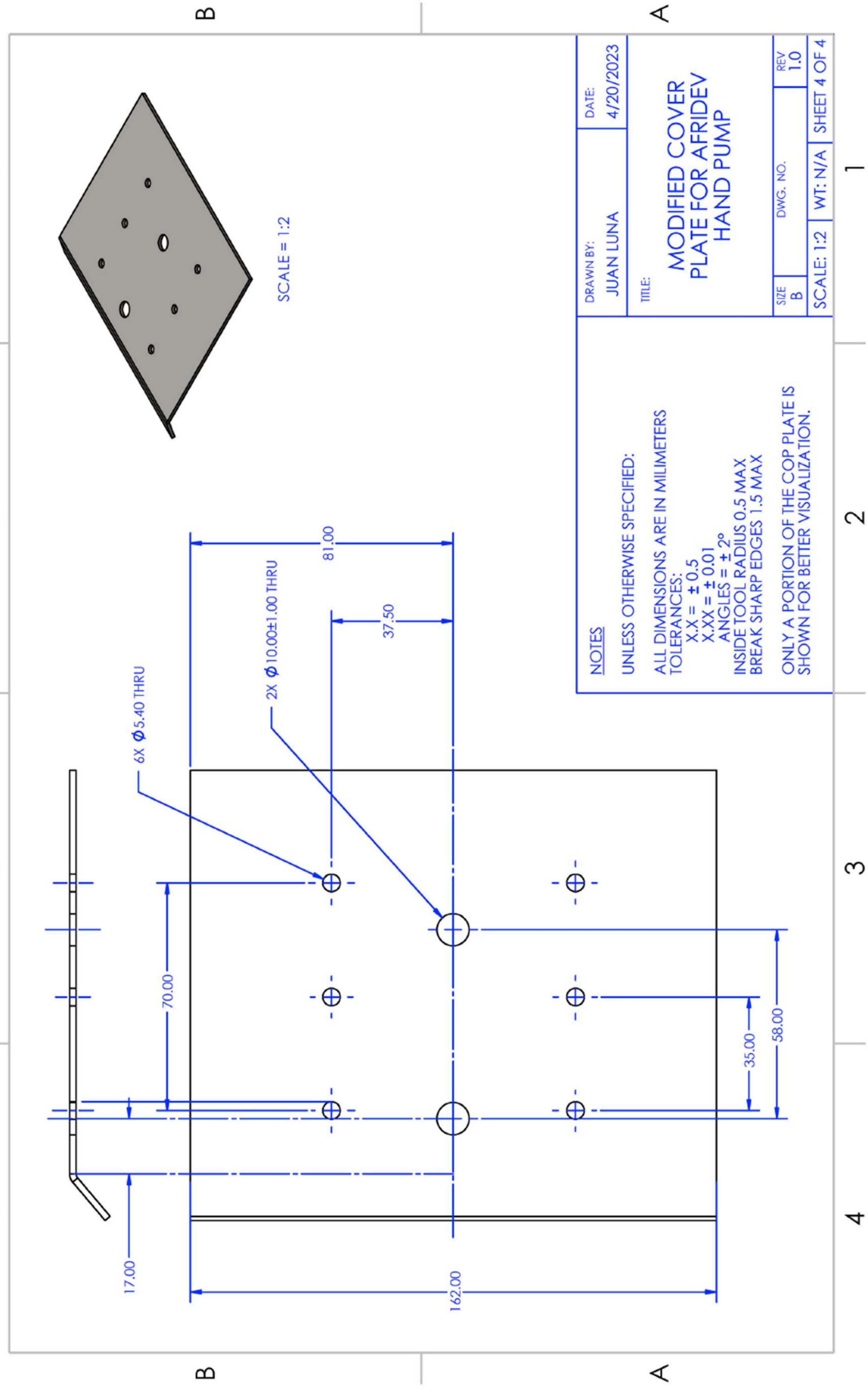


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	enclosure_top	Top part of enclosure, fastened to cover plate	1
2	enclosure_bottom	Bottom part of enclosure, holds printed-circuit board	1
3	pcb	Printed circuit board	1
4	97163A155	Tapered Heat-Set Inserts for Plastic	6
5	91287A125	18-8 Stainless Steel Hex Head Screw	6
6	cover_plate	Top cover of Afridev Hand pump	1


DRAWN BY: JUAN LUNA
DATE: 4/20/2023
TITLE: BOTTOM OF HOUSING FOR AFRIDEV HAND PUMP MONITORING SYSTEM
SIZE B
DWG. NO.
REV 1.0
SCALE: 3:2
WT: TBD
SHEET 2 OF 4
NOTES
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE IN MILIMETERS
TOLERANCES:
X.X = ± 0.5
X.XX = ± 0.01
ANGLES = ± 2°
INSIDE TOOL RADIUS 0.5 MAX
BREAK SHARP EDGES 1.5 MAX
MATERIAL: SEE BOM
FINISH: NONE
DETAIL ToF
SCALE 4 : 1
SECTION A-A
SCALE 3 : 2
SCALE = 2:3
ToF
IR
Ø11.00
R4.00
0.75
Ø8.00
Ø9.20
2X R6.50
2X R8.00
95.00
68.00
58.00
65.00
30.50
2.00
1.50
R3.00
3.00
3.50
7.00



SCALE = 2:3
SOLAR PANEL SLOT
12X Ø3.50
SECTION B-B
NOTES
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE IN MILIMETERS
TOLERANCES:
X.X = ± 0.5
X.XX = ± 0.01
ANGLES = ± 2°
INSIDE TOOL RADIUS 0.5 MAX
BREAK SHARP EDGES 1.5 MAX
MATERIAL: SEE BOM
FINISH: NONE
DRAWN BY: JUAN LUNA
DATE: 4/20/2023
TITLE: TOP OF HOUSING FOR AFRIDEV HAND PUMP MONITORING SYSTEM
SIZE B
DWG. NO.
REV 1.0
SCALE: 1:1
WT: TBD
SHEET 3 OF 4


SCALE = 1:2
6X Ø5.40 THRU
2X Ø10.00±1.00 THRU
81.00
37.50
70.00
17.00
162.00
35.00
58.00
NOTES
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS ARE IN MILIMETERS
TOLERANCES:
X.X = ± 0.5
X.XX = ± 0.01
ANGLES = ± 2°
INSIDE TOOL RADIUS 0.5 MAX
BREAK SHARP EDGES 1.5 MAX
ONLY A PORTION OF THE COP PLATE IS SHOWN FOR BETTER VISUALIZATION.
DRAWN BY:
JUAN LUNA
DATE:
4/20/2023
TITLE:
MODIFIED COVER PLATE FOR AFRIDEV HAND PUMP
SIZE
B
DWG. NO.
REV
1.0
SCALE: 1:2
WT: N/A
SHEET 4 OF 4

Appendix D Bill of Materials

Part	**Description**	**Unit Cost**	**Qty.**	**Supplier**
LoRa Transceiver + Microcontroller	RFM95W LoRa RF FEATHER PLATFORM EVALUATION EXPANSION BOARD	$34.95	2	DigiKey
*TOF Sensor	STEMMAQT VL53L4CX TIME OF FLIGHT SENSOR	$14.95	2	DigiKey
*IR Temp Sensor	SENSOR DGTL -40C-85C TO39	$22.48	2	DigiKey
Breadboard	HALF-SIZE BREADBOARD WITH MOUNTING PLATE	$5.00	2	DigiKey
Jumper Wires	JUMPER WIRE M TO M	$4.70	1	DigiKey
	Shipping + Tax	$19.05	1	
	Order 1 Total =	**$178.51**		
MPPT Solar Charger	Sunny Buddy (Part #12885)	$28.95	1	Spark Fun
	Shipping + Tax	$13.65	1	Spark Fun
Evaluation Board	MAX32660 DARWIN ARM® Cortex®-M4F MCU 32-Bit Embedded Evaluation Board	$20.91	1	DigiKey
Solar Cell	Monocrystalline Solar Cell 245 mW 8.29 V	$8.59	1	DigiKey
Batteries	18650 Lithium Iron Phosphate Battery Rechargeable (Secondary)	$22.99	1	DigiKey
	Shipping + Tax	$20.79	1	DigiKey
	Order 2 Total =	**$115.88**		
*Satellite Modem	STX3 Satellite Modem from Global Star	$60.00	1	GlobalStar
	Shipping + Tax	$15.69		
	Order 3 Total =	**$75.69**		
TOF Sensor Breadboard	1568-SEN-18993-ND	$19.95	2	DigiKey

IR Temp Sensor	SENSOR DGTL -40C-85C TO39	$20.79	2	DigiKey
Solar Cell	Monocrystalline Solar Cell 245 mW 8.29 V	$8.59	1	DigiKey
*MCU	ESP32-S2	$8.00	2	DigiKey
	Shipping + Tax	$16.40	1	DigiKey
	Shipping + Tax	$12.92	1	Spark Fun
	Order 4 Total =	**$135.39**		
*Solar Cells	2994-SM101K07L-ND	$6.22	2	DigiKey
*Electronic Components	Misc. Electronic Components to solder to PCB	$82.52	N/A	Mouser
*PCBs	Custom Perforated Bread Boards	$49.65	N/A	JLCPCB
	Order Total =	**$144.61**		
Single Prototype Cost = $162.67 **Total Project Budget Spent = $650.08**				

Appendix E List of vendors and contact information

Supplier	**Phone Number**
ANYSOLAR LTD.	+82-31-205-2550
Texas Instruments	+1-855-226-3113
Globalstar	+1-844-381-1589
Melexis Technologies	+1-408-313-9461
Adafruit	+*1-646-248-7822*
DigiKey	+1-800-344-4539
Sparkfun	support@sparkfun.com
Mouser	+1-800-346-6873
JLCPCB	+86 755 2391 9769

Appendix F Vendor supplied component specifications and data sheets

life.augmented

VL53L4CX

Datasheet

Time-of-Flight sensor with extended range measurement

Product status link
VL53L4CX

Features

Fast, accurate distance ranging

- Histogram based technology
- Distance measurement from 0 mm up to 6 m
- Short distance linearity down to 10 mm
- Major improvement in long distance-ranging performance across all targets and light levels
- Field of view (FoV) of 18°
- Multiobject detection capability
- Targets beyond 80 cm range are immune to crosstalk from cover glass, and smudge

VL53L4CX is a fully integrated miniature module

- Emitter: 940 nm invisible laser (VCSEL) and its analog driver
- Low-power microcontroller running advanced digital firmware
- Size: 4.4 x 2.4 x 1 mm
- Pin-to-pin compatible with VL53L0X, VL53L1X, VL53L1CB, VL53L3CX, and VL53L4CD

Easy integration

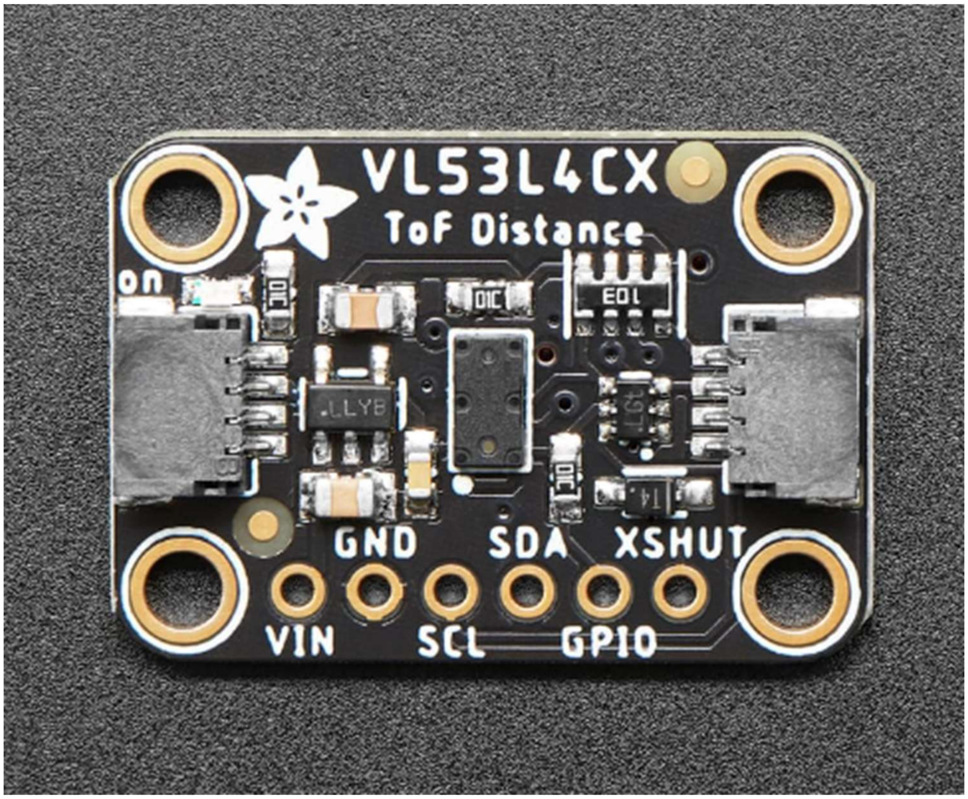
- Reflowable component
- Live crosstalk correction
- Part-to-part or generic shape crosstalk calibration available
- Single power supply 2v8
- Can be hidden behind cover glass
- I^2C interface (up to 1 MHz)
- Full set of software drivers (Linux compatible) for turnkey ranging
- Drivers are compatible with VL53L3CX ones

Applications

- Obstacle avoidance, cliff detection for robotics, service robots, and vacuum cleaners
- User presence detection for sanitary and smart lighting
- System activation for smart building and access control devices
- Content management for smart bins and logistics
- User and object detection for IoT devices
- Light curtain for industrial applications
- Landing assist and collision avoidance for indoor drones

DS13805 - Rev 4 - November 2022
For further information contact your local STMicroelectronics sales office. www.st.com

VL53L4CX ToF Sensor Breakout Board



MLX90614 family

Datasheet Single and Dual Zone

Infra Red Thermometer in TO-39

Features and Benefits

- Small size, low cost
- Easy to integrate
- Factory calibrated in wide temperature range:
  -40°C…+125˚C for sensor temperature and
  -70°C…+380˚C for object temperature.
- High accuracy of 0.5°C in a wide temperature range (0°C…+50°C for both Ta and To)
- High (medical) accuracy calibration
- Measurement resolution of 0.02°C
- Single and dual zone versions
- SMBus compatible digital interface
- Customizable PWM output for continuous reading
- Available in 3V and 5V versions
- Simple adaptation for 8V…16V applications
- Sleep mode for reduced power consumption
- Different package options for applications and measurements versatility
- Automotive grade

Application Examples

- High precision non-contact temperature measurements
- Thermal Comfort sensor for Mobile Air Conditioning control system
- Temperature sensing element for residential, commercial and industrial building air conditioning
- Windshield defogging
- Automotive blind angle detection
- Industrial temperature control of moving parts
- Temperature control in printers and copiers
- Home appliances with temperature control
- Healthcare
- Livestock monitoring
- Movement detection
- Multiple zone temperature control – up to 127 sensors can be read via common 2 wires
- Thermal relay / alert
- Body temperature measurement

Ordering Information

Part No.	Temperature Code	Package Code	- Option Code	Standard part	Packing form
MLX90614	E (-40°C...85°C) K (-40°C…125°C)	SF (TO-39)	- X X X (1) (2) (3)	-000	-TU

(1) Supply Voltage/ Accuracy
A - 5V
B - 3V
C - Reserved
D - 3V medical accuracy

(2) Number of thermopiles:
A – single zone
B – dual zone
C – gradient compensated*

(3) Package options:
A – Standard package
B – Reserved
C – 35° FOV
D/E – Reserved
F – 10° FOV
G – Reserved
H – 12° FOV (refractive lens)
I – 5° FOV
K – 13°FOV

Example:
MLX90614ESF-BAA-000-TU *** : See page 2**

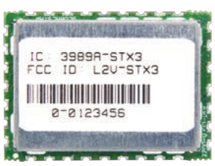
REVISION 13 - 13 SEPTEMBER, 2019

3901090614

STX3

Satellite modem

Globalstar



Globalstar offers the **STX3** Satellite Transmitter Unit to help customers design and build compact and efficient communications devices. Using the Globalstar Satellite Network, the STX3 allows information to be transmitted from areas well beyond the reach of reliable cellular coverage around the globe.

The STX3 provides additional opportunities to integrate satellite connectivity into products used for vehicle and asset tracking, remote data reporting and data logger reporting that have limited size requirements. Affordable pricing, low power consumption and its small size make the STX3 satellite transmitter a highly efficient device ready for integration in a wide variety of applications.

The STX3 is a low cost, OEM module which sends one-way data messages via the Globalstar Satellite Network when integrated into a tracking or monitoring device. The STX3 is ideal for delivering remote sensing, tracking and monitoring applications.

Advantages and Features

- Increases reliability through multiple transmissions
- Global coverage
- Low power consumption
- Surface mount design
- Versatile use: Module can be integrated for use in a wide range of applications including liquid petroleum gas (LPG) tanks, water tanks, pipelines, electricity, meters, cars, trucks, boats and sea or land containers

Technical Specifications

dimensions

- 1130 mils x 810 mils (28.70mm x 20.57mm) Overall thickness of the board with components/shields is 163 mils (4.13 mm)

weight

- 0.14 oz. (3.97 g)

ANYSOLAR TOTAL SOLAR SYSTEM **Preliminary** **SM101K07L**

IXOLAR™ High Efficiency SolarMD.

Description

IXOLAR™ SolarMD is an ANYSOLAR product line of Solar Module made of monocrystalline, high efficiency solar cells. The IXOLAR™ SolarMD is an ideal for charging various battery powered and handheld consumer products such as mobile phones, cameras, PDAs, MP3-Players and toys. They are also suitable for industrial applications such as wireless sensors, portable instrumentation and for charging emergency backup batteries.

With a cell efficiency of typically 25%, SolarMD gives the ability to extend run time even in "low light" conditions and increase battery life and run time in a small footprint, which can be easily accommodated in the design of portable products. The design allows connecting SolarMD flexibly in series and/or parallel to perfectly meet the custom-specific application's power requirements.

IXOLAR™ products have a very good photonic response over a wide range of wavelength and therefore can be used in both indoor and outdoor applications.

Product and Ordering Information

Part Number	Open Circuit Voltage [V]	Short Circuit Current [mA]	Typ. Voltage @ P_{mpp} [V]	Typ. Current @ P_{mpp} [mA]
SM101K07L	4.84	41.9	3.91	39.3

(Parameters given are typical values)
Dimensions (W x L x H): 22 x 35 x 1.8 ± 0.3 [mm]
SolarMD Weight: 2.6 grams
Storage Temperature: -40°C ~ +90°C
Operation Temperature: -40°C ~ +90°C
SolarMD are compliant to the RoHS Norm.

SolarMD Electrical Characteristics

Symbol	Cell Parameter	Typical Ratings *)	Units
V_{OC}	open circuit voltage	4.84	V
I_{SC}	short circuit current	41.9	mA
V_{mpp}	voltage at max. power point	3.91	V
I_{mpp}	current at max. power point	39.3	mA
P_{mpp}	maximum peak power	154	mW
FF	fill factor	> 70	%
η	solar cell efficiency	25	%
$\Delta V_{OC}/\Delta T$	open circuit voltage temp. coefficient	-12.2	mV/K
$\Delta I_{SC}/\Delta T$	max power temp. coefficient	18.9	uA /K

*) All values measured at Standard Condition: 1 sun (= 1000 W/m²), Air Mass 1.5, 25°C

Features

- Monocrystalline silicon technology
- High efficiency outdoor and indoor
- Long life and stable output
- Sealed Package
- High mechanical robustness

Applications

- Battery chargers for portables such as cell phones, PDAs, GPS-Systems, …
- "Green" electricity generation
- Power backup for UPS, Sensors, Wearables

Advantages

- One Product for Multiple Applications
- Flexible Integration into the Application

ANYSOLAR reserves the right to change limits, test conditions and dimensions

ANYSOLAR LTD.
U-Tower B#161, 120 Heungdeokjungang-ro,
Giheung-gu, Yongin-si, Gyeonggi-Do, Republic of Korea [16950]
Phone +82-31-205-2550, Fax +82-31-205-2550

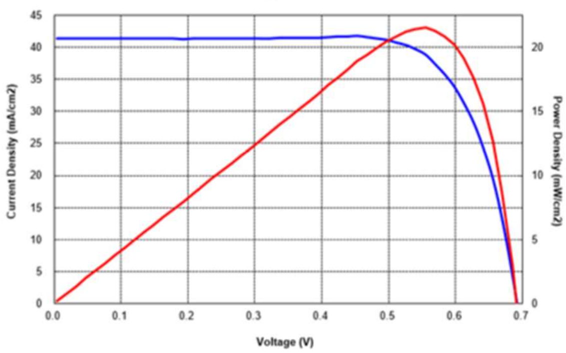
Rev. July 2020

http://www.anysolar.biz

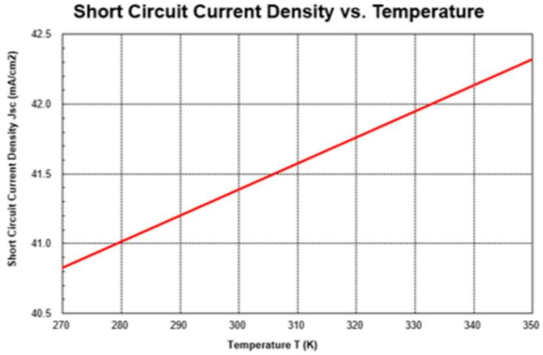
ANYSOLAR TOTAL SOLAR SYSTEM **Preliminary** **SM101K07L**

Typical SolarMD Performance Data

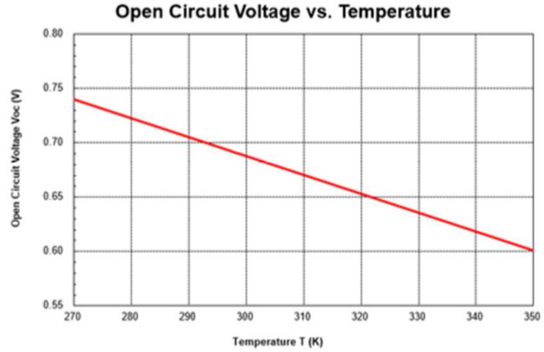
Current-Voltage Characteristics



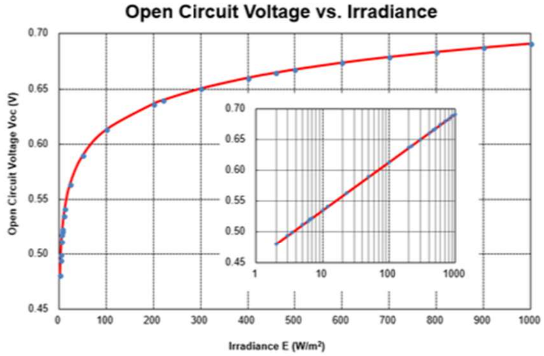
Short Circuit Current Density vs. Temperature



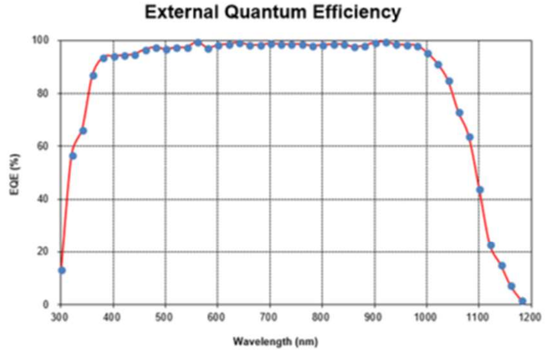
Open Circuit Voltage vs. Temperature



Open Circuit Voltage vs. Irradiance



External Quantum Efficiency



ANYSOLAR reserves the right to change limits, test conditions and dimensions

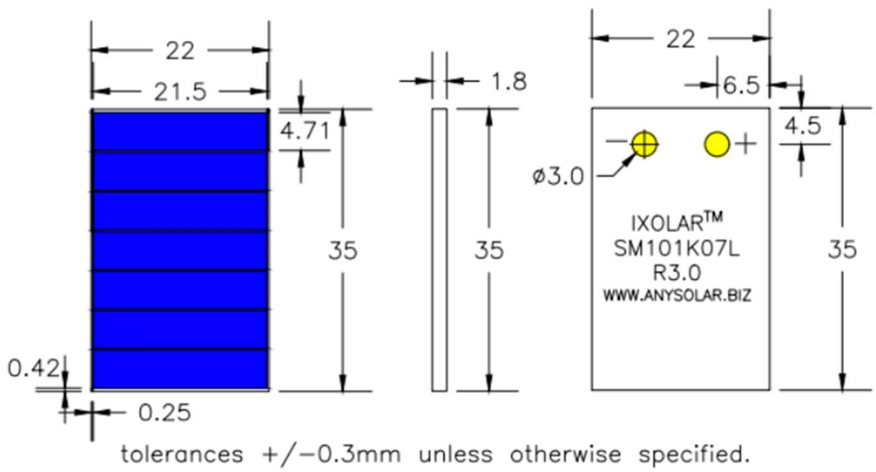
ANYSOLAR LTD.
U-Tower B#161, 120 Heungdeokjungang-ro,
Giheung-gu, Yongin-si, Gyeonggi-Do, Republic of Korea [16950]
Phone +82-31-205-2550, Fax +82-31-205-2550

2

Rev. July 2020 http://www.anysolar.biz

ANYSOLAR TOTAL SOLAR SYSTEM | **Preliminary** | **SM101K07L**

Package front-side and back-side view. (dimensions in millimeters)



Front-side View details **Back-side View details**

Moisture Sensitivity, Reflow Soldering and Washing Information

ANYSOLAR has characterized the moisture reflow sensitivity of the film laminated SolarMD. Moisture uptake from atmospheric humidity occurs by diffusion. During the soldering process to the electrode, the combination of moisture uptake and high temperature soldering may lead to moisture induced delamination and cracking of the component. To avoid this, this component must be handled with care when soldering. The film laminated SolarMD is not recommended for high temperature surface mount soldering reflow. SolarMD is encapsulated with EVA and polymer film by the lamination and thus excessively high temperatures soldering reflow is prohibited.

Instead, manual soldering is recommended for 2 sec below 260°C. Delamination or blistering may sometimes be seen during manual soldering, then the part has most likely already absorbed moisture. In this case, prebaking is recommended in a dry oven at 140°C for 1 hour to avoid potential blistering or delamination. ANYSOLAR does not recommend the use of chlorine-based solvents for washing.

★IF YOU HAVE ANY DIFFICULTIES WITH SOLDERING, PLEASE CONTACT US AT THE EMAIL;

techdevelop@anysolar.biz

ANYSOLAR LTD.
U-Tower B#161, 120 Heungdeokjungang-ro,
Giheung-gu, Yongin-si, Gyeonggi-Do, Republic of Korea [16950]
Phone +82-31-205-2550, Fax +82-31-205-2550

ESP32-S2 Series

Datasheet

SoC with Xtensa® Single-Core 32-bit LX7 Microprocessor

Supporting IEEE 802.11b/g/n (2.4 GHz Wi-Fi)

Including:

- ESP32-S2
- ESP32-S2FH2
- ESP32-S2FH4
- ESP32-S2FN4R2
- ESP32-S2R2

Version 1.5
Espressif Systems

www.espressif.com

Product Overview

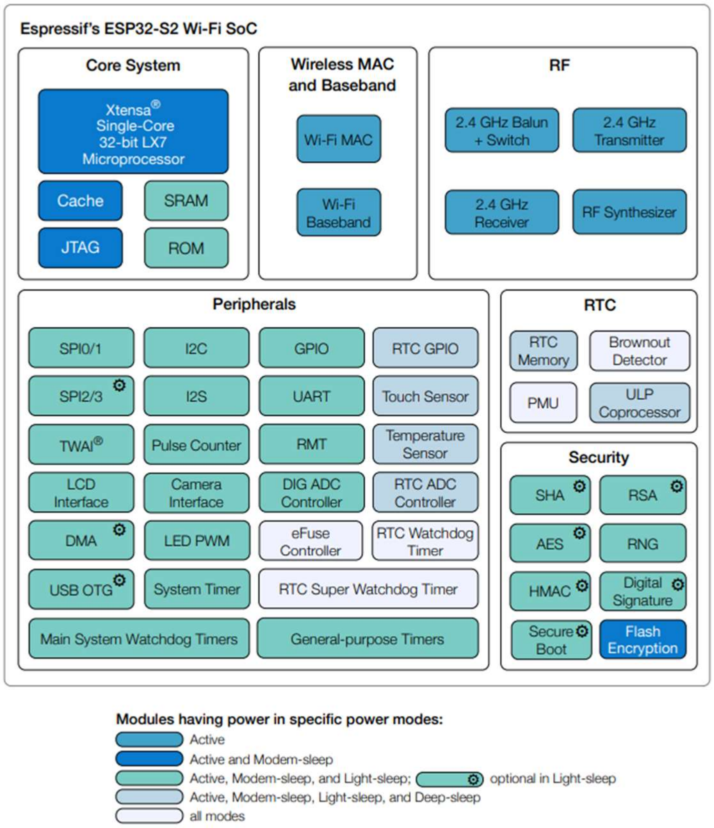


Figure 1: Block Diagram of ESP32-S2

ESP32-S2 series of SoC is a highly-integrated, low-power, 2.4 GHz Wi-Fi System-on-Chip (SoC) solution. With its state-of-the-art power and RF performance, this SoC is an ideal choice for a wide variety of application scenarios relating to Internet of Things (IoT), wearable electronics and smart home.

ESP32-S2 series of SoC includes a Wi-Fi subsystem that integrates a Wi-Fi MAC, Wi-Fi radio and baseband, RF switch, RF balun, power amplifier, low noise amplifier (LNA), etc. The chip is fully compliant with the IEEE 802.11b/g/n protocol and offers a complete Wi-Fi solution.

At the core of this chip is an Xtensa® 32-bit LX7 CPU that operates at up to 240 MHz. The chip supports application development, without the need for a host MCU.

The on-chip memory includes 320 KB SRAM and 128 KB ROM. It also supports multiple external SPI/QSPI/OSPI flash and external RAM chips for more memory space.

ESP32-S2 series of SoC is designed for ultra-low-power applications with its multiple low-power modes. The ULP coprocessor can operate in ultra-low-power mode. The chip's featured fine-grained clock gating, dynamic voltage and frequency scaling, and adjustable power amplifier output power, contribute to an optimal trade-off between communication range, data rate and power consumption.

The device provides a rich set of peripheral interfaces including SPI, I2S, UART, I2C, LED_PWM, LCD interface, camera interface, ADC, DAC, touch sensor, temperature sensor, as well as 43 GPIOs. It also includes a full-speed USB On-The-Go (OTG) interface to enable USB communication.

ESP32-S2 series of SoC has several dedicated hardware security features. Cryptographic accelerators are integrated for AES, SHA and RSA algorithms. Additional hardware security features are provided by the RNG, HMAC and Digital Signature modules as well as flash encryption and secure boot signature verification features. These features allow the device to meet stringent security requirements.

Features

Wi-Fi

- IEEE 802.11 b/g/n-compliant
- Supports 20 MHz, 40 MHz bandwidth in 2.4 GHz band
- Single-band 1T1R mode with data rate up to 150 Mbps
- WMM
- TX/RX A-MPDU, RX A-MSDU
- Immediate Block ACK
- Fragmentation and defragmentation
- Automatic Beacon monitoring (hardware TSF)
- 4 × virtual Wi-Fi interfaces
- Simultaneous support for Infrastructure Station, SoftAP, and Promiscuous modes
  Note that when ESP32-S2 is in Station mode and performs a scan, the SoftAP channel will change along with the Station channel.
- Antenna diversity
- 802.11mc FTM

CPU and Memory

- Xtensa® single-core 32-bit LX7 microprocessor, up to 240 MHz
- CoreMark® score:
  - 1 core at 240 MHz: 472.73 CoreMark; 1.97 CoreMark/MHz
- 128 KB ROM
- 320 KB SRAM
- 16 KB SRAM in RTC
- Embedded flash and PSRAM (see details in Chapter 1: *ESP32-S2 Series Comparison*)
- SPI/QSPI/OSPI supports multiple flash and external RAM chips
- Access to flash accelerated by cache
- Supports flash in-Circuit Programming (ICP)

Advanced Peripheral Interfaces

- 43 × programmable GPIOs
- Digital interfaces:
  - 4 × SPI
  - 1 × I2S
  - 2 × I2C
  - 2 × UART
  - 1 × RMT (TX/RX)
  - LED PWM controller, up to 8 channels
  - 4 × pulse counters
  - 1 × full-speed USB OTG
  - 1 × DVP 8/16 camera interface, implemented using the hardware resources of I2S
  - 1 × LCD interface (8-bit serial RGB/8080/6800), implemented using the hardware resources of SPI2
  - 1 × LCD interface (8/16/24-bit parallel), implemented using the hardware resources

of I2S
  - DMA controller
  - 1 × TWAI® controller compatible with ISO 11898-1 (CAN Specification 2.0)
- Analog interfaces:
  - 2 × 13-bit SAR ADCs, up to 20 channels
  - 2 × 8-bit DACs
  - 14 × touch sensing GPIOs
  - 1 × temperature sensor
- Timers:
  - 1 × 64-bit general-purpose timer
  - 1 × 64-bit system timer
  - 3 × watchdog timers
  - 1 × super watchdog timer
  - 1 × XTAL32K watchdog timer

Security

- Secure boot
- Flash encryption
- 4096-bit OTP, up to 1792 bits for users
- Cryptographic hardware acceleration:
  - AES-128/192/256 (FIPS PUB 197)
  - Hash (FIPS PUB 180-4)
  - RSA
  - Random Number Generator (RNG)
  - HMAC
  - Digital signature

Applications (A Non-exhaustive List)

- Generic Low-power IoT Sensor Hubs
- Generic Low-power IoT Data Loggers
- Cameras for Video Streaming
- Over-the-top (OTT) Devices
- USB Devices
- Speech Recognition
- Image Recognition
- Mesh Networks
- Home Automation
  - Light control
  - Smart plugs
  - Smart door locks
- Smart Buildings
  - Smart lighting
  - Energy monitoring
- Industrial Automation
  - Industrial wireless control
  - Industrial robotics
- Smart Agriculture
  - Smart greenhouses
  - Smart irrigation
  - Agriculture robotics
- Audio Applications
  - Internet music players
  - Live streaming devices
  - Internet radio players
  - Audio headsets
- Health Care Applications
  - Health monitoring
  - Baby monitors
- Wi-Fi-enabled Toys
  - Remote control toys
  - Proximity sensing toys
  - Educational toys
- Wearable Electronics
  - Smart watches
  - Smart bracelets
- Retail & Catering Applications

EVALUATION KIT AVAILABLE

Click here to ask about the production status of specific part numbers.

MAX77827

5.5V Input, 1.8A/3.1A Switch Buck-Boost Converter with 6μA I_Q

General Description

The MAX77827 is a high-efficiency buck-boost regulator targeted for one-cell Li-ion powered applications with the lowest typical quiescent current in the industry of 6μA. It supports input voltages of 1.8V to 5.5V and an output voltage range of 2.3V to 5.3V. The IC provides two different switching current levels (1.8A and 3.1A) to optimize external component sizing based on given load current requirements. With the 1.8A switching current-limit option, the IC can support up to 1.0A load current in buck mode and 900mA in boost mode (V_{IN} = 3.0V, V_{OUT} = 3.3V).

The peak efficiency of 96% makes the IC one of the best solutions as a DC/DC converter to supply a rail for battery-powered portable applications.

The IC features an adjustable output voltage, which can be programmed from 2.3V to 5.3V through a single resistor. Two GPIO pins are available to support force PWM enable function and power-OK (POK) indicator. A unique control algorithm allows high-efficiency, outstanding line/load transient response, and seamless transition between buck and boost modes. These options provide design flexibility that allow the IC to cover a wide range of applications and use cases while minimizing board space.

The MAX77827 is available in a 1.61mm x 2.01mm, 12-bump wafer-level package (WLP), and a 2.5mm x 2.5mm, 14-lead FC2QFN package.

Applications

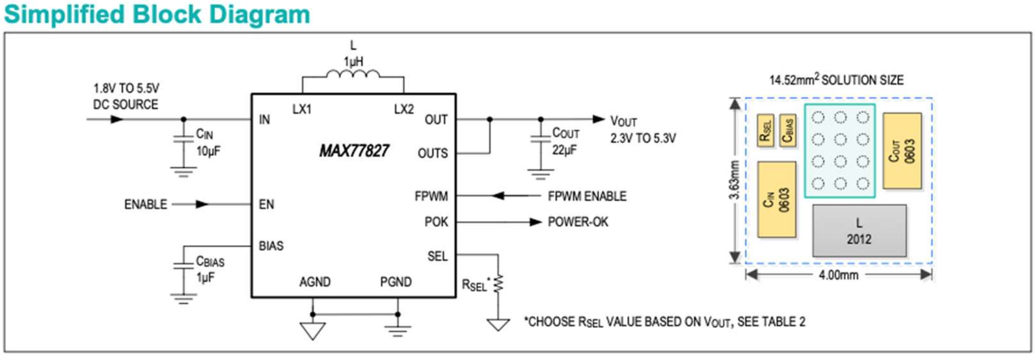
- 1-Cell Li+ Battery Powered Equipment
- Smartphones/Portable/Wearables
- Internet of Things (IoT) Devices
- LPWAN (LTE/NB-IoT, LTE/Cat-M1)

Benefits and Features

- 1.8V to 5.5V Input Voltage Range
- 2.3V to 5.3V Single Resistor Adjustable Output Voltage
- 1.6A Maximum Output Current (3.1A I_{LIM} Option, Buck Mode)
- 900mA Maximum Output Current (1.8A I_{LIM} Option, Boost Mode 3.0V_{IN}, 3.3V_{OUT})
- 96% Peak Efficiency (3.3V_{IN}, 3.3V_{OUT})
- SKIP Mode for Higher Light-Load Efficiency
- 6μA Ultra-Low Typical Quiescent Current (At T_J = +25°C)
- 2.5MHz Nominal Switching Frequency
- Enable Pin
- GPIO Pins for System Design Convenience
  - FPWM (Forced PWM) Mode Selection Pin
  - POK Indicator Pin
- UVLO, Soft-Start, Active-Output Discharge, Overcurrent, and Thermal Shutdown Protections
- 1.61mm x 2.01mm, 12-Bump WLP
- 2.5mm x 2.5mm, 14-Lead FC2QFN

Ordering Information appears at end of data sheet.

Simplified Block Diagram



19-100546; Rev 5; 8/21

maxim integrated

MICROCHIP

MCP3425

16-Bit Analog-to-Digital Converter with I²C Interface and On-Board Reference

Features

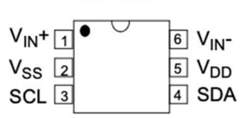
- 16-bit ΔΣ ADC in a SOT-23-6 package
- Differential Input Operation
- Self Calibration of Internal Offset and Gain per each conversion
- On-Board Voltage Reference:
  - Accuracy: 2.048V ± 0.05%
- On-Board Programmable Gain Amplifier (PGA):
  - Gains of 1, 2, 4 or 8
- On-Board Oscillator
- INL: 10 ppm of FSR (FSR = 4.096V/PGA)
- Programmable Data Rate Options:
  - 15 SPS (16 bits)
  - 60 SPS (14 bits)
  - 240 SPS (12 bits)
- One-Shot or Continuous Conversion Options
- Low Current Consumption:
  - 145 µA typical (V_{DD}= 3V, Continuous Conversion)
- One-Shot Conversion (1 SPS) with V_{DD} = 3V:
  - 9.7 µA typical with 16 bit mode
  - 2.4 µA typical with 14 bit mode
  - 0.6 µA typical with 12 bit mode
- Supports I²C Serial Interface:
  - Standard, Fast and High-Speed Modes
- Single Supply Operation: 2.7V to 5.5V
- Extended Temperature Range: -40°C to 125°C

Typical Applications

- Portable Instrumentation
- Weigh Scales and Fuel Gauges
- Temperature Sensing with RTD, Thermistor, and Thermocouple
- Bridge Sensing for Pressure, Strain, and Force.

Package Types

SOT-23-6 MCP3425



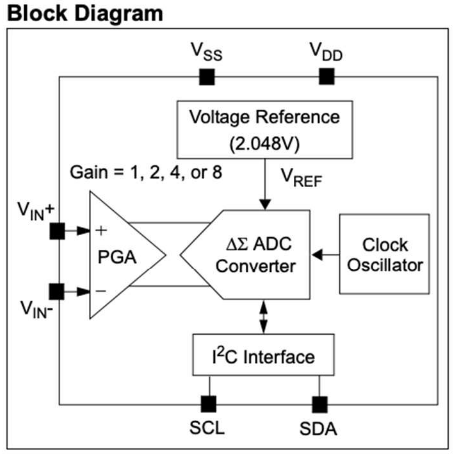
Description

The MCP3425 is a single channel low-noise, high accuracy ΔΣ A/D converter with differential inputs and up to 16 bits of resolution in a small SOT-23-6 package. The on-board precision 2.048V reference voltage enables an input range of ±2.048V differentially (Δ voltage = 4.096V). The device uses a two-wire I²C compatible serial interface and operates from a single 2.7V to 5.5V power supply.

The MCP3425 device performs conversion at rates of 15, 60, or 240 samples per second (SPS) depending on the user controllable configuration bit settings using the two-wire I²C serial interface. This device has an on-board programmable gain amplifier (PGA). The user can select the PGA gain of x1, x2, x4, or x8 before the analog-to-digital conversion takes place. This allows the MCP3425 device to convert a smaller input signal with high resolution. The device has two conversion modes: (a) Continuous mode and (b) One-Shot mode. In One-Shot mode, the device enters a low current standby mode automatically after one conversion. This reduces current consumption greatly during idle periods.

The MCP3425 device can be used for various high accuracy analog-to-digital data conversion applications where design simplicity, low power, and small footprint are major considerations.

Block Diagram



XB8358D0 Datasheet

One Cell Lithium-ion/Polymer Battery Protection

Xysemi **XB8358D0**

One Cell Lithium-ion/Polymer Battery Protection IC

GENERAL DESCRIPTION

The XB8358D0 product is a high integration solution for lithium-ion/polymer battery protection. XB8358D0 contains advanced power MOSFET, high-accuracy voltage detection circuits and delay circuits. XB8358D0 is put into an ultra-small SOT23-5 package and only one external component makes it an ideal solution in limited space of battery pack. XB8358D0 has all the protection functions required in the battery application including overcharging, overdischarging, overcurrent and load short circuiting protection etc. The accurate overcharging detection voltage ensures safe and full utilization charging. The low standby current drains little current from the cell while in storage.
The device is not only targeted for digital cellular phones, but also for any other Li-Ion and Li-Poly battery-powered information appliances requiring long-term battery life.

FEATURES

- Protection of Charger Reverse Connection
- Protection of Battery Cell Reverse Connection
- Integrate Advanced Power MOSFET with Equivalent of 45mΩ $R_{SS(ON)}$
- Ultra-small SOT23-5 Package
- Only One External Capacitor Required
- Over-temperature Protection
- Overcharge Current Protection
- Three-step Overcurrent Detection:
  - -Overdischarge Current 1
  - -Overdischarge Current 2
  - -Load Short Circuiting
- Charger Detection Function
- 0V Battery Charging Function
- Delay Times are generated inside
- High-accuracy Voltage Detection
- Low Current Consumption
  - Operation Mode: 2.8μ A typ.
  - Power-down Mode: 1.5μ A typ.
- RoHS Compliant and Lead (Pb) Free

APPLICATIONS

One-Cell Lithium-ion Battery Pack
Lithium-Polymer Battery Pack

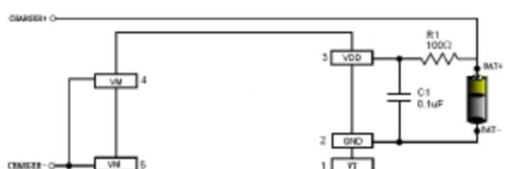


Figure 1. Typical Application Circuit

XySemi Inc - 1 - www.xysemi.com
REV0.3

XB8358D0 Datasheet

One Cell Lithium-ion/Polymer Battery Protection

Xysemi **XB8358D0**

ORDERING INFORMATION

PART NUMBER	Pack age	Overcharg e Detection Voltage [V_{CU}] (V)	Overcharge Release Voltage [V_{CL}] (V)	Overdischarge Detection Voltage [V_{DL}] (V)	Overdischarge Release Voltage [V_{DR}] (V)	Overcurrent Detection Current [I_{OV1}] (A)	Top Mark
XB8358D0	SOT 23-5	4.250	4.10	2.90	3.0	3.2	8358DYW(note)

Note: "YW" is manufacture date code, "Y" means the year, "W" means the week

PIN CONFIGURATION

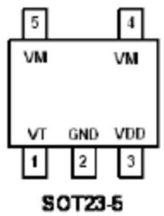


Figure 2. PIN Configuration

PIN DESCRIPTION

XB8358D0 PIN NUMBER	PIN NAME	PIN DESCRIPTION
1	V T	Test pin ; only for vendor not used by application
2	GND	Ground, connect the negative terminal of the battery to this pin
3	VDD	Power Supply
4,5	VM	The negative terminal of the battery pack. The internal FET switch connects this terminal to GND

ABSOLUTE MAXIMUM RATINGS

(Note: Do not exceed these limits to prevent damage to the device. Exposure to absolute maximum rating conditions for long periods may affect device reliability.)

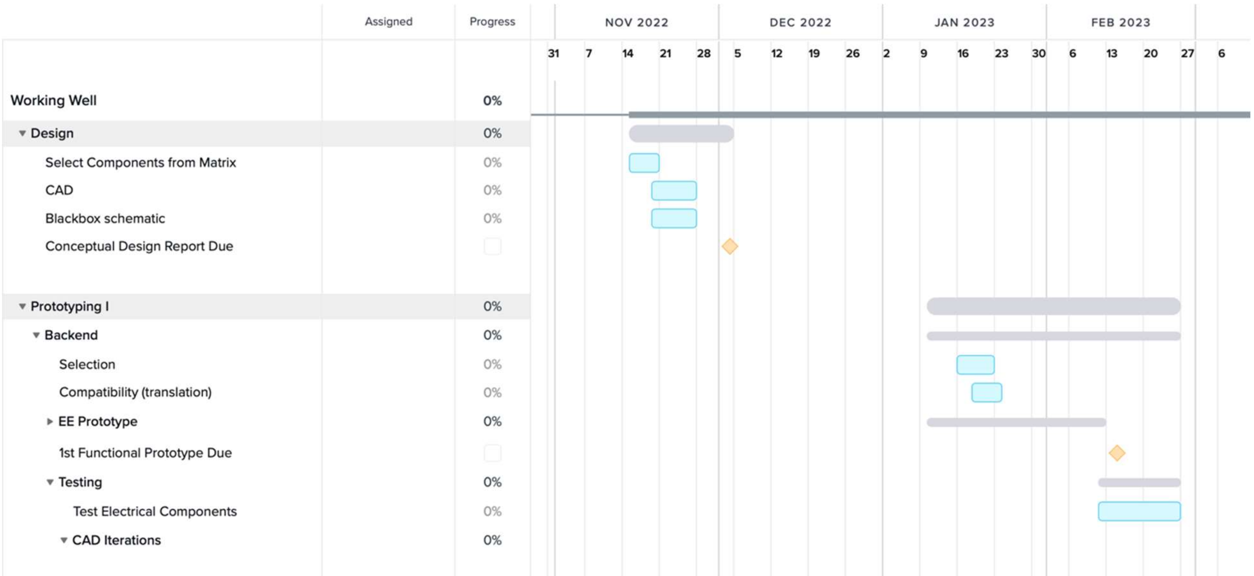
PARAMETER	VALUE	UNIT
VDD input pin voltage	-0.3 to 6	V
VM input pin voltage	-6 to 10	V
Operating Ambient Temperature	-40 to 85	°C

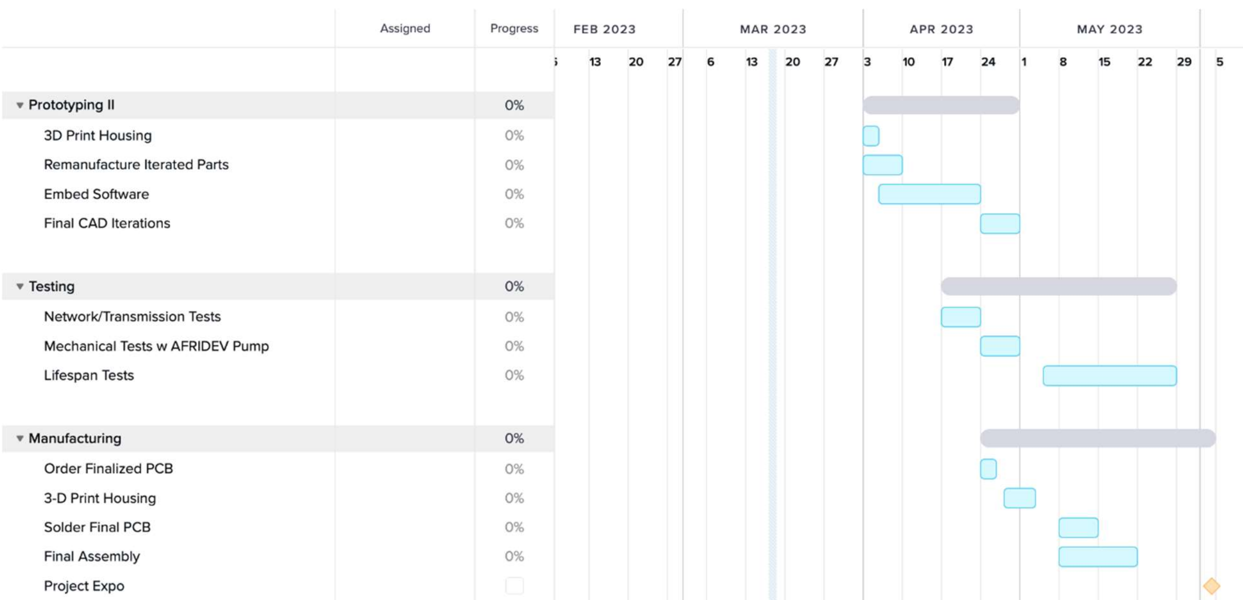
XB8358D

XySemi Inc - 2 - www.xysemi.com

REV0.3

Appendix G Gantt Chart





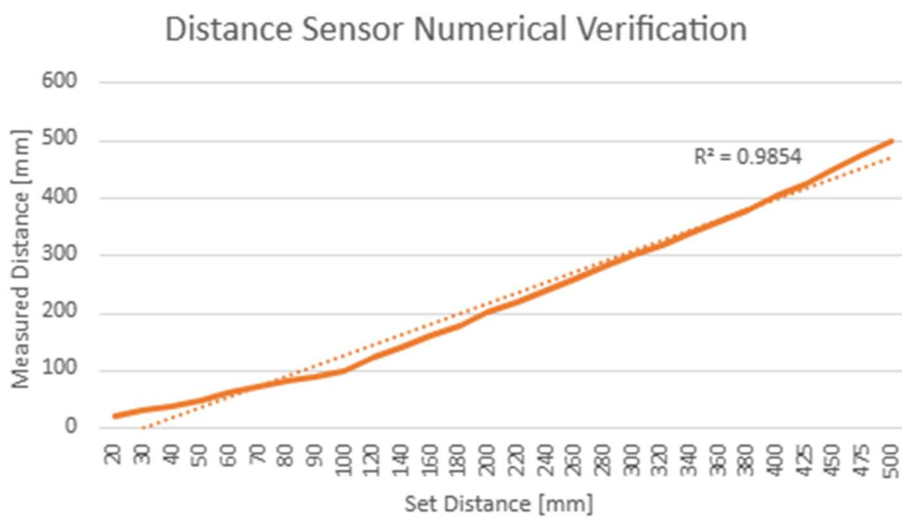
Appendix H: Safety Check List

SENIOR PROJECT CRITICAL DESIGN REVIEW HAZARD IDENTIFICATION CHECKLIST

Y	N	
	x	Do any parts of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points adequately guarded?
	x	Does any part of the design undergo high accelerations/decelerations that are exposed to the user?
	x	Does the system have any large moving masses or large forces that can contact the user?
	x	Does the system produce a projectile?
	x	Can the system fall under gravity creating injury?
	x	Is the user exposed to overhanging weights as part of the design?
	x	Does the system have any sharp edges exposed?
	x	Are there any ungrounded electrical systems in the design?
	x	Are there any large capacity batteries or electrical voltage in the system above 40 V either AC or DC?
x		Is there any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids when the system is either on or off?
	x	Is there any explosive or flammable liquids, gases, dust, or fuel part of the system?
	x	Is the user of the design required to exert any abnormal effort and/or assume an abnormal physical posture during the use of the design?
	x	Are there any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	x	Will the system generate high levels of noise?

	x	Will the product be subjected to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc. that could create an unsafe condition?
	x	Is it easy to use the system unsafely?
	x	Are there any other potential hazards not listed above? If yes, please explain on the back of this checklist?

Appendix I: Verification Testing Results



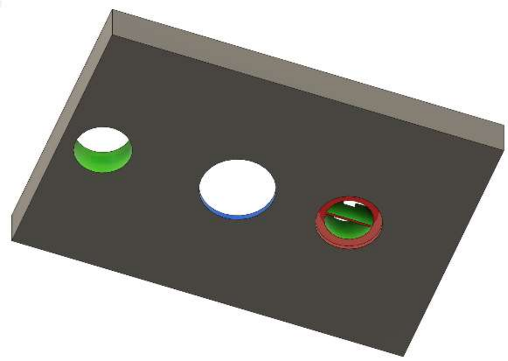
Object	Object Temp (°F)	Ambient Temp (°F)	Temp Change (°F)
No Object	70.26	70.26	0
Human Forehead	97.5	70.26	37.24
Soda Can (chilled)	48.92	70.27	-21.35
Ice water	32.06	70.26	-38.20
Tap Water	62.43	70.26	-7.83

Appendix J: User Assembly Guide

Acquiring Components

The PCB and both enclosure halves should first be manufactured. The exact methodology for the obtainment of each is at the discretion of CLEAN. For our purposes, the PCB was manufactured by JLCPCB, and the enclosure was 3d printed.

Preparing The Lower Enclosure



1. a circular transparent window should be epoxied in the circular recess below the LIDAR sensor (Red, in the image to the left). This is designed to protect the LIDAR from moisture.

2. a small amount of putty should be placed around the top of each sensor hole, to prevent epoxy from intruding onto the sensors. More putty should be used around the edges of the PCB to prevent epoxy leakage.

3. The PCB should be placed into its recess, with each sensor pointing out the proper hole. Make sure to press down, allowing the putty to spread and seal.

4. Pot the lower enclosure by filling the cavity with epoxy through the fill hole (Blue). Let cure according to its instructions.

5. Once cured, install batteries, and ensure powerup.

Preparing the Upper Enclosure

1. Solder wires to the solar panel. If needed, crimp the corresponding JST-SH connector to them.

2. Place the panel in its recess in the top enclosure. Route the wires through the large hole. Seal around the edges of the panel using tape.

3.Carefully pour epoxy onto the panel from the other side into its recess (Green) and allow curing. Make sure the panel wires are out of the way, so they don't cure into the epoxy.

Bringing it All Together

2. With the top enclosure solar-panel-down, lower the bottom enclosure into it, plugging in the solar panel as you do so. Route the panel wires in-between the tops of the batteries, such that they're not pinched. Make sure the lower enclosure sits flush in the upper enclosure.

3. Place a thin bead of epoxy or silicone sealant on the seam between the two enclosures and wait for cure.