EE494: Senior Capstone Group Design Project

Spring 2020

Final Design Review:

Energy Harvesting System for a Water Meter

Xylem — 2

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Preface

We collectively that attest Engineers: Siddhant Khera, Serena LaFave and Krystal Bakr are the owners of this report and produced all parts of the initial design review presented. We further confirm that the works presented in this document are fully Ours and were completed between January 2020 and May 2020. All material used from external sources is referenced appropriately.

Document Scope

This document serves as a record, documentation, and a proof our work. The main purpose of this document is to record and define the work in ongoing in the Senior Design Project during the Spring 2020 semester in EE494. This document covers basis behind the design choices, the final status of the project and the next steps going forward. It includes an in-depth discussion of our analysis and provides an overview of the work that has gone into meeting the requirements.

Intended Audience

The expected and intended audience for this report is the EE494 session Teaching Assistants, Dr. Jennifer Zirnheld, Peter Casey of Xylem, and the authors of the report. Future students in EE494 at University at Buffalo, to whom the material be relevant, as well as authorized recipients within Xylem are invited to view the document but should keep confidentiality and copyright etiquette in mind when doing so.

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1 Executive Summary

Xylem requests a designed hardware solution to harvest energy for a water meter which will be located in Yuma, Arizona. This must be done in a cost-efficient and energy efficient matter. The design we are recommending meets the technical requirements given by Xylem. This design we are proposing will be able to harvest energy for the water meter, and will be easily reproducible in high-volume production.

The recommended design includes the use of a solar panel as the energy source. With the longevity, lack of constant maintenance, and low cost of solar panels, this was the preferred method of sourcing energy for the harvester. The input voltage of the solar panel will be stepped-up, and will be used to charge a 3.7V Lithium-Ion battery, which will power the water meter load.

The cost of this design will be just under $3, which includes the cost of all components, PCB assembly and production, as well as the enclosure which will store our circuit. Each component we chose can be bought in bulk order of 1000 units or more, which allows for our circuit and design to be reproduced in high-volume.

Safety factors were considered in our design. With the high temperatures that are anticipated given the location of the water meter, the proposed circuit includes protections that will protect the components from experiencing any damage. In addition, with the Lithium-Ion battery we will be using, we wanted to especially protect it from over charging. Throughout our design we have taken precautions that should preserve the circuit and maintain the longevity and efficiency of the water meter.

2 Introduction

Over the last 15 weeks, our team has worked towards the completion of our Xylem Energy Harvester project. The goal of the project was to create a prototype for an energy harvester for an off-grid water meter in Yuma, Arizona. The output requirement is 3.7V DC, with a peak load of 5mW. There must be enough energy storage to maintain the water meter for 14 days without energy harvesting. The total size of the harvesting system must be $100mm \times 60mm \times 60mm$ or less. The module must be able to withstand a temperature range of -40^{o}C to 85^{o}C. Lastly, in high volume production (5 million units), the module must cost under $3. [5]

Within this report, we will be discussing our initial goals for the project and how those goals shifted as the weeks went by. We intend on displaying the steps we took from the beginning of our project to the end, and lastly, showcasing the final design. We will also discuss the implications of our design, catalog our time spent on the project, and considerations for the future. The sections will continue as follows: Problem Definitions, Conceptual Model, Design Description, Results, Ethics, Project Management, Conclusions, Recommendations for Future Work, References, and Appendices. In the following sections, we will be describing our progress and how we have been working to fulfill the expectations presented by Xylem.

3 Problem Description

Water meters are used to measure the flow of water. Generally, they require to be placed in between the path of the water so that they can measure the rate of flow of water (usually measured in Gallons Per Minute). Newer designs of water meters do not require cutting the pipe for installation [6], and use ultrasonic technology to measure the rate of flow of water [7] when placed in the path of the water. All these applications require a constant energy source. The water meter design in use for this project will be in an open-air environment and will be installed at Yuma, Arizona [5] While water-meters are essential devices, it is not viable to power them across large fields.

The overall purpose of the project is to design a hardware solution that will harvest energy to power a water meter. We are allowed to consider different energy sources such as solar, thermoelectric, and hydroelectric. This water meter in particular will be located in Yuma, Arizona. The specific constraints laid out by Xylem are:

- **Energy Harvester Enclosure**
  - Maximum: $100mm \times 60mm \times 60mm$ (L x W x H)
- **Energy Generation/Sourcing**
  - 3.7Vdc
  - Average output power: 1mW
  - Peak output power: 5mW
- **Operating Temperature**
  - -40°C to 85°C
- **Energy Storage**
  - 14 days minimum
- **Prototype Bill of Materials Cost**
  - $150
- **Manufactured Cost**
  - < $3 in high volume production (more than 5M units)

After the Interim Design Review, Xylem challenged us to only implement one of the four charge controller chips we discussed in the Interim Design review, namely MCP73831, TP4056, CN3083, or CN3791. Other constraints added were using an NTC Thermistor for temperature sensing and adding a circuit between the solar panel and the charging circuit to compensate for the minimum V_{CC} of the charging chip. These new requirements were also taken into consideration in the final design.

Another important note is that after moving to distance learning, the prototype expectations changed from physical to digital. Thus, no produced physical module is presented in this report.

4 Assumptions

The following simplifying assumptions were made in this design:

- The water meter operates at peak power of 5mW for 14 days when calculating the required battery size.
- A sunny day at the location has at least 8 hours of direct sun.

5 Conceptual Model

5.1 Initial Conceptual Model

To begin our initial design plan, we started with the conceptual diagram in Fig. 1 and 2. It consisted of a solar panel, a charge controller, and a battery connected to the load.

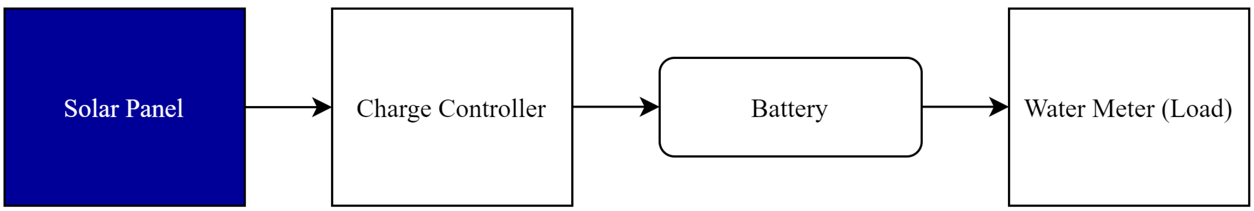

Figure 1: Conceptual Model Representing the Initial System

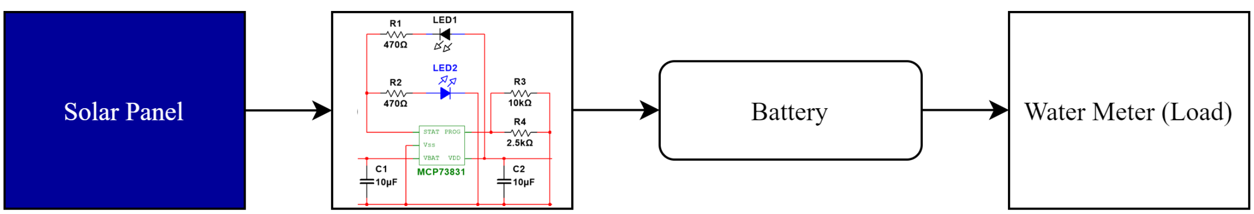

Figure 2: Charge Controller Overlaid with an Actual Circuit Design of Current Prototype (Full Image of Overlaid Circuit is Visible in Fig. 30)

5.2 Final Conceptual Model

The final conceptual model is shown below in Fig. 3 and 4. Additions include a DC/DC boost converter, temperature sensor, and battery protections. The module is now shown enclosed in a box to differentiate it from the load.

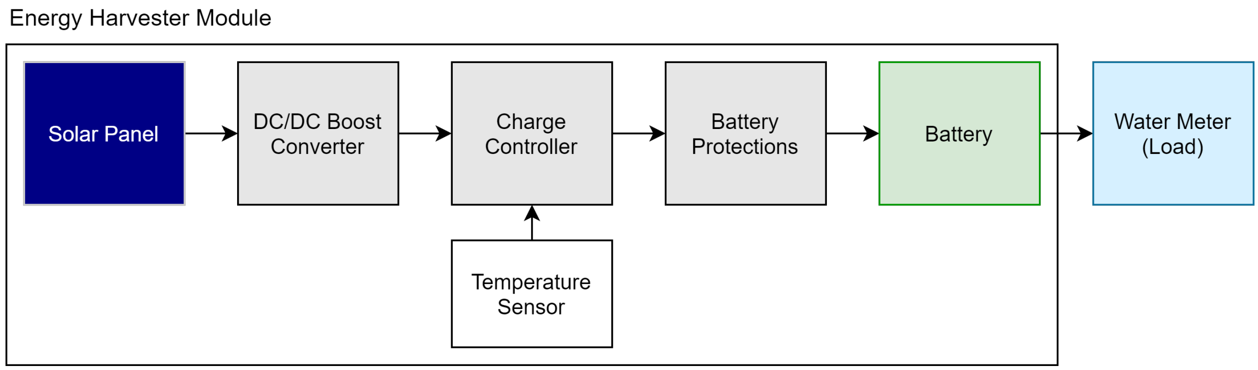

Figure 3: Conceptual Model Representing the Initial System

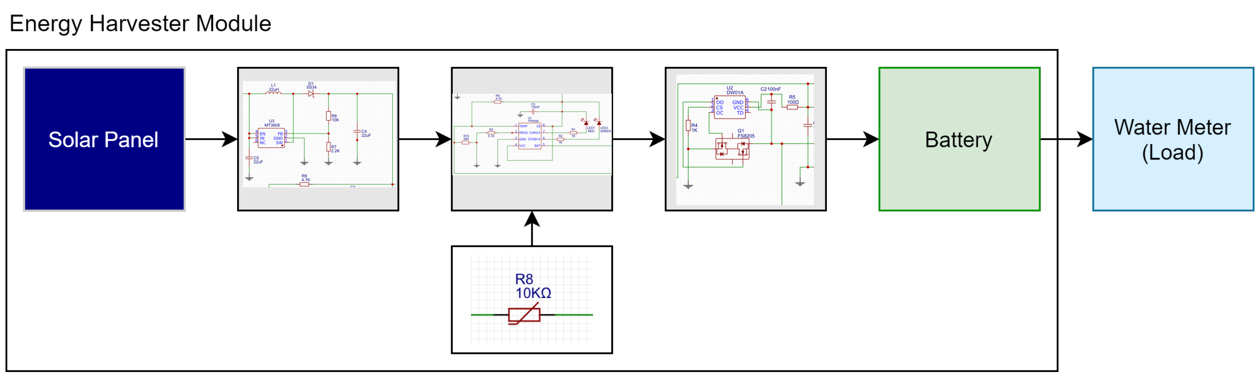

Figure 4: Charge Controller Overlaid with an Actual Circuit Design of Current Prototype (Full Image of Overlaid Circuit is Visible in Fig. 24)

5.3 Rationale for Changes to the Conceptual Model

5.3.1 DC/DC Boost Converter Stage

As explained in Section 6.6 we changed the charge controller chip from MCP73831 to TP4056. The latter required a higher minimum input voltage than the solar panel's average output [1,8].

Because Xylem challenged us to use the same solar panel as the Interim Design Review, the boost converter was necessary to boost the solar panel voltage. This way, the charge controller could be properly powered over a wide range of irradiance levels. Please see Section 6.7 for more information on the DC/DC boost converter.

5.3.2 NTC Thermistor: Temperature Control

Changing the charge controller chip to TP4056 allowed for a new feature - the ability to control charging based on a temperature sensor's readings [1]. The prior charge controller chip was able to stop charging the battery when temperatures were too high; however, we were concerned about low temperature charging. By connecting a temperature sensor to the TP4056, we were able to include these low temperature protections. Please see Section 6.6.5 for more detail.

5.3.3 Battery Protection

We felt that the TP4056 charge controller did not include enough important battery protections. Thus, we added DW01, a Li-ion battery protection IC. This chip includes overcharge, overdischarge, and overcurrent protections [9]. Please see Section 6.8 for more information.

6 Design Description

6.1 Metrics for Consideration

A project can affect the surrounding world in many ways. In this section, we discuss economic, environmental, sustainability, Manufacturability, ethical, health and safety, social, and political impacts our design could have. The following metrics were consistently measured:

- **Economic:** Is our design cost-efficient on a large scale (i.e., less than \$3 as per Xylem's requirement)?
  - Yes, we have guaranteed it with our BOM, available in Appendix B.
- **Environmental:** How does our design impact the environment?
  - Our design uses many materials, including many plastics such as the enclosure and the IC chip packages. These materials, as is true in all manufacturing, must be extracted from the natural environment, processed, transported, and later disposed of. These actions consume energy, release carbon dioxide, create non-biodegradable waste, and can threaten ecosystems. In this sense, our module has negative effects.
  - There are also positives of our design; firstly, by harvesting renewable energy, fossil fuels consumption is avoided. Secondly, the ABS plastic enclosure and the lithium-ion battery can be recycled [10, 11].

- **Sustainability:** Can our design be maintained into the future? The components of our module are designed to be long lasting. For example, the enclosure is made for outdoor electrical installations and is highly waterproof and dustproof at IP65. Also, due to the temperature protections, Li-ion battery degradation is prevented, allowing it a longer lifespan.
- **Manufacturability:** Can our design be reproduced on a larger scale of 5M or more units?
  - Though our design has many components, most of those would already be assembled onto the PCB prior to the module's assembly. The solar panel holders and the plate within the enclosure would be pre-machined. The only steps needed for assembly would be attaching screws and glue. Thus, we believe that it is sufficiently reproducible.
  - Though our design has many components, most of those would already be assembled onto the PCB prior to the module's assembly. The solar panel holders and the plate within the enclosure would be pre-machined. The only steps needed for assembly would be attaching screws and glue. Thus, we believe that it is sufficiently reproducible.
- **Ethical:** Are we adhering to moral principles and respecting human rights? Please see Section 8 for an in-depth discussion of this topic.
- **Health and Safety:** Does our design pose danger to people?
  - The only component of our design that could be dangerous is the Li-ion battery. When subject to extreme temperature due to a short circuit (140°C or above), an Li-ion battery can enter thermal runaway and catch fire [12]. However, because of the circuit protections provided by DW01, a short circuit and thermal runaway are unlikely. Adding these demonstrates our commitment to health and safety.
- **Social:** Is our design beneficial for the surrounding community it will be located in?
  - We believe it will, since it will allow the function of a low cost water meter system without the need to tap into the electrical grid or otherwise use fossil fuels.

6.2 Choosing an Energy Source

We were given an option of three different renewable energy technologies we would use to power the water meter - solar, hydroelectric, and thermoelectric. Each of these types of technologies had

Source	Feasibility	Maintenance	Longevity	Cost
Solar	Feasible, given the sunny location and compact size	Little to no maintenance	25-30 years for maximum energy production	$0.5-$1 (in bulk order)
Hydroelectric	Not feasible, requires a waterflow through a turbine to generate electricity	Maintenance typically every 50 years	50 years	$0.05/kWh, on average
Thermoelectric	Feasible, differences in temperature produce a voltage that converts into heat	Low maintenance	Roughly 11 years	$3-$5 for one generator

Table 1: Component Details and Seller Details

their benefits and drawbacks, so we decided to make a decision matrix, shown as Table 1, that helped us narrow down to the best option. The metrics that were used in order to judge each technology were:

- Ability to meet the required energy goals (Feasibility)
- Sizing requirements (Feasibility)
- Maintenance required
- Cost
- Longevity

In Table 1, Feasibility includes the ability to meet the required energy goals, potential at the location and sizing requirements.

Furthermore, we wanted our design to last for a long duration without the need for repairs or diagnostics. This goal helped us reject hydroelectric, since such a system required moving parts that are more prone to breaking [13]. Next, we rejected Thermoelectric since it requires a significant temperature difference between each side; the entire module will exist in the same ambient temperature and thus it would be difficult to achieve a large enough temperature difference to produce a viable energy output [14]. Additionally, placing a heat sink facing the inside of the enclosure to create the generator's cool side would release heat towards the battery. This is

Technology	Benefits	Drawbacks	Feasibility
Solar	Given the environment the harvester will be in (Yuma, AZ) where it is susceptible to ample sunlight. In Yuma, AZ, on average, 4015 hours of sunlight is received per year and an average of 308 sunny days per year. The direct sunlight produced will produce optimal conditions for the sun panels.	During the nighttime, solar panels do not work as well as there is no sunlight to create the electricity.	Feasible and more than likely the most efficient solution.
Thermoelectric	Thermoelectric generators do not have dynamic parts, which reduces the maintenance.	Thermoelectric generators are not as efficient as Solar and Hydroelectric.	Also feasible, however we may not be able to fit the requirements stated by the company.
Hydroelectric	A clean fuel source — meaning it won't produce harmful pollutants to the air — as it is fueled by water, also not very expensive.	Requires mechanical parts that can cause malfunction/increases maintenance.	Not very feasible in our time frame or in achieving the goals of the project.

Table 2: Comparison of different harvesting technologies

undesirable, as Li-ion batteries perform best in the range of 15°C – 35°C [15]. Average temperatures in Yuma already exceed this range from May to September, so adding more heat would worsen conditions [16].

Furthermore, according to [17], Yuma receives over 10 hours of daylight per day, even on the shortest days in December.

Ultimately, this leads to the conclusion that solar panels are the most appropriate options for the solution. Along with avoiding the aforementioned issues, solar panels are readily available in small sizes like our project demands. They are also quite economical: in bulk orders of 1000+ units, solar panels that we investigated were as cheap as $0.35 [18]. Since in large-scale manufacturing, the cost requirement is less than $3, we felt this price was quite reasonable considering it fit the bill.

Lastly, concerning energy production, solar was a great choice for our location. Yuma, Arizona has high direct normal irradiance (DNI), a measurement of how much direct sunlight hits an area

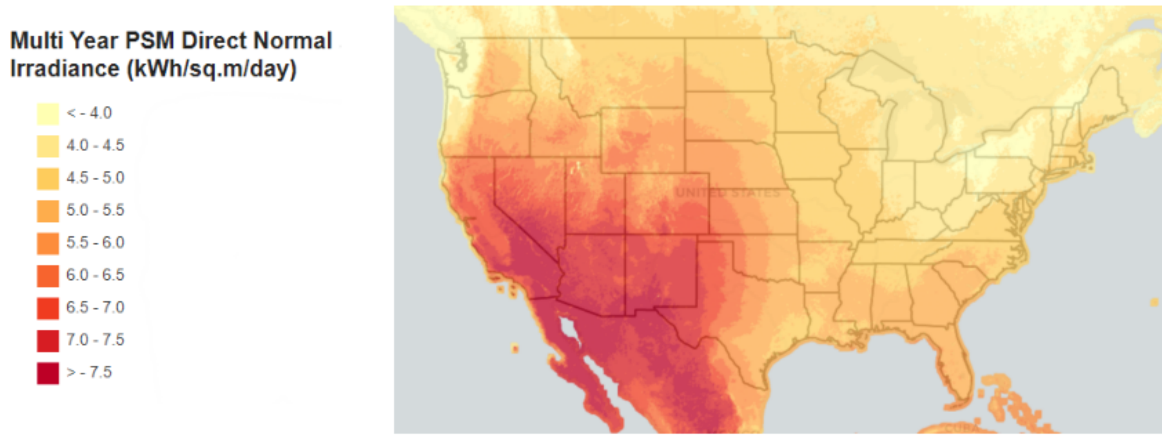

Figure 5: The Average DNI Across the United States

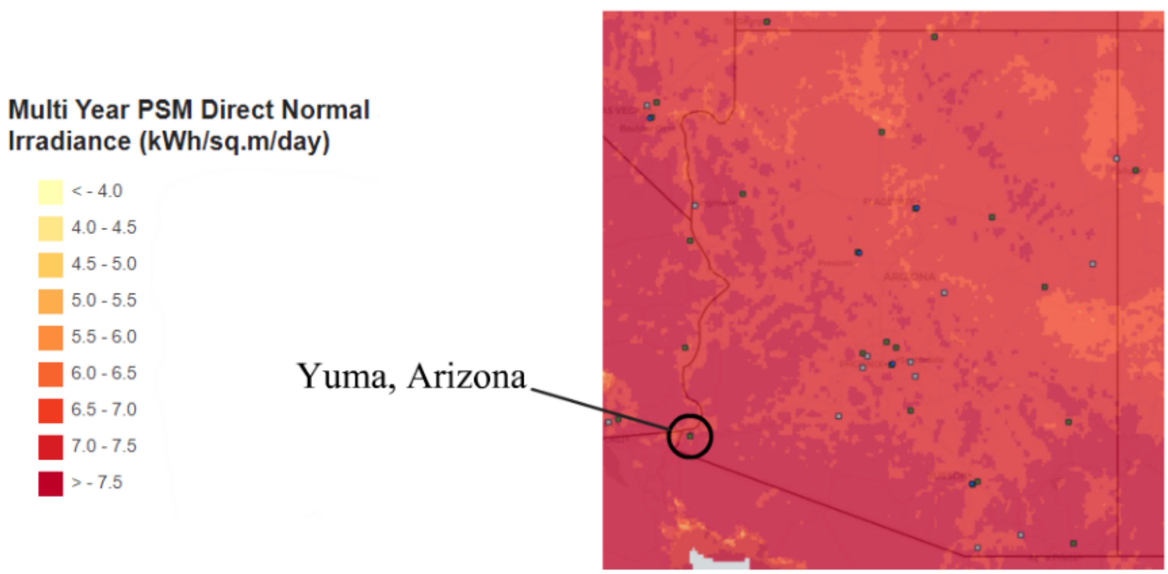

Figure 6: The Average DNI Across the Arizona

over the course of a day $\frac{\frac{kWh}{m^2}}{day}$. Fig. 5 and Fig. 6 display the average DNI across the country and across Arizona [19].

With an average DNI of about 7.58 $\frac{\frac{kWh}{m^2}}{day}$, Yuma, Arizona sits in the highest range available in the United States [9]. This means there is a large potential for solar energy harvesting.

6.3 Solar Panel

We based the solar panel size on how many hours of charging at full capacity was needed to charge the battery to 14 days-worth of charge. To have a reliable system, it was assumed that the water meter would operate at peak power of 5 mW at all times. Therefore,

$$\text{Energy required} = 0.005W \times 24hours \times 14days = 1.68Wh \tag{1}$$

Then, a solar panel that operates at 1W can recharge the battery (assuming it is 1.68Wh) in 1.68 hours, also assuming that it operates at full capacity for the full hour.

1W Solar Panel = Recharge a 1.68Wh battery in 1.68 hours at peak power

We created decision matrices to help us decide on a suitable solar panel for our design. In our Interim Design Report, we had used the following metrics:

- Physical size
- Peak wattage
- Cost (for a low volume purchase, not in high production)
- Approximate shipping time
- Environmental impact and sustainability - Recyclable vs. non-recyclable packaging
- Manufacturability – How many components are readily available?
- Economic impact – Is the order fulfilled through a US company?

Many of these metrics are no longer relevant as our goals have changed. Firstly, at the time, we were concerned about cost for a low volume purchase. This is because we were purchasing them out-of-pocket and only needed one to three units to create our physical prototype. Now, we are concerned about the cost for a high volume purchase since it is most relevant for our final project goals and because we are no longer actually buying components. The latter reason also applies to removing the metric “Approximate shipping time”.

Additionally, environmental impact and sustainability as well as economic impact are to be removed. Though unfortunate, the requirement of $3/unit in high volume production does not allow us to source goods from the US. Thus, all packaging is assumed to be unrecyclable and no US companies will be involved.

The solar panel we chose at the time was 5V, 60mA, and $68mm \times 37mm$. It was manufactured by AOSHIKE and shipped through Amazon. The decision matrix we used to choose a solar panel for prototyping is referred to in Table 15 in Appendix C.

As discussed in the Interim Design Report, we knew that eventually we would need to find a cheaper solar panel. However, we created our circuit with a 5V, 60mA solar panel in mind, so we didn’t want to stray too far from that voltage or current. Our new metrics included:

- Cost/unit for high volume purchase (including shipping)
- Physical size: is it small enough to be comfortably mounted on the enclosure?
- Voltage/Current (to compare to 5V/60mA)
- Peak wattage
- Components available (manufacturability)
- Sourcing time: though we are no longer buying components, this metric is still important if the project were to be implemented.

Table 3 shows the new decision matrix that helped us choose the final solar panel. We decided to move forward with Yucosolar panel.

When choosing our solar panel, we again wanted to find a panel that, again, was at low cost for a bulk purchase. We also wanted a max wattage of 1W, because at peak power, we deduced that 1W solar panel can recharge a 1.68Wh battery in 1.68 hours, which is the energy required when the water meter is operating at maximum power for 14 days (reference back to the interim report). We also prioritized the voltage because with a DC voltage of 3.7V, the recommended solar

Panel	Cost (US$)	Size (mm)	Voltage	Current	Wattage	Manufacturability	Sourcing Time
Panneau Solaire	$0.75	53x30	5V	30mA	0.15W	10,000 Pc Available	~2 weeks
Yucosolar	$0.73	80x35	5.5V	70mA	0.385W	12,437 Pc Available	~6 weeks
AMX3d 4X	$5.44	68x37	5V	60mA	0.3W	9,927 Pc Available	~3 days
Polysilicon Panel	$3.50	100x60	5V	200mA	1W	8,987 Pc Available	~3-8 weeks

Table 3: Decision Matrix for Choosing the Solar Panel

panel voltage is between 5V to 6V. Any discrepancies in voltage may affect the performance of our design. Additionally, size is a very important attribute to keep in mind, as our enclosure and overall design had to fit the specifications set by Xylem. When we chose the solar panel we thought was acceptable, we prioritized size and performance, as we wanted our design to be as efficient and reproducible as possible. The panel we chose would be coming from AliExpress, which is one of the better sites to use when ordering parts in bulk. For orders about 800 units, each panel will cost just over $0.70. This solar panel in particular has a size of $80mm \times 35mm$, which will be easily integratable into our enclosure.

6.4 Battery

When choosing a battery, we had a plethora of battery types to choose from. In order to make our decision we used a comparison chart. We decided to use for Li-ion batteries due to the high charge cycle and energy density, low maintenance, and lack of memory effect. We also found that lithium-type batteries are readily available at 3.7V, eliminating the need to change the voltage before supplying it to the load. All considered batteries were 18650 size due to its standardization and satisfactory dimensions ($18mm \times 65mm$) that would allow easy integration into the circuit.

We found a comparison chart [4], shown as Table 4.

Parameter	**Ni-Cd**	**Ni-MH**	**Li-Ion**	**Li-Polymer**
Cell Voltage	1.2V	1.2V	**3.67**	3.7V
Cost	Moderate	High	**Very High**	Very High
Internal Resistance (IR)	Very Low	Moderate	**High**	Low
Self Discharge (%/month)	15% to 30%	18% to 20%	**6% to 10%**	5%
Charge Cycle	500 to 1000	500 to 800	**1000 to 1200**	>1000
Overcharge Tolerance	Medium	Low	**Very Low**	Very Low
Energy Density (Wh/kg)	45 to 50	55 to 65	**90 to 110**	130 to 200
Memory Effect	Yes	Yes	**No**	No
Maintenance	High	Low	**Low**	Low
Safety	Safe	Safe	**Un-Safe**	Un-Safe

Table 4: Comparison of Various Battery Types [4]

The capacity of the battery was evaluated by the number of days of charge available at constant peak power usage (5mW). As such:

$$\text{Power Usage} = 5mW \times 24h = 120\frac{mWh}{day} \tag{2}$$

$$\text{Charge Required} = \frac{5mW}{3.7V} \times 24h = 32.432\frac{mAh}{day} \tag{3}$$

$$\text{Days of Charge} = \frac{\text{Battery Capacity in mAh}}{32.432mAh} \tag{4}$$

Then, the capacity of the battery required for this scenario is:

$$\text{Capacity} = \frac{1.68Wh \times 1000}{3.7V} = 454mAh \tag{5}$$

Battery Required Capacity for 14 days Backup = $454mAh$

Note: This does not account for energy usage by the PCB board in-use or when not-in-use. This simply notes the minimum battery size required (without losses) to reach the 14 day minimum required, considering non-ideal circumstances (peak power usage of 5mW throughout the 14 days).

6.5 Choosing the Li-ion Battery

When choosing the type of lithium ion battery, we again judged our decision by the cost, size, and shipping times. We also used capacity and days of charge as a factor for comparison. From our decision matrix, we decided to choose a battery that was very efficient from a price point and provided sufficient battery capacity. From Table 5 the Kanavano 18650 1200mAh 3.7V Li-ion battery from AliExpress was our desired choice. This battery, at a low cost point, will provide us with max 37 days of charge; and, with the option of bulk ordering, this makes our design manufacturable for high volume production

Battery	Cost	Capacity	Backup	Vendor	Sourcing Location	Manufacturability	Sourcing Time
Unbranded Battery, 1200mAh	$0.62	1200 mAh	Max 37 Days	AliExpress	China	4159 Pc Available	9 weeks
Kanavano, 1200mAh	$0.73	1200 mAh	Max 37 Days	AliExpress	China	4992 Pc Available	5 weeks
PKCELL, 350mAh	$3.32	350 mAh	Max 11 Days	Amazon	US	Not Specified	1 week
Samsung 25R, 2500mAh	$2.76	2500 mAh	Max 77 Days	Li-ion Wholesale	US - Georgia	1000+ Pc Available	2 weeks

Table 5: Decision Matrix for Choosing the Solar Panel

6.6 Charging Chip: TP4056

The TP4056 is a charge controller IC for single cell Li-ion batteries, manufactured by the NanJing Top Power ASIC Corporation. It uses a constant-current, constant-voltage linear charging method with an output voltage of 4.2V and a programmable output current. It's SOP-8 package and pin-out are shown in Fig. 8.

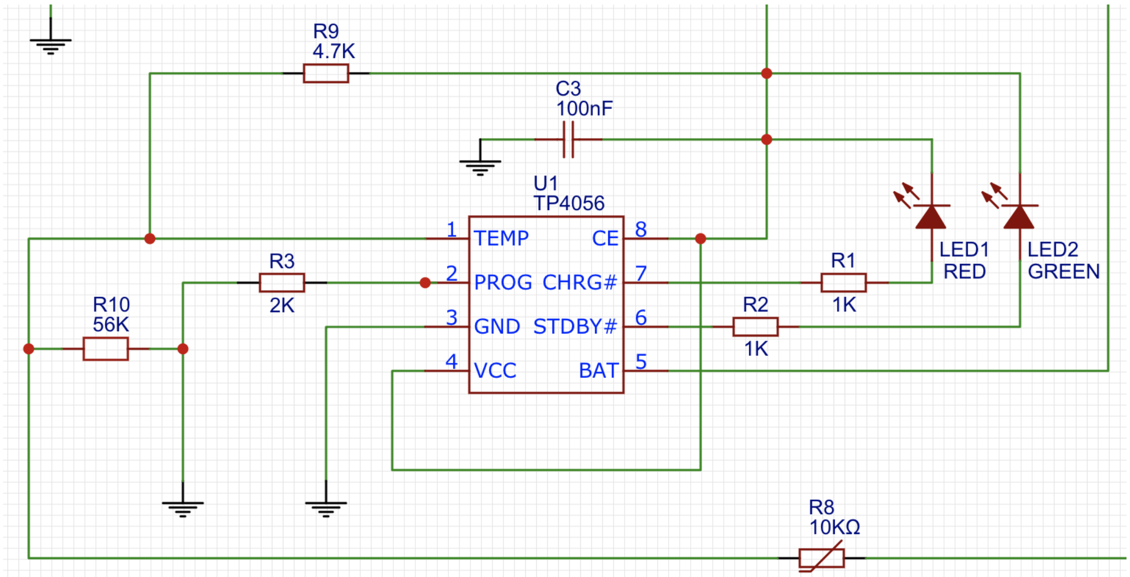

Figure 7: TP4056 Sub-circuit in the Final Schematic. Refer to Fig. 24 for The Full Circuit Schematic

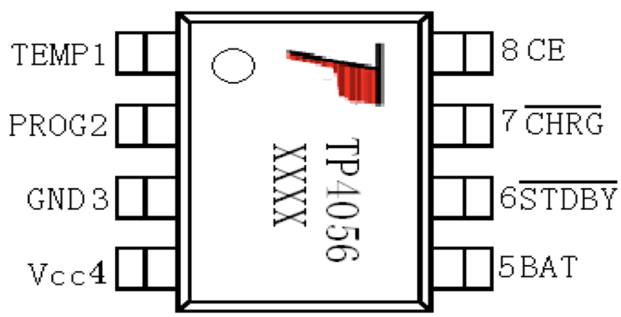

Figure 8: TP4056 Pinout of its SOP-8 Package

Table 6 summarizes the function of each pin. The operation of pins 1, 2, and 4-7 are discussed further in this section.

Pin	Details	Pin	Details
1 – TEMP	Connects to a temperature sensor	**5 – BAT**	Connects to the battery to charge it
2 – PROG	Connects to a resistor whose value determines the charging current	**6 – STDBY**	Connects to an LED to signal that charging is complete
3 – GND	Ground	**7 – CHRG**	Connects to an LED to signal charging in progress
4 – V_{CC}	Input voltage	**8 – CE**	Chip enable

Table 6: TP4056 Pinout Details

The input voltage range to V_{CC} is 4V to 8V. Its operating temperature is -40°C to +85°C, meeting the project requirements. Key features are outlined in the following sections.

6.6.1 Temperature Sensing and Control

The biggest issue with the original choice of MCP73831 as the charge controller was its inability to protect from low temperature charging. Charging a Li-ion battery below 0°C can cause permanent damage [20]. Since design requirements included the ability to withstand down to -40°C, low temperature protections were necessary.

The present charge controller chip, TP4056, has a TEMP pin that can connect to a Negative Temperature Coefficient (NTC) Thermistor, a highly sensitive resistor. Though temperature affects the resistance of all resistors, an NTC Thermistor is especially sensitive. As the temperature of the thermistor increases, its resistance drops dramatically and precisely over a typical range of about -55°C and 200°C [21].

By connecting the NTC Thermistor to the battery cell and to the TEMP pin of TP4056, the charging can be stopped at threshold temperatures. If the TEMP pin's voltage is below 45% or above 80% of the supply voltage to TP4056 for more than 0.15 seconds, this means that the battery's temperature is either below 0°C or above 45°C — charging is terminated [1]. This is further detailed in Section 6.6.5.

6.6.2 Programmable Charge Current, R_{prog}

Charge current is set by the value of resistor R_{prog}, connected from the PROG pin to ground. Table 7 shows charging currents for a range of R_{prog} values [1].

R_{prog}	I_{bat}
$10k\Omega$	130mA
$5k\Omega$	250mA
$4k\Omega$	300mA
$3k\Omega$	400mA
$2k\Omega$	580mA
$1.6k\Omega$	690mA
$1.5k\Omega$	780mA
$1.33k\Omega$	900mA
$1.2k\Omega$	1000mA

Table 7: R_{prog} Values for Setting Charge Rate on TP4056 [1]

TP4056 has a Constant Charge Current Setting and Charge Current Monitor Pin (Pin 2). The charge current for this chip is set by choosing an appropriate R_{prog} [1]. When the chip is in pre-charge mode — that is, when the cell voltage is near or below 3V — I_{SET} voltage is regulated to 0.2V [1]. In Constant Charge Current Mode, I_{SET} voltage is regulated to 2V. For all other modes of charging, the voltage on I_{SET} Pin is used to measure I_{BAT} using the following:

$$I_{BAT} = \frac{V_{PROG}}{R_{PROG}} \times 1200 \tag{6}$$

A safe Charge Rate for a lithium-ion battery is 0.5C to 0.8C to prevent extra heat, where C is Coloumbs [22]. Although lithium-ion batteries can be charged up to 1C without much issue [22], the goal is to regulate heat because of already hot weather at Yuma. Since the system will not benefit from faster charging anyway, the Charge Rate can be limited to 0.5C. A Charge Rate of 0.5C for a 1200mAh battery is equal to 600mAh. Using Table 7 and Fig. 9, a $2k\Omega$ value gives 580mA for I_{BAT}, which is reasonably close to 600mA. Therefore, R_{prog} was set at $2k\Omega$ to ensure a safe Charge Rate of 0.5C.

6.6.3 Start and Stop Functions

The chip features soft-start, limiting the inrush of current at the beginning of charging. This helps prevent damage to the battery [23]. It also features automatic recharge when the battery

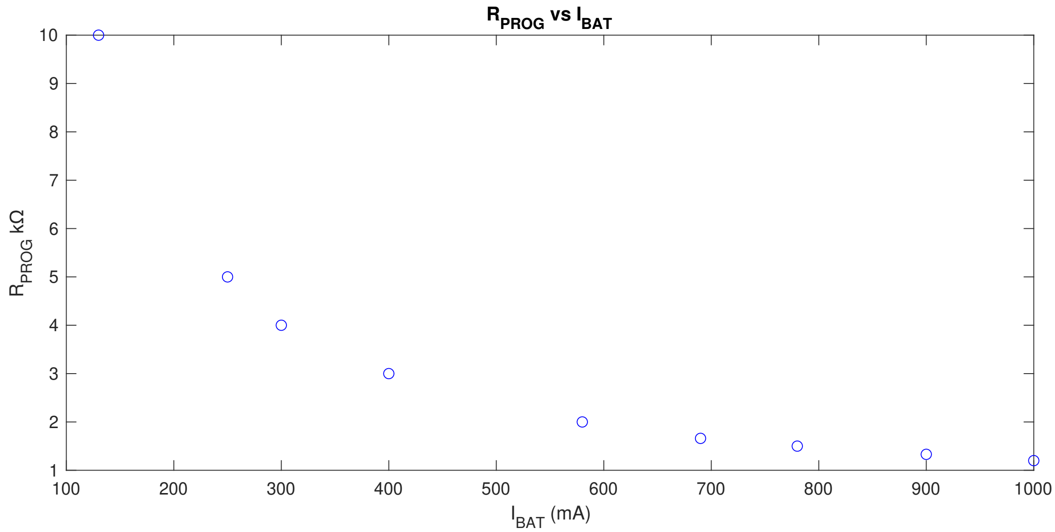

Figure 9: R_{PROG} vs I_{BAT}

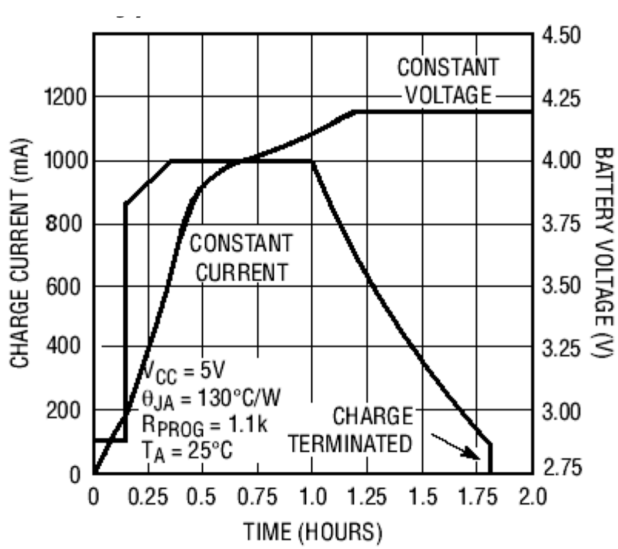

Figure 10: An Example of a Complete Charge Cycle for a 1000 mAh Battery [1]

level drops after use. Once the battery voltage reaches 4.2V, the chip terminates the charge cycle after the charge current drops to 10% of the programmed value. Fig. 10 shows an example charge cycle for a 1000mAh battery with a charge current of 1A.

6.6.4 Charge Status

The chip enables a display of charge status through its STDBY and CHRG pins. For STDBY, the pin stays in high impedance state until charging is complete, pulling the pin to low. For

CHRG, the pin is pulled low during charging and is switched to its high impedance state otherwise. Additionally, if the temperature is too high or low, the input voltage to V_{CC} is too low, or if there is no battery connected, both pins will be switched to their high impedance states.

By connecting LEDs to these pins, the charge status of the module can be visualized. Table 8 summarizes the different states of connected LEDs.

Charge State	**CHRG Pin LED**	**STDBY Pin LED**
Charging	On	Off
Charge Terminated	Off	On
V_{CC} too low, Battery temperature out of range, No battery connected	Off	Off

Table 8: CHRG & STDBY Pin States on TP4056 [1]

6.6.5 NTC Thermistor

An NTC Thermistor is simply a Negative Temperature Coefficient resistor. The usage of the word *Negative* implies that the value of the resistance decreases with an increase in temperature. These are highly functional when used as analog temperature sensors. The temperature sensitivity coefficient is about five times greater than that of silicon temperature sensors (silistors) and about ten times greater than those of resistance temperature detectors (RTDs) [21]. One of the biggest benefits of an NTC Thermistor is that since it is very highly sensitive resistor it's change in resistance in guided by a precise and a predictable decrease as the temperature changes.

The NTC Thermistor used in this system is supplied by Murata in a R0201 package. The manufacturer part number is NCP03XH103F05RL. From the datasheet, it is a Plated Termination Series resitor with a package size of $0.60mm \times 0.30mm$, a a nominal Beta value at 3477K of $10k\Omega$ Resistance with a tolerance of $\pm 1\%$ [24].

The most important value here is the Beta since that is used in calculating the voltage divider values at the TEMP pin at TP4056.

From the data-sheet, the TEMP pin checks if the voltage is below 45% or above 80% of supply voltage V_{IN} for more than 0.15S, and suspends charging whenever that is true. Since the chip itself does not have a digital sensor that completes those operations, we utilize an NTC Thermistor in a voltage divider setting.

We know the temperature of a NTC Thermistor at various temperature points from it's datasheet. Since we want to cut charging at 0°C and 45°C, and TP4056 measures voltage at the TEMP pin from 45% to 80%, we simply setup a voltage divider that goes:

- below 45% of supply voltage when temperature is below 0°C
- above 80% of supply voltage when temperature is above 45°C

When voltage drops below 45% or goes above 80%, the TEMP pin at TP4056 essentially cuts off the output.

6.6.6 Finding Resistor Values to be Used with NTC Thermistor and TP4056

According to the TP4056 data-sheet, the TEMP pin has to be between 45% and 80% to ensure that charging is continued. If we use 5V for supply, the voltages required at the TEMP pin then are 2.25V and 4V for 45% and 80% values.

The data sheet mentions two resistors: R_1 — which is the pullup resistor to 5V — and R_2 —which is the pull down resistor to ground. The NTC (R) is connected in parallel with R2. Using a 10k NTC Thermistor with a Beta value of 3477K, the resistance at 0°C and 45°C is $28.5k\Omega$ and $4.1k\Omega$ [24]. Therefore, two equations are:

$$\frac{R_1}{R_2||4.1k\Omega} = \frac{2.75V}{2.25V} \tag{7}$$

$$\frac{R_1}{R_2||28.5k\Omega} = \frac{1V}{4V} \tag{8}$$

Then Eq. 7 becomes:

$$0.82V \times \frac{R_1}{R_2||4.1k\Omega} = 1 \tag{9}$$

And Eq. 8 becomes:

$$4 \times \frac{R_1}{R_2||28.5k\Omega} = 1 \tag{10}$$

Combining the two equations, we get:

$$0.82V \times \frac{R_1}{R_2||4.1k\Omega} = 4 \times \frac{R_1}{R_2||28.5k\Omega} \tag{11}$$

Then, Eq. 11 simplifies to:

$$\frac{4.89V \times R_1}{R_2||4.1k\Omega} = \frac{R_1}{R_2||28.5k\Omega} \tag{12}$$

Then, after re-writing parallel resistances, Eq. 12 is:

$$4.89V \times \left(\frac{R_2 \times 4.1k\Omega}{R_2 + 4.1k\Omega}\right) = \frac{R_2 \times 28.5k\Omega}{R_2 + 28.5k\Omega} \tag{13}$$

Finally, from Eq. 13, we get

$$R_2 = 54k\Omega \approx 56k\Omega \text{ (rounded to the nearest available resistor)} \tag{14}$$

Then from Eq. 8 and Eq. 14, we can find R_1:

$$R_1 \approx 4.7k\Omega \text{ (rounded to the nearest available resistor)} \tag{15}$$

Therefore, to ensure that the battery is not charged below 0°C or above 45°C, a $10k\Omega$ NTC Thermistor is used with a beta value of 3477k, and the required R_1 and R_2 are:

$$\boxed{R_1 = 4.7k\Omega}$$

$$\boxed{R_2 = 56k\Omega}$$

R_1 is represented as R_3, R_2 is represented as R_{10}, and the $10k\Omega$ NTC Thermistor is represented as R_8 in the final schematic, presented in Fig 24 in Appendix A.

6.7 DC/DC Boost Converter: MT3608

The MT3608 is a current mode boost converter manufactured by Aerosemi Technology. It operates with a fixed 1.2 MHz frequency and reaches up to 97% efficiency. It accepts an input voltage of 2-24V and outputs a constant programmable output voltage up to 28V. The SOT23-6 package and pin-out are shown in Fig. 11.

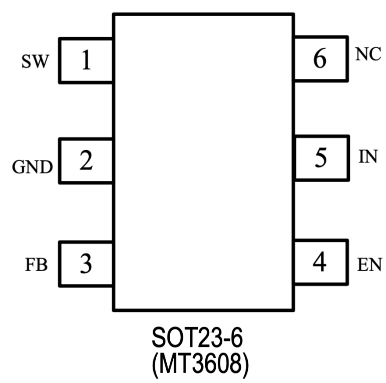

Figure 11: MT3608 pin-out of its SOT23-6 package [2]

Table 9 summarizes the function of each pin for MT3608.

6.7.1 Motivation to Include MT3608

Our motivation for adding a boost converter was due to TP4056, the charge controller chip, having a minimum input voltage of 4V. This is higher than the average performance of our solar panel. An excerpt from the Interim Design Review (Section 3.5.2, page 15) explains the voltage output characteristics of our initial solar panel:

Pin	Details	Pin	Details
1 − SW	Output Voltage	**4 − EN**	Chip Enable
2 − GND	Ground	**5 − IN**	Input Voltage
3 − FB	Feedback Input That Enables Error Correcting	**6 − NC**	No Connection

Table 9: MT3608 Pinout Details

"We also did, however, test the capabilities of the solar panel itself by shining bright sources of (two to three) LED spotlights. The solar panel we used is rated for 5V and did indeed deliver up to 4.91V according to the lab multimeter. We found that the voltage of the solar panel under regular light was 2.3V to 2.7V."

Therefore, to ensure that TP4056 will have reasonable access to its minimum input voltage, boosting the solar panel's output voltage was necessary. We did decide to use a different solar panel due to its lower cost, but it is also rated at 5V. This means the TP4056's minimum 4V input is still at the high end of the solar panel's abilities. Thus, we included the boost controller in order to maximize the range of operating irradiance, as well as properly power the charge controller with a margin of security.

6.7.2 Constant Output Voltage Programming

The constant output voltage is programmed using a voltage divider connected to the FB pin. The relationship is presented below:

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R_1}{R_2}\right);\text{ where } V_{REF} = 0.6V \text{ [2]} \tag{16}$$

A typical application from the MT3608 datasheet that shows a voltage divider system is highlighted in a red box in Fig. 12.

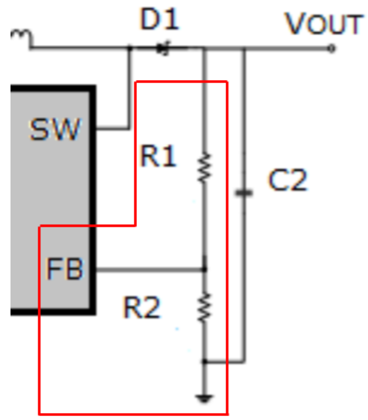

Figure 12: Typical Application of a Voltage Divider to Control Constant V_{OUT} in MT3608 [2]

We decided that an output of 4.5V would be appropriate from MT3608. This leaves a 0.5V margin above the minimum 4V that TP4056 requires. A voltage higher than this would be unnecessary and continue to drop the current.

Choosing 4.5V as the output voltage, from Eq. 16:

$$4.5 = 0.6 \times \left(1 + \frac{R_1}{R_2}\right); \text{ where } V_{REF} = 0.6V \tag{17}$$

Therefore, we can find that $R_1 = 1.2M\Omega$ and $R_2 = 180k\Omega$. These resistors were chosen firstly because their large values minimize the current drawn to the FB pin from the path towards the battery. Secondly, they are standard valued resistors that will prevent extra steps in manufacturing [25]. These resistors result in an output voltage of 4.6V, which we feel is close enough to our goal. The part that contains the MT3608 circuit in the final schematic (in Fig. 24) is referred to in Fig. 13. R_1 is referred to as R_6 in the figure, and R_2 is referred to as R_7.

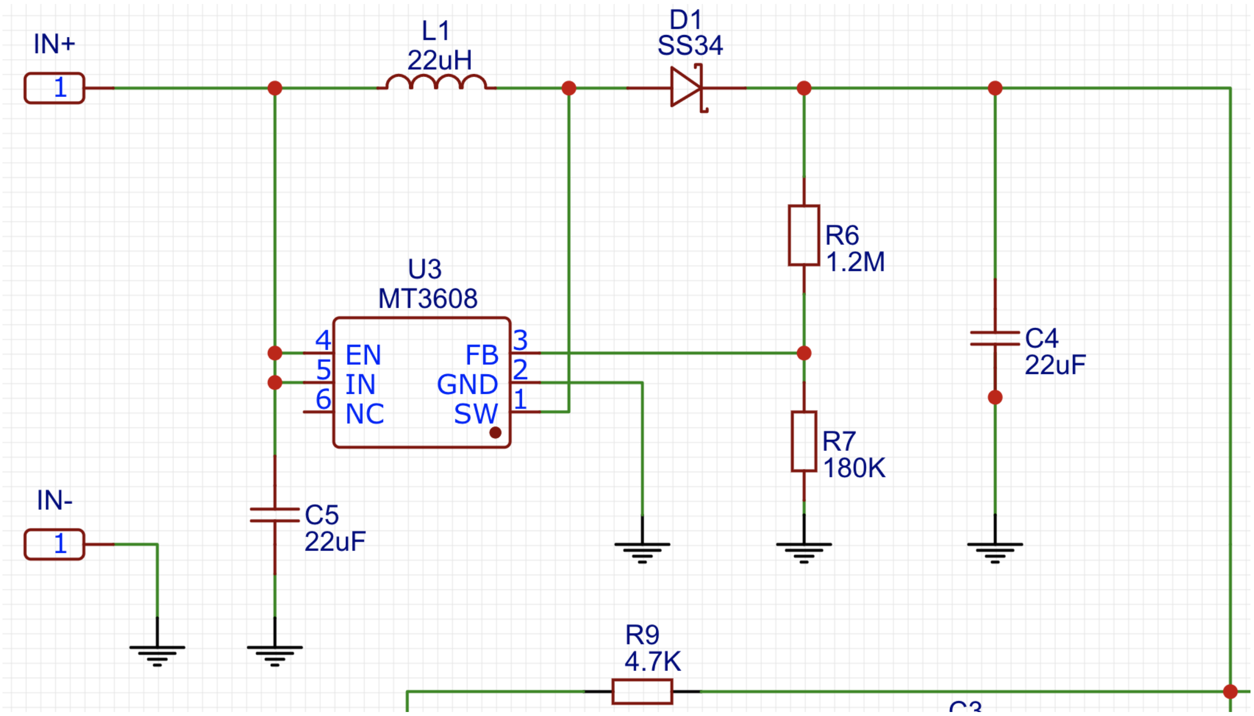

Figure 13: MT3608 Sub-circuit in the Final Schematic. Refer to Fig. 24 for The Full Circuit Schematic

6.8 DW01 and FS8205

DW01 is a battery protection IC and includes features to protect a one-cell li-ion battery. The features of DW01 include overcharge protection, over-discharge protection and/or over-current protection. It implements these function using two MOSFETs included in FS8205. DW01 provides over-discharge protection with an accuracy of $\pm 50mV$, with very low standby current, limiting power-draw when not in use [9]. Table 10 mentions the pinout of DW01 and Table 11 includes threshold voltage for each protection feature.

The DW01 implements the protection by controlling the return current from the system ground to the negative battery terminal, as shown in Fig. 14. Since FS8205 is a dual N-channel MOSFET, the current is controlled at the negative terminal of the battery. DW01A Pin 3 in DW01 is for overcharge control and is connected to pin 5 in FS8205. Next, pin 1 in DW01 is for discharge control and is connected to pin 4 in FS8205.

In most cases, DW01 will never activate since some primary protections are already provided by TP4056. Since TP4056 stops discharging at voltages below 2.9V, DW01 will not activate since V_{ODP} is 2.4V. Next, since TP4056 stops charging at voltages above 4.2V, DW01 will not activate again since V_{OCP} is approximately 4.25V. DW01 is used to provide over current protection and short circuit protection.

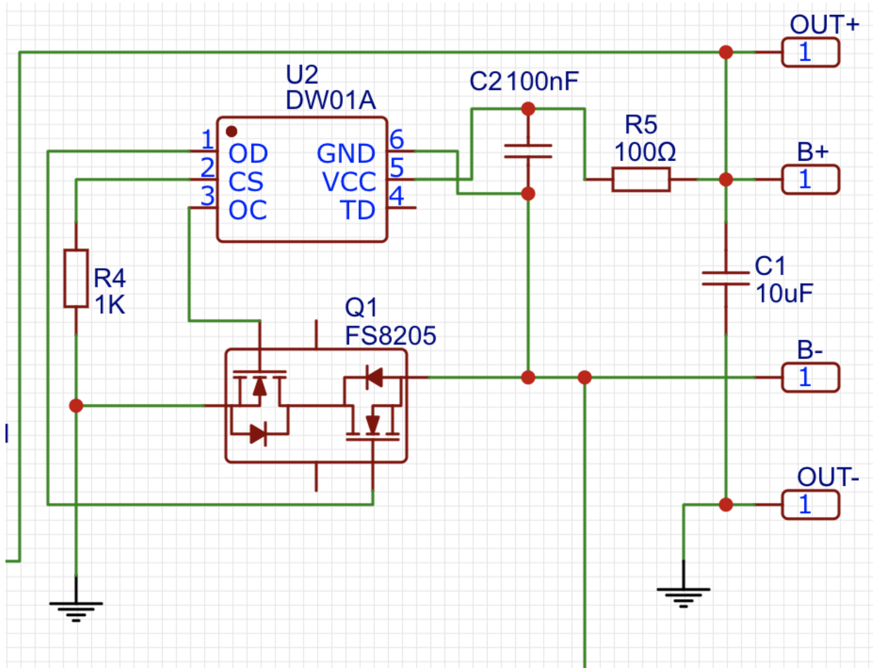

Figure 14: DW01 & FS8205 Sub-circuit in the Final Schematic. Refer to Fig. 24 for The Full Circuit Schematic

6.8.1 Overcharge Protection

This protects the cell from being overcharged, that is, going over +4.25V. Li-ion cells over 4.3V are prone to damage [22]. If the overcharge protection voltage V_{OCP} is exceeded in the battery cell beyond the overcharge delay time T_{OC}, then charging is turned off [9]. This condition is released in two scenarios:

- The voltage of the battery drops below 4.05V through self discharge [9].
- The voltage of the battery drops below 4.25V when a load is connected [9].

6.8.2 Overdischarge Protection

This protects the cell from being over-discharged, that is, below +2.4V. Li-ion cells that drop below 2.4V can be permanently damaged [22]. If the overcharge protection voltage V_{ODP} is exceeded in the battery cell beyond the overcharge delay time T_{OD}, then charging is turned off [9]. This condition is released in one scenario:

Pin	Details	Pin	Details
1 - OD	MOSFET gate connection pin for discharge control	**6 - GND**	Ground pin
2 - CS	Input pin for current sense, charger detect	**5 -** V_{CC}	Power supply, through a resistor (R1)
3 - OC	MOSFET gate connection pin for charge control	**4 - TD**	Test pin for reduce delay time

Table 10: DW01 Pinout Details

Overcharge detection voltage, V_{OCP}	**Overcharge Release Voltage,** V_{OCR}	**Overdischarge Detection Voltage,** V_{ODP}	**Overdischarge Release Voltage,** V_{ODR}	**Overcurrent Detection Coltage,** V_{OIP}
4.250 ± 0.050 V	4.050 ± 0.050 V	2.40 ± 0.050 V	3.0 ± 0.100 V	150 ± 30 V

Table 11: DW01 Features

- The voltage of the battery drops below 4.05V through self discharge [9].

6.8.3 Overcurrent Protection

If the voltage at the CS pin crosses 150mV, discharging is cut-off and the load (in this case, rest of the circuit and the solar panel) loses access to the battery. It returns to normal when the load is disconnected. [9].

6.8.4 Power-Down after Overdischarge

DW01 enters power-down or sleep mode once it detects an over-discharge and the quiescent current is reduced to just 0.1 μA, when $V_{CC} = 2V$.

6.8.5 Short-Circuit Protection

DW01 also provides short-circuit protection by measuring the current flowing through pin CS [9].

6.9 Final Circuit and PCB

The final circuit consists of MT3608, TP4056, DW01 + FS8205.

The solar panel is fed into the input V_{CC} of MT3608, which then outputs a constant 4.5V to V_{CC} of TP4056, which then charges the battery through Pin 5 through DW01 and FS8205 pair. The Final Schematic is represented in Fig. 24 in Appendix A.

MT3608 is important since it provides a constant output voltage to the TP4056. TP4056 is essential to the circuit since it charges the Li-ion battery, and DW01 + FS8205 provide the necessary protections to prolong the battery life of the Li-ion cell. These chips were chosen because they allowed us to achieve our goals, and equally importantly, are one of the cheapest chips available due to their mass-production. The components placed in the schematic are also hand-picked and researhced to be the cheapest in large quantities ($< 10,000$ units, based on minimum quantity for maximum discount per item).

The same design has also been implemented on Printed Circuit Board (PCB) of size $33.02mm \times 22.61mm$. A custom PCB allows us to keep within the objectives of a small size, as well as allowing for customaization that is not available with an off-the-shelf PCB. Furthermore, as noted in Appendix B, the cost to produce and assemble the custom PCB is really cheap on a large-scale (the required 5M units). For example, for a quote for 80,000 units, the cost to produce was only \$0.03 and the cost to assemble the board was just \$0.15, bringing the total to \$0.18.

The PCB is represented in Fig. 25, Fig. 26 and Fig. 27 in Appendix A. The trace-width's on the PCB are at least 0.25mm with a board thickness of 1.6mm— which ensures that the PCB is rated to be used with up to 1A [26]. Larger traces and board thickness ensure that more current can pass through, as heat can be dissipated more easily.

6.10 Drawbacks of the Current Design

This design is not perfect, and these are the limitations we are currently aware of:

- The current design lacks reverse polarity protection. While not relevant because this battery will be permanently installed, it is something that will make the design more robust during assembly and service.
- In the current design, load cannot be connected with the battery simultaneously, as that interferes with the charging logic of the TP4056. If a load is connected simultaneously with the battery, depending on the load, the voltage draw at Pin 5 would be affected — which may mean that TP4056 might stop charging prematurely.

6.11 Enclosure

We decided on the following goals for our enclosure:

- IP64 or greater (dust tight and waterproof against splashed water from any direction) [27]
- Costs $1 or less per enclosure
- Made for outdoors (UV, heat, and impact resistant)

And of course, we also kept in mind the applicable project requirements:

- 100 x 60 x 60 mm or smaller
- Can withstand -40°C to 85°C

Initially, we felt that a 3D printed enclosure would be a good fit. However, research revealed that nearly all 3D printing plastics are not suitable for outdoor use due to poor heat and UV resistance. Other materials, such as metal alloys, are often more expensive [28]. Most importantly, at high volume production, 3D printing will likely take far longer than a molded product [29]. Thus we decided to search for an available enclosure to fit our needs. The metrics we used included:

- Enclosure cost/Shipping cost
- Dimensions: Is it large enough to comfortably fit our components?
- Material/Color: Is the material sturdy and light in color to reduce heat absorption?
- IP rating
- Mountable - Internal: Are there screw holes or card slots to mount components?
- Mountable - External: Are there screw holes for the enclosure to be mounted to something, such as a stand next to the water pipe?
- Available units (Manufacturability)

Table 12 shows a decision matrix for three enclosures.

Based on the decision matrix, we chose the enclosure from Hongfa. It is also interesting to note that the other two enclosures are sold through the vendor Aliexpress, while the Hongfa enclosure is through Alibaba. Aliexpress targets consumers, while Alibaba is a wholesale retailer for businesses. This is why the shipping price is negotiable, which is a positive attribute since such a high volume

Company	Enclosure + Shipping Cost	Dimensions (L x W x H) (mm)	Material	IP Rating	Internal Mount	External Mount	Available Units
Improvement Store	\$1.05 + \$0.86	85 x 58 x 53	Plastic/White	IP65	Yes	Yes	999
Improvement Store	\$0.95 + \$0.86	100 x 60 x 25	Plastic/Black	IP65	No	No	11,988
Hongfa	\$0.90 + Negotiable	84 x 59 x 33	ABS Plastic/White	IP65	Yes	Yes	>2,000

Table 12: Decision Matrix for Choosing the Enclosure

purchase would surely drive down the shipping cost per unit. Additionally, working with wholesale manufacturers allows customization. As discussed later in this section, holes will need to be drilled on the lid for mounting the solar panel. We were actually able to get in touch with the seller, who told us the \$0.558 price would include drilling of the holes. Figure 15 and 16 show the chosen enclosure.

Figure 15: Enclosure: External View with Lid Covered

Figure 16: Enclosure: Overview with Lid Removed. Rubber Gasket and Lid Screws are Shown

Unfortunately, we were not provided with a CAD model. In order to finalize the layout, we recreated the enclosure in AutoCAD. Four holes were created in the lid, each with a diameter of 1.8mm. These were created for M2 (2mm diameter [30]) screws that would join custom made high-density polyethylene (HDPE) holders for the solar panel. Fig. 17 shows the holder and Fig. 18 displays how they will join together the components.

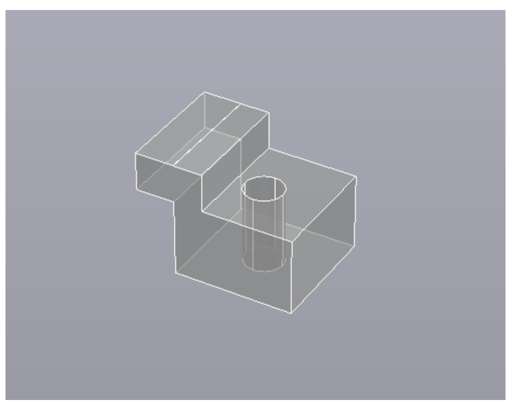

Figure 17: Enclosure: Custom Holder for the Solar Panel

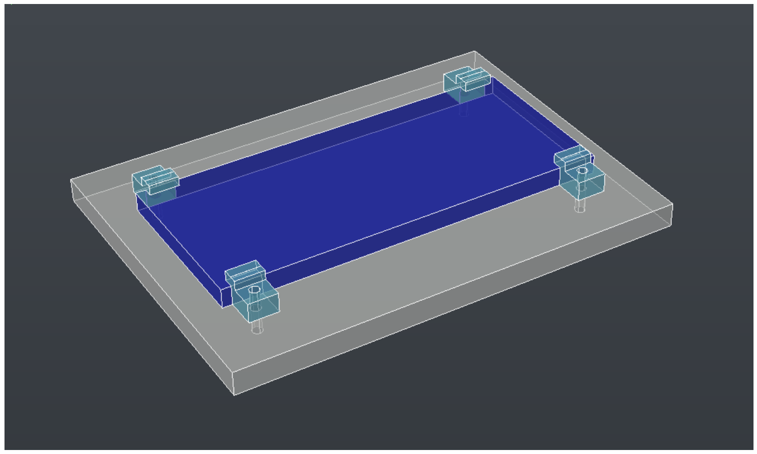

Figure 18: Enclosure: External View of Lid with Solar Panel Attached using Custom Holders

The lid also had a 2mm hole in the center to allow the solar panel leads to enter the enclosure. It is important to note that by drilling holes, the enclosure would of course lose its waterproofing and dust resistance. Thus, we would suggest using a sealant such as EP42HT-2, manufactured by MasterBond. This sealant is a two component epoxy that cures at room temperature. It is waterproof, electrically insulating, and can withstand temperatures from -52^{o}C to 232^{o}C [31]. We have not included this sealant in our BOM because we feel it is part of the manufacturing cost.

Next, we had to decide how to secure the battery and PCB inside the enclosure. We took advantage of the internal mounting capabilities by mounting a 2mm thick plate of (HDPE), which can easily be machined [32]. The material is sold at \$2.00/kg and has a density of 940 $\frac{kg}{m^3}$ [33, 34]. With the plate dimensions of $7.6cm \times 5.2cm \times 0.2cm$, each plate would cost roughly \$0.0075 if machining is done during manufacturing of this module. If it is to be done by the seller, an increase of up to \$0.02 per plate is a reasonable estimate. Fig. 19 shows an isolated view of the plate.

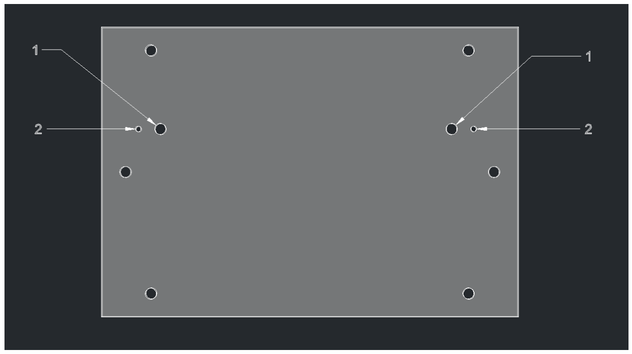

Figure 19: Enclosure: HDPE Plate Four Mounting Components

Unlabeled holes are for mounting the plate into the enclosure. Only two points of securement are truly necessary for the plate. We recommend the upper left and lower right holes. Holes labeled "1" are for securing the battery holder. Holes labeled "2" are for the leads of the battery holder. Fig. 20 below shows the battery holder, with red arrows pointing to the leads.

Figure 20: 18650 Battery Holder, Leads Extending Outwards

Along with the battery, the PCB can also be mounted onto the plate. Fig. 21 shows the battery holder (green) and PCB (red) in the enclosure.

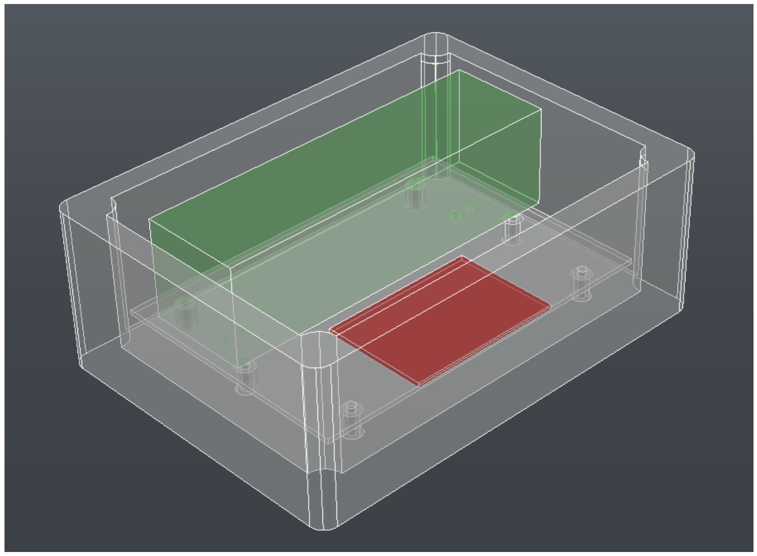

Figure 21: Complete Enclosure Body with Battery Holder (Green) and PCB (Red) Inside

In conclusion, the list of materials for the enclosure include:

- Hongfa enclosure
- 4 custom HDPE solar panel holders
- HDPE mounting plate
- Sealant
- 10 – 2 x 4mm screws

A final Bill of Materials (BOM) is referred in Appendix B.

6.12 Evidence That Final Design is Reproducible

One of our goals for this project was to make our design reproducible. If our design were to be manufactured in high volumes by Xylem, we wanted it to be simple to produce a vast amount. According to the Bill of Materials in Appendix B, we found many of the components needed for the design on websites that offered bulk shipping. We also tried to condense the amount of websites used in order to have most of these components sourced from the same place and to arrive at similar time periods. For the analog electronic components (i.e., resistors, capacitors, and LED's) as well as the IC chips, we compared bulk prices from different online vendors such as Digikey and All

Electronics; but, we ultimately found better prices on LCSC Electronics. Our battery and solar panel were both found on AliExpress, which we deemed was the best site to order these types of material in bulk due to its cheaper pricing. Using EasyEda to build our circuit schematic, we used its recommended PCB development website, JLCPCB, to source and assemble our PCB's. And finally, as mentioned previously, we opted to use Alibaba to source our enclosures as it was the most cost-efficient option, from a consumer standpoint.

Being able to source most of our items from one vendor at 1000 or more units, shows that our design can be reproduced. In the end, our total cost for all parts needed to create our design is about \$2.93, which meets the maximum \$3 goal set by Xylem.

7 Results

The COVID-19 outbreak in 2020 and the University's subsequent decision to move to distance learning, on March 13th, 2020, affected efforts to produce a physical design. With shelter-in-place orders across New York from at least March 2020, parts could not be sourced due to shipping restrictions. Another factor that affected our ability to prototype and produce was the inability to physically meet due to self-isolation. Although we wanted to simulate the design, we were unable to do so due to non-availability of SPICE libraries. We tried getting in touch with the suppliers as well as the manufacturers, but we were not able to obtain SPICE libraries required for simulation. While not related to the COVID-19 outbreak, this affected the design process for this system. We believe physical prototyping could have allowed us to successfully resolve issues even though we weren't able to simulate digitally.

From the successful prototype we built in March, we were able to get an underlying idea of how we needed to move forward with our project. Successful testing and prototyping allowed us to set the stage for a socially isolated next 7 weeks without hampering the progress. We changed the solar charge controller form MCP73831 to TP4056, added an NTC Thermistor for temperature detection, added MT3086, a DC-DC boost converter with 97% efficiency.

From the conceptual model in Fig 3 and schematic in Fig. 24, the following will occur if we were able to produce a physical design:

- Sunlight meets the solar panel which then converts the light to DC voltage
- This voltage is then boosted due to the DC-DC converter

- Output of the DC-DC converter will go directly to the input of the charge controller, V_{CC}. The charging chip then charges the battery as well as provides temperature protection. LEDs, which are connected to Pin 6 (CHRG) and Pin 7 (STDBY), light up to reflect the current charging status.
  - Using an NTC Thermistor, the charge controller will stop charging the battery if the resistance changes significantly (that is, if temperatures are out of range)
- MT3608 and TP4056 circuit is connected to DW01, which provides the necessary over-charge, and discharge protections.
- Through DW01, the battery is then connected to the load which is the water meter.

The enclosure, solar panel, and the PCB are all within the required dimensions and with the schematic built from research and following the data-sheets, we would be able to produce a functioning product. However, due to conditions beyond our control, we were unable to present a physical prototype or get data results to supplement that.

7.1 Data Collection

7.1.1 Materials Required

- Energy harvester module with its battery depleted
- Ultrasonic water meter
- Pyranometer (Solar irradiance meter)
- Dimmable full spectrum sunlight bulb
- Data recording multimeter(s) with probes for simultaneous voltage and current measurement
- Battery indicator (Battery charge level reader)

7.1.2 Measuring energy usage of the module

Shine the light on the solar panel at different irradiance levels as read by the pyranometer placed next to the panel. Keep the angle constant. At each level, measure the voltage change from just after the solar panel to just before the battery. Then, measure the current at each of those points as well. Using P = IV, calculate the power at each measure site. The difference is the usage by the circuit. Plot the power usage vs irradiance to visualize the results.

7.1.3 Measuring the charge cycle

Deplete the battery. Set the bulb to a constant irradiance. Connect the multimeter to the circuit right before the battery. Read voltage and current data until TP4056's STDBY LED indicates complete charging. Verify full charge with the battery indicator Plot current vs time and voltage vs time to document the charge cycle.

This experiment should also be repeated with the load connected and pulling maximum power (5mW). Connect a probe right before the load as well to take any load variation into consideration. This will record the module's behavior when energy harvesting and usage are happening simultaneously.

7.1.4 Measuring discharge

Start with a fully charged battery. Connected the load with a probe directly before it at maximum power (5mW). Record the voltage and current data. After 30 minutes or another desired time period, check the battery level with the battery indicator. Compute the discharge rate and verify that the load is being powered properly.

7.1.5 Testing temperature protections

In a professional laboratory setting and with proper safety measures, shine the bulb on the module with its battery at least 25% depleted. Place a probe just before the battery and begin recording data. Heat the ambient temperature up to 50°C and watch for the charging current to drop to near 0 mA. This will confirm that high temperature protections are functioning. Allow the battery to cool to room temperature. Repeat the experiment but cool the ambient temperature to -5°C instead.

8 Ethics

Ethics is, as a topic, is subjective. It is often guided by a person's individualistic experiences and through education. Therefore, it differs per person but we can define the direction of the group by aligning where the moral compass of each person is pointed towards.

Throughout the design process, least cost was the number one priority. At each juncture, China was always the cheapest for each aspect of the design: sourcing parts, manufacturing as well as assembly. Looking from a least-cost perspective, this is a business-win.

A successful design does not just win on the business-level. There are much larger forces at play in our lives than just what the financial world entails. While there are obvious business benefits to using Chinese parts and labor in the proposed system, we had to ignore some other reasons we were not comfortable with. Those include labor issues within China. It has long been established that China is consistently involved in child labor [35] along-with mistreatment of laborers [36] and consistent increases in suicide rates for migrant laborers [37]. For migrant laborers, work is tied to dormitory which makes their mistreatment more prevalent [36, 37].

No, morally, the authors of this report were not okay with this position. It is not about singling, but about sourcing all parts/labor from places where there isn't mistreatment of laborers or child-labor involved. That includes other parts of the world as well, but the focal point of this report is China since that's where our parts are being sourced from.

While under-developed countries do benefit by getting business from developed countries — China is by no means under-developed. As a Xylem employee, It's about where we, as a company, draw the line when it comes to morality. It's about how we consistently define where our moral compass is pointed towards.

Moving on, China has also been involved in severe oppressionism in Hong Kong and Taiwan [38], as well as being involved in severe human rights violations against Uyghur Muslims [39]. Stories about forced labor are also increasingly common in China [40].

Bringing it all together, the point is that in a capitalist society, money speaks louder than words. In a financially capitalist society, maybe we can look at capitalism from a human perspective instead of a financial one. As a company, we should preferably ensure that our products are not used in exploitation of humans to enrich other humans' lives — instead, we can manage our supply-chain to only include sourcing from where labor malpractices aren't rampant.

It all begins at the source — the Engineering team. The supply chain team can only do so much without a similar direction from Engineering. Then understandably, part of this proposal is to look for alternatives as part of future work into this project. Perhaps it could be proposed that the cost restriction be relaxed, so we can meet the ethical goals as well.

9 Project Management

9.1 Timetable

Our original timetable is visible in Fig. 22. Fig. 23 the final project timetable. The following were modified:

- **Design Development and Components:** These tasks could not be completed nearly as quickly as we had assumed. The problem wasn't deciding the desired specifications of the components, but finding real products on the market that fit those specifications and were compatible with the rest of the design. Our component choices changed often, due to an improvement of performance, size, or cost, forcing us to redesign significant portions of the module.
- **Enclosure:** Specifying an enclosure was not something we had thought very hard about in the beginning. However, it was a time-consuming and important piece of the project.
- **Write user manual removed:** We felt that the final report already described the module in detail and that writing a user manual would take time away from improving the final report.
- **Power electronics design:** This took far longer than we had anticipated. It was the most intense part of our design. For example, we created a whole prototype around the MCP73831, then decided to change to TP4056, overhauling the core of the entire design.
- **Build & Test:** We did buy, receive, and construct a prototype. However, we finished it and did minimum testing right before Spring break. After we moved to distance learning, constructing any new prototypes and testing them were no longer options.
- **Tasks by group members:** Many individual tasks are now listed as group tasks ("All").This is because they took more time or were more complex than we expected. Thus, everyone collaborated and helped each other out.

9.2 Team Meetings

Throughout the duration of our project, we followed a method similar to the Agile Project Management strategy. This strategy calls for constant improvement, flexibility, and team communication. For the initial 15 weeks, we set up meeting times and locations on campus to congregate and do research, and gather ideas. At the end of each meeting, we set out a plan on what needs to be done during the week, assign tasks, and plan the next meeting date. We also wrote out meeting minutes after every meeting to keep track of the progress we made every week. When we had a plan on how to develop our initial prototype, we drew out a basic schematic, went to the Tinkering Lab, and designed. After this, we planned out how we can improve the prototype and how we can work towards our final design.

In the latter 15 weeks, when our project was changed to a simulated project, we had to suddenly adapt to these changes and work on a new plan with new goals. We then started again by contacting our EE494 instructors and Peter Casey, as well as had a meeting of our own, to plan out how we will continue. We continued to keep constant communication and hold our weekly meetings to continue assigning tasks, track progress, and ultimately design our circuit schematic, PCB, and enclosure.

Having consistent goals and tasks to work on each week along with weekly meetings helped us relay information off each other and allowed us each to make our own small progress that would eventually go towards finishing the actual project. Teamwork and communication were a key factor as well because it allowed us to ask questions and clarifications even after our meetings and throughout the week. It also helped each other understand different aspects of the project. This strategy was very useful and helped us immensely during our time with the project.

9.3 Summary of Hours

The summary of hours completed by each person is presented in Table 13.

Name	**Time Input**	**Leader On**
Siddhant Khera	255 Hours	Report Compilation and Electrical Design Development & Production, General Management
Serena LaFave	136 Hours	Report Writing, Soldering and Prototyping
Krystal Bakr	136 Hours	Managing Technical Documentation, Project Financials and Research

Table 13: Summary of Hours Per Person

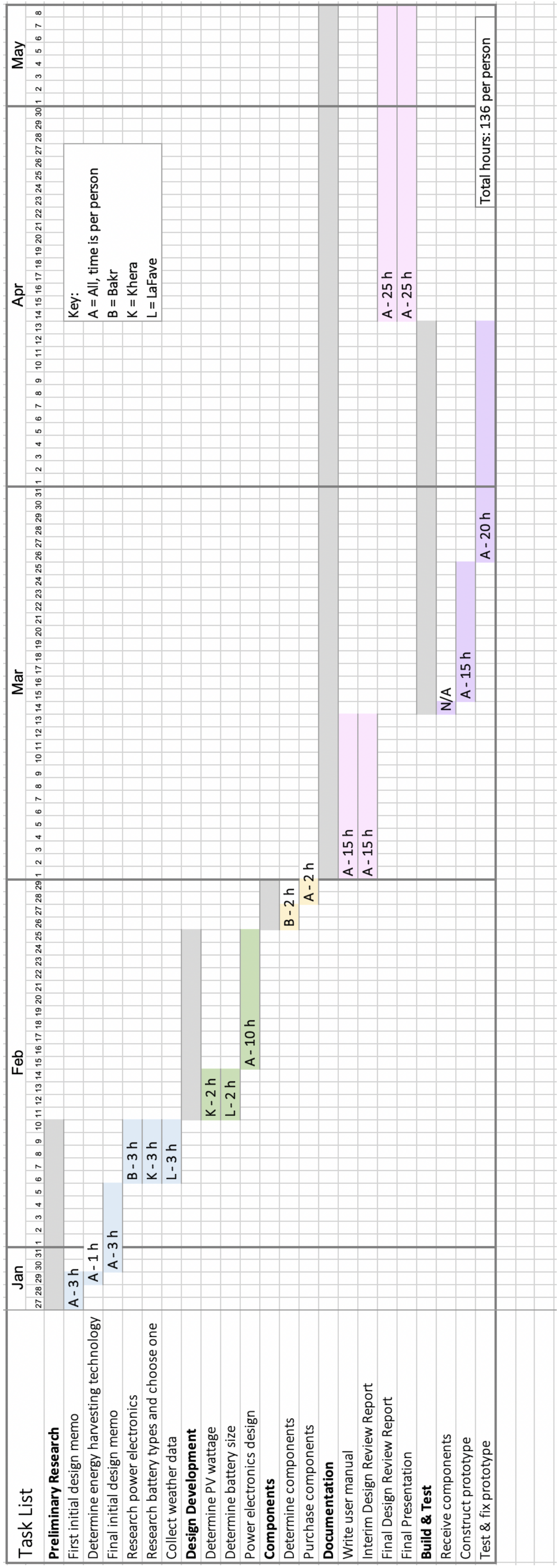

Figure 22: Originally Planned Timeline for the Semester

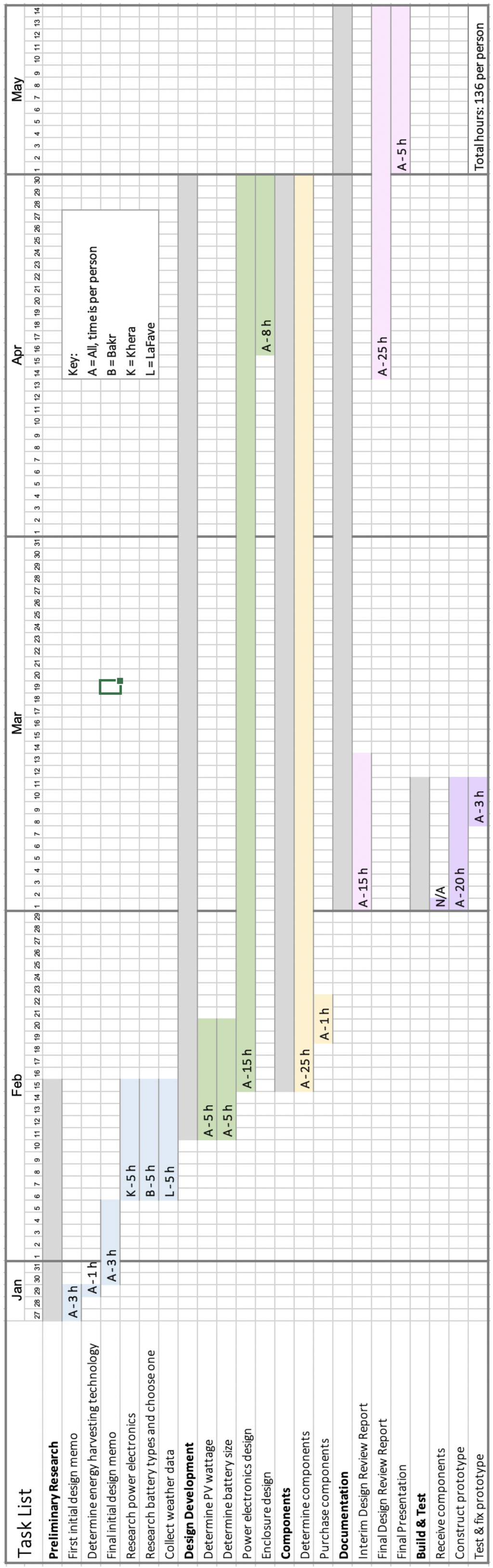

Figure 23: Final Timeline for the Semester

10 Conclusions

Our goal was to design an energy harvester that, with the use of alternative energy sources, will harvest energy for an off-grid water meter — with a consideration for cost and size efficiency. The final design we have presented achieves the goal and the requirements. Our final design includes the drivers necessary to harvest energy from the sun through a solar panel, and produce a sufficient voltage that will charge the Li-Ion battery which powers the water meter. This design and all components were considered for size requirement and the protection measures added to the circuit were considered for the overall safety and longevity of the design. In the end, on a high-volume scale, our design can be reproduced for just under $3.

Despite the inability to produce a physical prototype, our final design was made with careful considerations and thoughtful research. A functioning product could be achieved if given more time to work on the project, and under ideal societal circumstances. However, our design is sufficient in cost, safety, and performance - all of which will be very beneficial for Xylem and the consumers. In the following section, we have listed possible ways we could have taken the project further.

11 Future Work

11.1 Improved Enclosure — Using Aluminum and Heat Sink

Li-ion battery life can degrade in temperatures below -20°C or above 60°C [15]. Li-ion charging is also not recommended below 0°C or above 45°C — which is why we added a temperature protection circuit, but the enclosure can still be further insulated. Thus, a better enclosure would be made of aluminum. This way, we could attach heat sinks to the sides of the enclosure and help cool down the battery [41]. Plastic is a thermal insulator, so the current design doesn't have an efficient way of ridding heat [42]. Such a design improvement could help lengthen the battery's life. We would need to spend more time customizing an aluminum enclosure and heat sinks that would meet our budget needs, since Aluminum work is usually more expensive than plastics [41].

11.2 Physically Produced Prototype

We were able to get a working initial prototype that helped us navigate our path for working towards our final prototype. However, we were not able to construct a final prototype due to lack of resources available as a result of laboratory closures. In the future, our project could be immensely improved if we were able to construct an actual prototype. It would help us be able to continue the design process by allowing us to test in different weather conditions, get data, and adjust our design as needed to agree with all of the water meter requirements. This would be a great way to present evidence to Xylem that we have met all requirements of the project, and propose a functional prototype that can be used for commercial purposes.

11.3 Obtaining SPICE for Simulation for use in Further Development

As mentioned in a previous section, we were not able to obtain a SPICE library, which we would have needed for a simulation. Despite contacting suppliers, we were not able to get these libraries. This was detrimental for our project as it prevented us from verifying if our design worked at all. If given more time to reach out to more manufacturers, we may have been able to get access to the items we needed in order. Even more time to reach out to Xylem for their assistance in getting access to the libraries would have also aided us in being able to simulate and prove that we have a working design.

11.4 Empirically Finding Exact Energy Usage of PCB board

One important value that we have had to estimate is the circuit's total energy usage. It is recommended that experiments would be carried out to measure this exact value. This could be done by shining light onto the solar panel at varying intensities. At each intensity, measure the voltage change from just after the solar panel to just before the battery. Then, measure the current at each of those points as well. Using $P = IV$, calculate the power at each measure site. The difference is the usage by the circuit. Plot the power usage at the different light intensities to gather a strong data-set.

11.5 Modeling the Solar Panel and System Performance Curve

In our original plan, part of the physical prototyping was to model the performance of the system — specifically of the solar panel — to understand and predict various scenarios. With a historical baseline and predictive modeling, performance patterns can be discovered.

11.6 Sourcing Parts from Nations with Effective Labor Laws

As discussed in Section 8, we were not comfortable sourcing our design from China due to ethical and moral reasons. The sole reason why we limited our parts and labor to China was because of the limitation on cost for a manufactured product. Work could be conducted going to forward to complete a cost-analysis for how much it would cost to source from countries with strong and effective labor laws. It doesn't have to be within the US, but could be any country where we, as a company, could confirm that no humans were harmed in the making of our product.

Perhaps upon completion of a successful cost-analysis, a proposal could be put forward to the stake-holders to increase the cost restriction by $x\%$ to allow for parts to be sourced from ethically responsible areas.

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A Schematics and Design

This Appendix contains the Schematic of the final design, as well as PCB design related images.

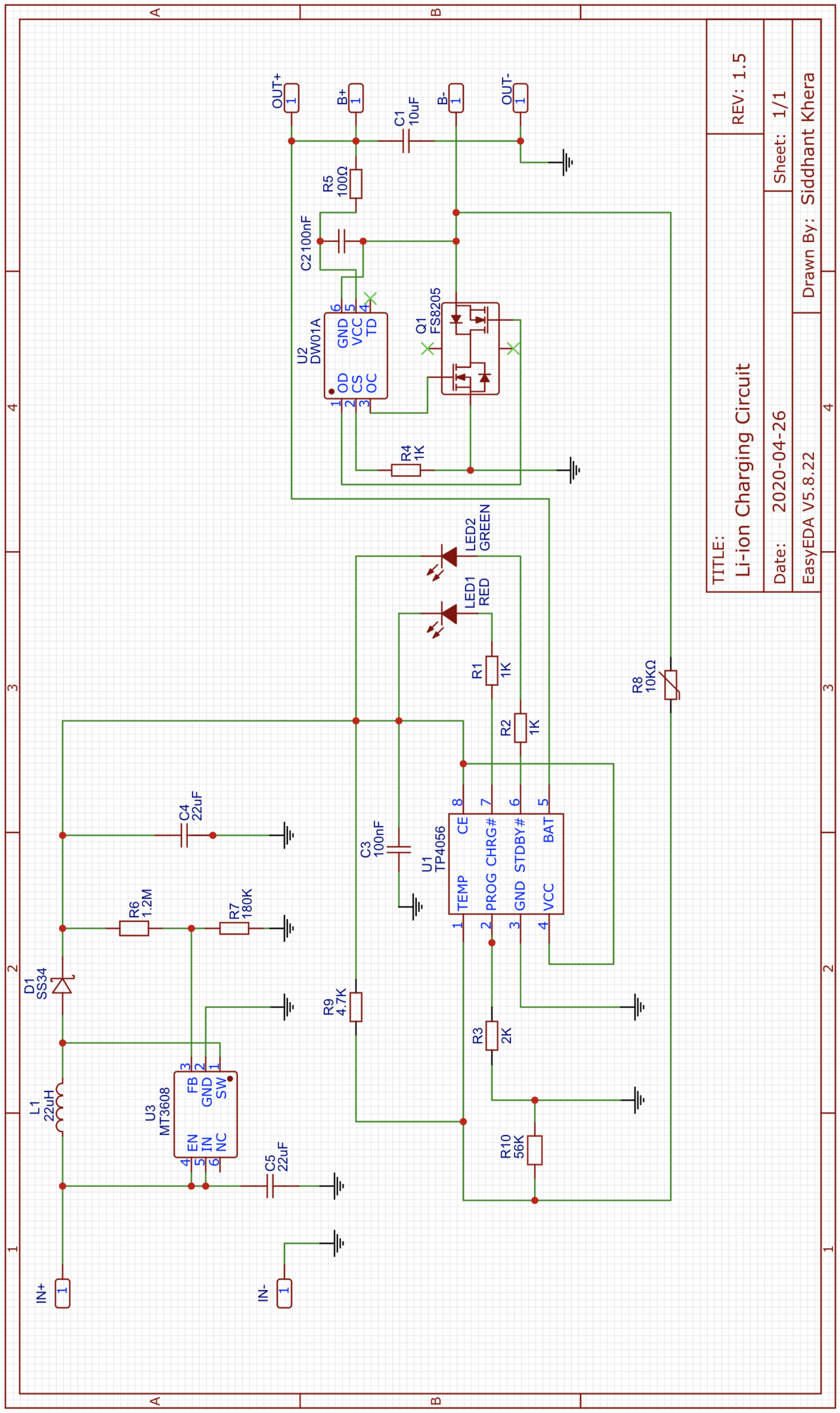


Figure 24: Final Li-ion Charging Circuit

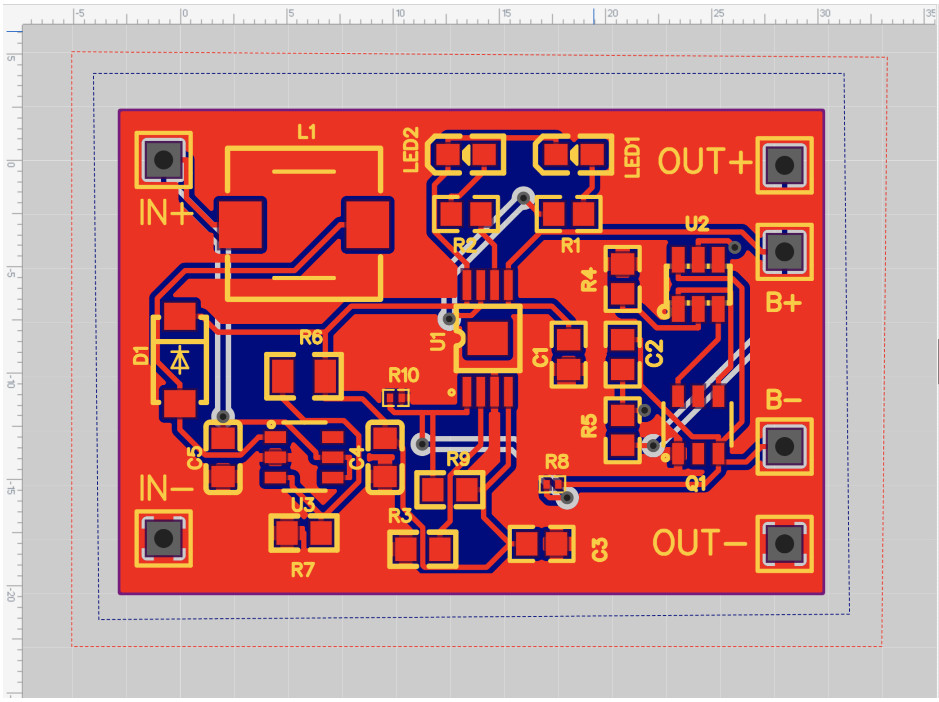


Figure 25: The Custom Designed PCB on the Design Board

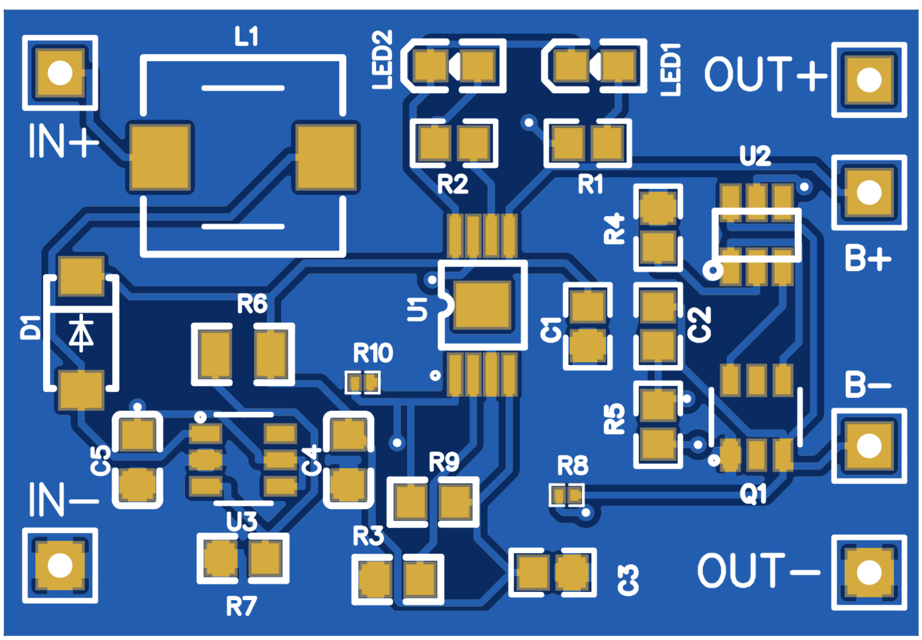


Figure 26: Photo View of the Custom Designed PCB

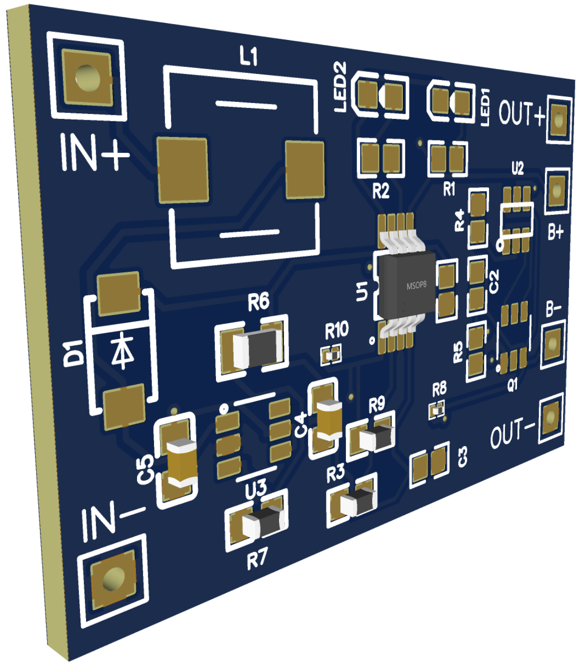


Figure 27: 3D View of the Custom Designed PCB

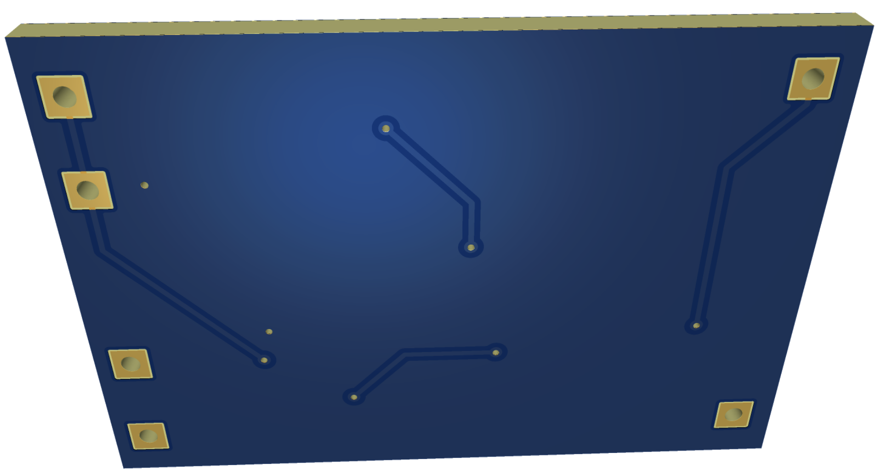


Figure 28: Back Layer (3D) View of the Custom Designed PCB

B Bill of Materials

This appendix contains the Bill of Materials — the cost to produce this design. As noted below, it is under the $3 requirement set forth by Xylem.

Table 14: Bill of Materials for Solar Energy Harvester for Water Meter

Source	Type	Part	Cost	# Available
https://lcsc.com	IC	MT3608	$0.0537	69,490 Units
https://lcsc.com	IC	TP4056	$0.0422	79,120 Units
https://lcsc.com	IC	DW01	$0.0324	750 Units
https://lcsc.com	IC	FS8205	$0.1019	2,489 Units
https://lcsc.com	R_7	$120k\Omega$	$0.002	17,900 Units
https://lcsc.com	R_6	$1.2M\Omega$	$0.0015	3,500 Units
https://lcsc.com	R_3	$2k\Omega$	$0.003	164,700 Units
https://lcsc.com	R_1	$180k\Omega$	$0.0011	6,500 Units
https://lcsc.com	R_2	$1.2M\Omega$	$0.0018	3,350 Units
https://lcsc.com	R_4	$1k\Omega$	$0.0033	399,550 Units
https://lcsc.com	R_5	100Ω	$0.0017	10,700 Units
https://lcsc.com	R_8	$10k\Omega$	$0.0077	3,350 Units
https://lcsc.com	R_9	$4.7k\Omega$	$0.0012	108,800 Units
https://lcsc.com	R_10	$56k\Omega$	$0.0016	92,300 Units
https://lcsc.com	C_1	$10\mu F$	$0.0016	85,360 Units
https://lcsc.com	C_4	$22\mu F$	$0.002	17,990 Units
https://lcsc.com	C_5	$22\mu F$	$0.0196	17,990 Units
https://lcsc.com	C_2	100 nF	$0.0068	1,058,950 Units
https://lcsc.com	C_3	100 nF	$0.0068	1,058,950 Units
https://lcsc.com	LED_1	Red	$0.0105	189,220 Units
https://lcsc.com	LED_2	Green	$0.0107	234,231 Units
https://lcsc.com	L_1	$22\mu H$	$0.0109	15,308 Units
https://lcsc.com	Diode	SS34	$0.0163	757,700 Units

Continued on next page

Table 14 – continued from previous page

Source	Type	Part	Cost	# Available
https://lcsc.com	Battery		$0.62	775 Units
https://lcsc.com	Solar Panel		$0.7255	800 Units
https://jclpcb.com	PCB Production		$0.0335	80,000 Units
https://jclpcb.com	PCB Assembly		$0.15	80,000 Units
https://alibaba.com	Enclosure		$0.558	1000+ Units
https://alibaba.com	Mounting Plate		$0.0075	>3000 kg
https://aliexpress.com	Solar Panel Holders (4)		$0.01	>3000 kg
https://aliexpress.com	2x4 mm Screws (10)		$0.146	20,000 Units
https://alibaba.com	Battery Holder		$0.3368	5000+ Units
		Total:	**$2.9276**	

Note: Prices listed in Table 14 are current as of 5/10/2020, and are subject to change.

Therefore,

$$\boxed{\text{Total Cost to Produce Present Design } = \$2.9276}$$

C Relevant Material from Interim Review

This appendix relevant material from the Interim Design Review, most of which heavily influenced our work since and has been referenced.

C.1 Solar Panel

Though important, some societal factors were not considered: Health and safety as well as ethics, because all panels are manufactured in China and are thus subject to the same laws and regulations. Similarly, due to no difference in origin, any social and political impacts of buying from China are the same. We feel that social and political impacts of the final product itself are nonexistent or at most, irrelevant. We chose to evaluate only the environmental impact and sustainability of the packaging itself since the shipping distance from the origin is similar. Also, all panels are of polycrystalline type, thus using mostly the same materials. Table 15 shows the decision matrix for the solar panels.

Company	Size (mm)	Peak Wattage	Panel Cost	Shipping Time	Packaging	Units Available	Economic Impact
SUNYIMA	52x52	0.48W	$0.81*	2 weeks	Non-recyclable	>64k units	Non-US Company
TxHang	90x60	0.6W	$1.82	6-9 weeks	Non-recyclable	No data	US Company
AOSHIKE	68x37	0.3W	$1.59	0.5 weeks	Recyclable	13 units	US Company

Table 15: Solar Panel Decision Matrix

*This set had 100 panels, which was far more than necessary; it was a negative trait.

Component	Details	Seller	Fulfillment By
Solar panel	5V, 60mA, 0.3W	AOSHIKE	Amazon
Battery 1	1200mAh, Li-ion, 3.7V	iMahDirect	Amazon
Battery 2	1200mAh, Li-ion, 3.7V	Kanavano	Aliexpress
Charge controller	IC MCP73831T-2	Microchip	Digi-Key
Chip Adapter	SOT-23 to DIP	NKC Electronics	Amazon
Battery Holder	18650 Battery Case	Jninsens	Aliexpress

Table 16: Component Details and Seller Details

Despite the lower peak wattage and lack of availability, we chose the AOSHIKE panel particularly due to the quick shipping time. We wanted to get started on the project as soon as possible. We also knew that the most important aspect of the initial design was the charge controller, and that the solar panel could be relatively easily switched out to a better one for the final design.

C.2 Battery

First, we had to decide on the battery type. The selection criteria included the following:

- Days of charge capacity at 5mW constant power usage

- Cost (for a low volume purchase, not in high production)
- Approximate shipping time
- Manufacturability - How many components are readily available?

Other societal impacts were again not considered for the same reasons as mentioned before for the solar panel. Additionally, environmental impact and sustainability of the packaging and economic impact were not considered because all packaging was non-recyclable and all orders were fulfilled through non-US companies. This is because US-based fulfillment companies sold far more expensive batteries.

Table 17 below shows the decision matrix for the batteries.

Company	**Days of Charge**	**Cost (USD)**	**Approx. Shipping Time (Weeks)**	**Components Available (Manufacturability)**
Kanavano	37	0.71	<5	998
PINTTENEN	40	0.93	6	938
Liitokala	61	1.8	9	883

Table 17: Battery Decision Matrix

We decided on the Kanavano battery (lithium-ion). Because they were due to take a while to ship, we bought a similar 3.7 V, 1200 mAh non-18650 (because other package types were cheaper) battery on Amazon to use while we wait. However, the Kanavano batteries arrived in about one week, so we never used the Amazon battery.

C.3 Charge Controller

The last component on our list was a charge controller. We looked at a few off the shelf charge controllers [43–45] but they were too expensive for our application.

Since the off the shelf PCBs were expensive, we decided that we would engineer/reverse-engineer our own charge controller. All the IC chips we looked at included pre-conditioning and a temperature sensing pin. Pre-conditioning is important for lithium batteries to safely revive deeply discharged cells and also to avoid high heat during initial state of charging [46]. Managing charging at different temperatures is also essential because Li-ion batteries can only operate within certain temperature ranges. Safe temperatures for operation of a Li-ion battery is between 10°C and 45°C [22]. Operation of a Li-ion battery at or under 0°C permanently damages the cells [22].

A Chinese company called Consonance manufactures lithium-type charge controller chips specially suited for solar systems, such as the CN3083 chip [47]. Unfortunately, their website does not allow direct purchase — must inquire about the chips, something we wanted to avoid due to possible wait times. We also checked on Ebay, where we were told that due to the Coronavirus outbreak, the office was closed. Thus, we searched for other alternatives for our initial design.

We decided on using the MCP73831. At only $0.56 per chip, it includes the following features:

- Selectable preconditioning
- Selectable end-of-charge control
- Programmable charge current
- Reverse discharge protection
- LED-connectable charge status indication
- Thermal regulation for high temperatures
- Constant-current, constant-voltage charging
- Automatic power down

A decision matrix was not created for selecting a chip because the options for a low-cost, single cell lithium-type charge controller were quite limited. However, the relevant characteristics are still described below, proving it is a favorable choice:

- Physical size: Miniature
- Cost (for a low volume purchase, not in high production): Very low — $0.56
- Approximate shipping time: Fast — 5 days

- Environmental impact and sustainability: Recyclable packaging
- Manufacturability: High — 6 weeks of lead time allows for virtually any desired number
- Economic impact: Positive — US based company fulfills order
- -40°C to 80°C operation

When we received the chips, we were quite shocked at the miniature size: roughly $3.1mm \times 2.5mm$ (which is a regular SOT-23 package size). We had assumed the chip would be of similar size to those used in lab, and did not look up the size of its SOT-23 package. Since we were planning on using a breadboard to build prototypes, we purchased a set of SOT-23 to DIP adapters at $0.70 each. We then soldered the chip in place, along with six header pins which we already owned. Though it was an extra step in the prototyping process, if used in the final design, it can be directly integrated into a PCB without an adapter.

C.4 Building Successful Prototype

Component	**Date Received**	**Units**	**Item Cost**	**Shipping**	**Total Cost**
Solar panel	Feb-25	10	$15.87	$0	$15.87
Battery 1	Feb-25	1	$7.99	$0	$7.99
Battery 2	Mar-04	5	$3.82	$6.3	$10.12
Charge controller IC	Feb-29	5	$3.48	$4.99	$8.47
Chip Adapter	Mar-06	10	$6.95	$0	$6.95
Battery Holder	Not yet received	3	$1.11	$0.86	$1.97
				Total	**$51.37**

Table 18: Cost and Delivery Details of the Components Ordered

C.4.1 Prototype One

The first circuit that was built using MCP78381 is visible in Fig. 29. This was a modification of a sample application described [8] in the datasheet of the chip. This design failed to work, even though we confirmed that the battery was connected to the system, the solar panel was supplying enough voltage and the system was fully grounded. We attributed it to either a misconnected charge indicator since the DC Bias points were correct.

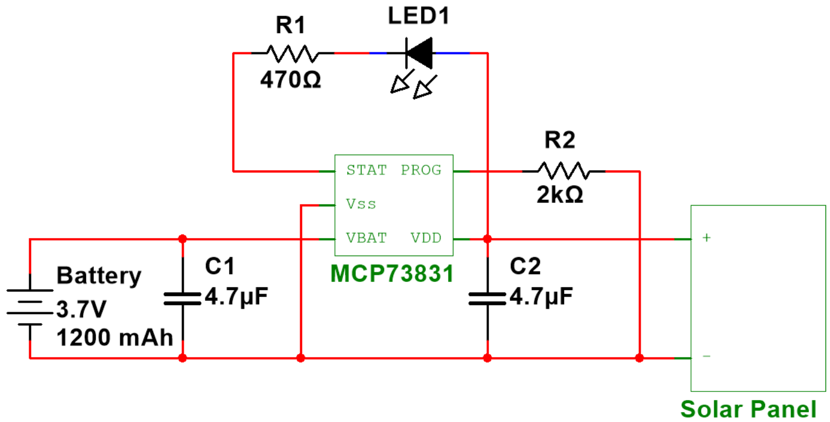


Figure 29: First Prototype Design — Did Not Work

C.4.2 Prototype Two

The second prototype was also built using MCP78381. For this one, we looked at the datasheets of all other charge controllers as well as the system block diagram for MCP78381 [8] to design the circuit. The circuit that is used in Prototype Two is visible in Fig. 30. Prototype Two worked from the beginning. The Red LED lit up since the battery was charging. Since we completed this prototype a few days before we wrote this section, we weren't able to test this prototype under the sun due to cloudy weather in Buffalo.

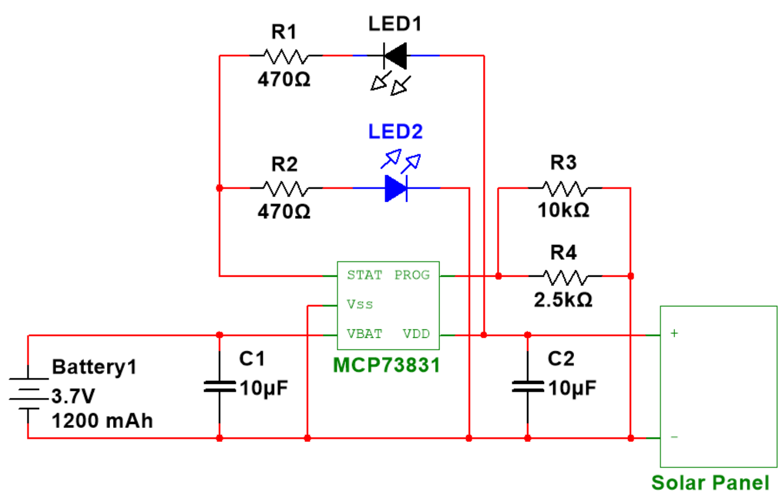


Figure 30: Second Prototype Design — Worked

We tested the charge controller circuit by simulating the voltage and the current, delivered by the solar panel, through a DC Power Supply. This allowed us to test if our charge controller was working as designed, and we verified that the DC Bias points were exactly as designed and calculated.

We also did, however, test the capabilities of the solar panel itself by shining bright sources of (two to three) LED spotlights. The solar panel we used is rated for 5V and did indeed deliver up to 4.91V according to the lab multimeter. We found that the voltage of the solar panel under regular light was 2.3V to 2.7V.

Though the prototype was successful, there are several issues related to temperature, circuit protections, and charging voltage. Our plans for these issues are discussed in Section C.5.

Additionally, we plan to further include temperature sensing to avoid permanent damage to the battery as well as Charge Protection IC to avoid overcharge, over-discharge, overvoltage and under-voltage. All of these conditions are potentially dangerous because they can ignite the battery.

Finally, further pictures of Prototype Two are also included. The frontal view and the top view of our prototype board is visible in Fig. 31 and Fig. 32.

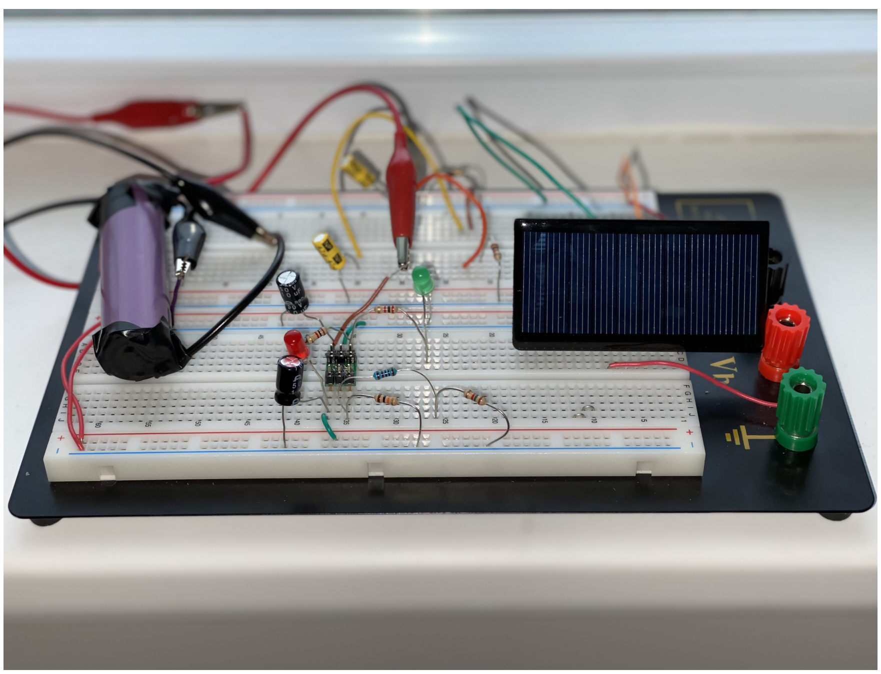


Figure 31: Protoype Two — Front View

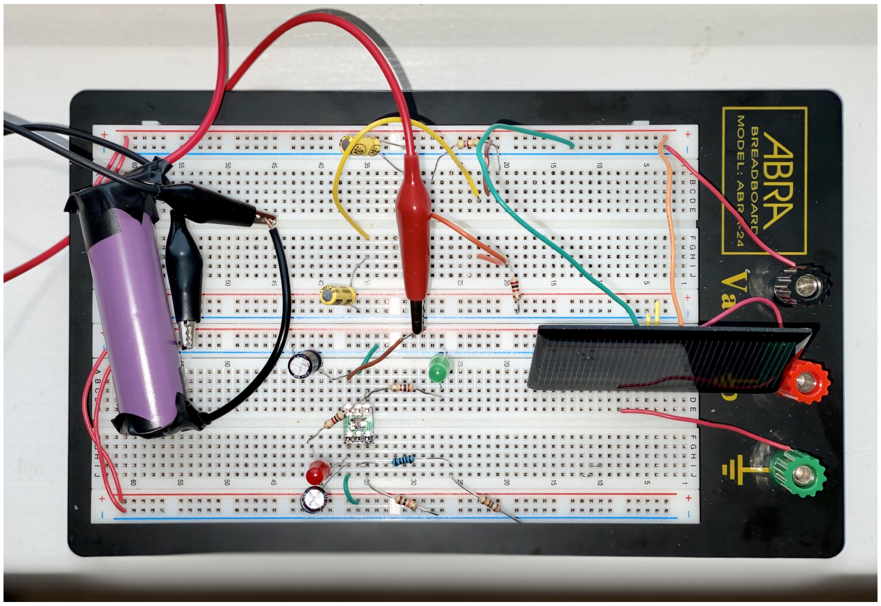


Figure 32: Protoype Two — Top View

C.5 Next Steps

C.5.1 Temperature Protections

The current IC we are using for the charge controller (MCP78381) does not have support for temperature sensing, and this is currently we would like to implement even though it was not defined specifically in the initial design memo. One option is to use an NTC Thermistor [3]. TP4056, CN3083 and CN3791 all have support for NTC Thermistors on their TEMP pin [1,47,48]. An NTC Thermistor is usually found in the battery, and it is a resistor that is very sensitive to changes in the temperature. The three chips mentioned measure if "TEMP pin's voltage is below 45% or above 80% of supply voltage VIN for more than 0.15S" [1]. This works since Li-ion batteries cannot supply the rated voltage if they are freezing or overheating [22]. So, the cut-off ensures that the Li-ion battery is not charged when it is not at an optimal temperature. The TEMP pin is directly connected to the negative terminal of the battery so is directly connected to the battery.

The battery we have ordered does not have an included NTC Thermistor within the cell, so we plan to use an external resistor. An example of an external NTC Thermistor is visible in Fig. 33.

Figure 33: External NTC Thermistor in Our Plans [3]

C.5.2 More Circuit Protections

Due to the demanding temperature range requirements and the danger and sensitivity of lithium-ion batteries, more circuit protections are needed. Our goal is to integrate all of the following protections:

- Short-circuit
- Overcharge
- Over-discharge
- High discharge rate
- Over-voltage
- High and low temperature, as discussed earlier

Without all of these protections, the battery is subject to damage, accelerated degradation, and poses a fire hazard. MCP73831 has overvoltage, short-circuit, and high temperature protections. In addition to these, the TP4056, CN3083, and CN3791 chips have explicit overcharge, overdischarge, and overcurrent protections. And, as mentioned before, these chips support NTC thermistor integration, allowing for low temperature protections as well. Lastly, the TP4056 includes a "Soft-Start-Inrush-Current" [1] feature which lets the Li-ion battery warm up by supplying it with lower current in the initial charging stage. This helps reduce degradation over time.

C.5.3 Relatively High-Voltage Required for Charging

As mentioned in Section C.4.2, the voltage produced by the solar panel in lower light was 2.3 to 2.7 V. However, the minimum V_{DD} of MCP78381 is 3.7V. Thus, the battery does not charge at all in these conditions. Though Yuma offers high radiation, we want the system to be more reliable by charging at lower radiation as well. Other chips we've discussed require even higher input voltages: TP4056 at 4.0 V [1], CN3083 at 4.4 V [47], and CN3791 at 4.7 V [48]. There are several options of dealing with this issue:

- Test the current solar panel. Our current solar panel does not have a datasheet; in order to see voltage vs. radiation, we would have to conduct tests on the panel. These tests likely won't be very accurate, but will allow us to compare the panel's capabilities to Yuma's radiation. This way, we can see if it will still supply enough energy for the system's needs. However, this option is not our top choice because the present 5V peak voltage panel is only really viable for the 3.7V minimum input voltage of the MCP78381. Meanwhile, the other chips discussed have more desirable features; this brings us to option 2.

- Buy a panel with a higher maximum voltage. This will enable a wider range of radiation with which the battery can be charged. It will also decrease the radiation needed to meet 14 days worth of energy, making the system more robust. Lastly, it will allow us to use the other chips mentioned that require higher input voltages.

C.5.4 Improve Yuma weather analysis

Our current Yuma weather data only includes the minimum number of daylight hours. This is not enough information to speak of the final system's abilities - engineering standards require exact values. We plan to utilize Climate Consultant 6, weather data analysis software by UCLA. So far we have loaded in Yuma's data and briefly checked out the radiation data. The plan is to analyze this data and figure out how much radiation will actually be converted into electricity, taking into account seasons, solar panel efficiency, and, if possible, tilt angle and direction.

C.6 Future Plans

Between March 12, 2020 until May 8, 2020, we plan on improving the state of our prototype and testing in different settings to get accurate data to analyze and present at the conclusion of the project period. As mentioned in the previous section, we plan on adding a thermistor in order to detect and protect the battery from damage due to heat and quicker discharge in low temperatures. We also want to adhere to the goals we set in our initial design memo that were not necessarily outlined by Xylem. We plan on making our design waterproof, using the IP51 standard to determine our success. We also want to make this project as environmentally friendly as possible. As discussed in Section C.5, there are many fallbacks to the MCP78381 chip used in our current prototype. We shall create a decision matrix that includes all the aforementioned chips; MCP78381, TP4056, CN3083, CN3791 and possibly others. We will then make a decision and update our prototype.

In the coming weeks, we will be working towards testing our prototype in different environments and in different temperatures in order to test the efficiency of our design. We will do this with a simulated load of 1mW to 5mW, and will get data for each environment we will be testing in. These environments include: day time on a sunny day, day time on cloudier days, and also night time. We also would like to test our prototype in various temperatures, mainly temperatures that will emulate the average temperatures in Yuma, Arizona. Also, we will be implementing our circuit on a PCB. Thankfully to the choice of our chips, moving our circuit from a breadboard to a PCB should not be complicated.

C.7 Conclusion

In conclusion, looking at the start of our project in late January, to now in mid March, our group has made good progress to the completion of our project. According to the Gantt Chart timeline presented in our initial design memo, we are not only on track with the deadlines we have set for ourselves, but we have surpassed our schedule. In the coming weeks until the completion of the project, we will be working to continue fixing our prototype and including materials that we feel will optimize our design and fulfill the requirements in the project. We also will be working on testing our prototype to get data that we can use to support the credibility of our design. Ultimately, we plan on putting everything together in a PCB and in an enclosure and produce our final product to the instructors of EE494 and Xylem.

D Datasheets

This section includes data-sheets from the following page to the end of the document. These are listed in the following order:

- TP4056 Data-sheet
- MT3608 Data-sheet
- DW01 Data-sheet
- FS8205 Data-sheet

Note: Since these data-sheets begin and end without headers. A cover page for each data-sheet is included to help navigate through multiple data-sheets.

TP4056 1A Standalone Linear Li-Ion Battery Charger with Thermal Regulation in SOP-8

DESCRIPTION

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its SOP package and low external component count make the TP4056 ideally suited for portable applications. Furthermore, the TP4056 can work within USB and wall adapter.

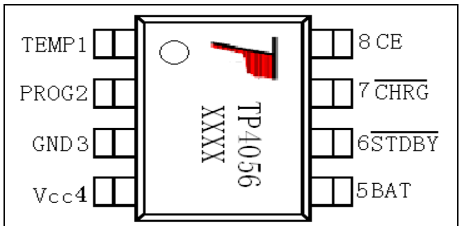
No blocking diode is required due to the internal PMOSFET architecture and have prevent to negative Charge Current Circuit. Thermal feedback regulates the charge current to limit the die temperature during high power operation or high ambient temperature. The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

TP4056 Other features include current monitor, under voltage lockout, automatic recharge and two status pin to indicate charge termination and the presence of an input voltage.

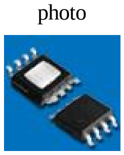
FEATURES

- Programmable Charge Current Up to 1000mA
- No MOSFET, Sense Resistor or Blocking Diode Required
- Complete Linear Charger in SOP-8 Package for Single Cell Lithium-Ion Batteries
- Constant-Current/Constant-Voltage
- Charges Single Cell Li-Ion Batteries Directly from USB Port
- Preset 4.2V Charge Voltage with 1.5% Accuracy
- Automatic Recharge
- two Charge Status Output Pins
- C/10 Charge Termination
- 2.9V Trickle Charge Threshold (TP4056)
- Soft-Start Limits Inrush Current
- Available Radiator in 8-Lead SOP Package, the Radiator need connect GND or impending

PACKAGE/ORDER INFORMATION



SOP—8

photo	ORDER PART NUMBER
	TP4056-42-SOP8-PP
	PART MARKING TP4056

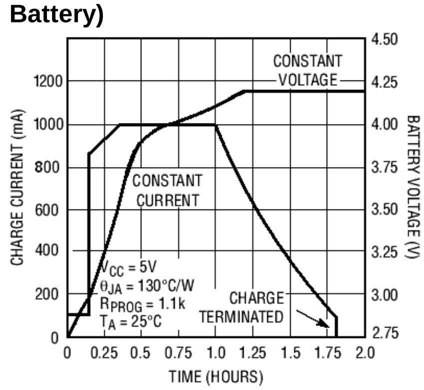
ABSOLUTE MAXIMUM RATINGS

- Input Supply Voltage(V_{CC})：-0.3V～8V
- TEMP：-0.3V～10V
- CE：-0.3V～10V
- BAT Short-Circuit Duration：Continuous
- BAT Pin Current：1200mA
- PROG Pin Current：1200uA
- Maximum Junction Temperature：145℃
- Operating Ambient Temperature Range：-40℃～85℃
- Lead Temp.(Soldering, 10sec)：260℃

APPLICATIONS

- Cellular Telephones, PDAs, GPS
- Charging Docks and Cradles
- Digital Still Cameras, Portable Devices
- USB Bus-Powered Chargers,Chargers

Complete Charge Cycle (1000mAh Battery)



TEMP(Pin 1) :Temperature Sense Input Connecting TEMP pin to NTC thermistor's output in Lithium ion battery pack. If TEMP pin's voltage is below 45% or above 80% of supply voltage V_{IN} for more than 0.15S, this means that battery's temperature is too high or too low, charging is suspended. The temperature sense function can be disabled by grounding the TEMP pin.

PROG(Pin 2): Constant Charge Current Setting and Charge Current Monitor Pin charge current is set by connecting a resistor R_{ISET} from this pin to GND. When in precharge mode, the ISET pin's voltage is regulated to 0.2V. When in constant charge current mode, the ISET pin's voltage is regulated to 2V.In all modes during charging, the voltage on ISET pin can be used to measure the charge current as follows:

$$I_{BAT} = \frac{V_{PROG}}{R_{PROG}} \times 1200 \quad (V_{PROG}=1V)$$

GND(Pin3): Ground Terminal

Vcc(Pin 4): Positive Input Supply Voltage V_{IN} is the power supply to the internal circuit. When V_{IN} drops to within 30mv of the BAT pin voltage, TP4056 enters low power sleep mode, dropping BAT pin's current to less than 2uA.

BAT(Pin5): Battery Connection Pin. Connect the positive terminal of the battery to BAT pin. BAT pin draws less than 2uA current in chip disable mode or in sleep mode. BAT pin provides charge current to the battery and provides regulation voltage of 4.2V.

$\overline{STDBY}$(Pin6): Open Drain Charge Status Output When the battery Charge Termination, the $\overline{STDBY}$ pin is pulled low by an internal switch, otherwise $\overline{STDBY}$ pin is in high impedance state.

$\overline{CHRG}$ (Pin7): Open Drain Charge Status Output When the battery is being charged, the $\overline{CHRG}$ pin is pulled low by an internal switch, otherwise $\overline{CHRG}$ pin is in high impedance state.

CE(Pin8): Chip Enable Input. A high input will put the device in the normal operating mode. Pulling the CE pin to low level will put the YP4056 into disable mode. The CE pin can be driven by TTL or CMOS logic level.

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are at **T_A=25℃， V_{CC} =5V**，unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{CC}	Input Supply Voltage		●	4.0	5	8.0	V
I_{CC}	Input Supply Current	Charge Mode, R_{PROG} = 1.2k StandbyMode(Charge Terminated) Shutdown Mode (R_{PROG} Not Connected,V_{CC} < V_{BAT}, or V_{CC} < V_{UV})	● ● ●		150 55 55	500 100 100	μA μA μA
V_{FLOAL}	Regulated Output (Float) Voltage	0℃≤T_A≤85℃，I_{BAT}=40mA		4.137	4.2	4.263	V
I_{BAT}	BAT Pin Current Text condition:VBAT=4.0V	RPROG = 2.4k, Current Mode RPROG = 1.2k, Current Mode Standby Mode, V_{BAT} = 4.2V	● ● ●	450 950 0	500 1000 －2.5	550 1050 －6	mA mA μA
I_{TRIKL}	Trickle Charge Current	V_{BAT}<V_{TRIKL}, R_{PROG}=1.2K	●	120	130	140	mA
V_{TRIKL}	Trickle Charge Threshold Voltage	R_{PROG}=1.2K, V_{BAT} Rising		2.8	2.9	3.0	V
V_{TRHYS}	Trickle Charge Hysteresis Voltage	R_{PROG}=1.2K		60	80	100	mV
T_{LIM}	Junction Temperature in Constant Temperature Mode				145		℃

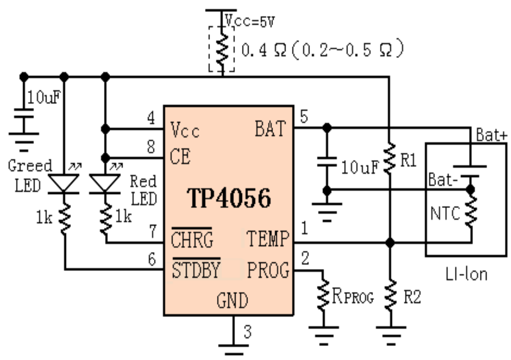
indicator light state

Charge state	Red LED $\overline{CHRG}$	Greed LED $\overline{STDBY}$
charging	bright	extinguish
Charge Termination	extinguish	bright
Vin too low; Temperature of battery too low or too high; no battery	extinguish	extinguish
BAT PIN Connect 10u Capacitance; No battery	Greed LED bright，Red LED Coruscate T=1-4 S	

Rprog Current Setting

RPROG (k)	IBAT (mA)
10	130
5	250
4	300
3	400
2	580
1.66	690
1.5	780
1.33	900
1.2	1000

TYPICAL APPLICATIONS



AEROSEMI

MT3608

High Efficiency 1.2MHz
2A Step Up Converter

FEATURES

- Integrated 80mΩ Power MOSFET
- 2V to 24V Input Voltage
- 1.2MHz Fixed Switching Frequency
- Internal 4A Switch Current Limit
- Adjustable Output Voltage
- Internal Compensation
- Up to 28V Output Voltage
- Automatic Pulse Frequency Modulation Mode at Light Loads
- up to 97% Efficiency
- Available in a 6-Pin SOT23-6 Package

APPLICATIONS

- Battery-Powered Equipment
- Set-Top Boxed
- LCD Bais Supply
- DSL and Cable Modems and Routers
- Networking cards powered from PCI or PCI express slots

GENERAL DESCRIPTION

The MT3608 is a constant frequency, 6-pin SOT23 current mode step-up converter intended for small, low power applications. The MT3608 switches at 1.2MHz and allows the use of tiny, low cost capacitors and inductors 2mm or less in height. Internal soft-start results in small inrush current and extends battery life.

The MT3608 features automatic shifting to pulse frequency modulation mode at light loads. The MT3608 includes under-voltage lockout, current limiting, and thermal overload protection to prevent damage in the event of an output overload. The MT3608 is available in a small 6-pin SOT-23 package.

TYPICAL APPLICATION

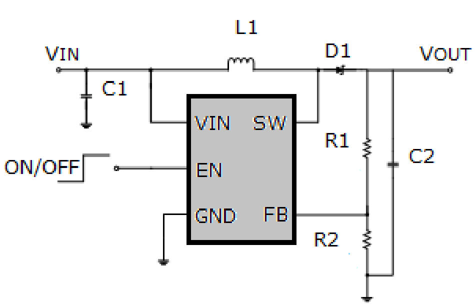


Figure 1. Basic Application Circuit

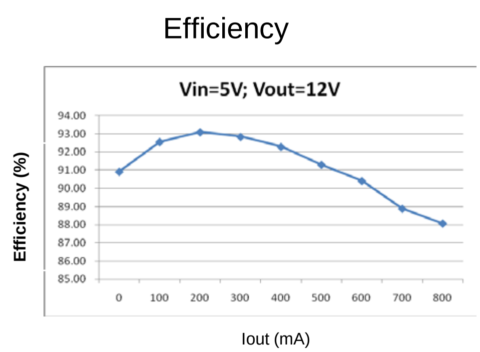


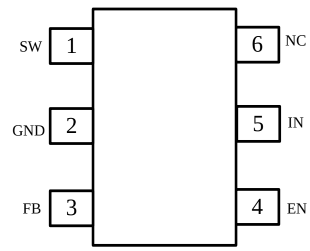
Figure 2. Efficiency Curve

ABSOLUTE MAXIMUM RATINGS

IN, EN voltages ………………… -0.3V to 26V
Operating Temperature……. -40°C to +85°C
FB Voltages ....-0.3V to 6V
Junction Temperature ………………..160°C

SW Voltage ……………………..-0.3V to 30V
Storage Temperature Range -65°C to 150°C
Peak SW Sink and Source Current ………4A
Lead Temperature (Soldering, 10s) ...+300°C

PACKAGE/ORDER INFORMATION



SOT23-6
(MT3608)

PIN DESCRIPTION

PIN	NAME	FUNCTION
1	SW	Power Switch Output. SW is the drain of the internal MOSFET switch. Connect the power inductor and output rectifier to SW. SW can swing between GND and 28V.
2	GND	Ground Pin
3	FB	Feedback Input. The FB voltage is 0.6V. Connect a resistor divider to FB.
4	EN	Regulator On/Off Control Input. A high input at EN turns on the converter, and a low input turns it off. When not used, connect EN to the input supply for automatic startup.
5	IN	Input Supply Pin. Must be locally bypassed.
6	NC	NC

ELECTRICAL CHARACTERISTICS

(V_{IN}=V_{EN}=5V, T_A = 25°C, unless otherwise noted.)

Parameter	Conditions	MIN	TYP	MAX	unit
Operating Input Voltage		2		24	V
Under Voltage Lockout				1.98	V
Under Voltage Lockout Hysteresis			100		mV
Current (Shutdown)	V_{EN}= 0V		0.1	1	µA
Quiescent Current (PFM)	V_{FB}=0.7V， No switch		100	200	µA
Quiescent Current (PWM)	V_{FB}=0.5V， switch		1.6	2.2	mA
Switching Frequency			1.2		MHz
Maximum Duty Cycle	V_{FB} = 0V	90			%
EN Input High Voltage		1.5			V
EN Input Low Voltage				0.4	V
FB Voltage		0.588	0.6	0.612	V
FB Input Bias Current	V_{FB} = 0.6V	-50	-10		nA
SW On Resistance (1)			80	150	mΩ
SW Current Limit (1)	V_{IN}= 5V, Duty cycle=50%		4		A
SW Leakage	V_{SW} = 20V			1	µA
Thermal Shutdown			155		℃

Note:
1) Guaranteed by design, not tested.

OPERATION

The MT3608 uses a fixed frequency, peak current mode boost regulator architecture to regulate voltage at the feedback pin. The operation of the MT3608 can be understood by referring to the block diagram of Figure 3. At the start of each oscillator cycle the MOSFET is turned on through the control circuitry. To prevent sub-harmonic oscillations at duty cycles greater than 50 percent, a stabilizing ramp is added to the output of the current sense amplifier and the result is fed into the negative input of the PWM comparator. When this voltage equals The output voltage of the error amplifier the power MOSFET is turned off. The voltage at the output of the error amplifier is an amplified version of the difference between the 0.6V bandgap reference voltage and the feedback voltage. In this way the peak current level keeps the output in regulation. If the feedback voltage starts to drop, the output of the error amplifier increases. These results in more current to flow through the power MOSFET, thus increasing the power delivered to the output. The MT3608 has internal soft start to limit the amount of input current at startup and to also limit the amount of overshoot on the output.

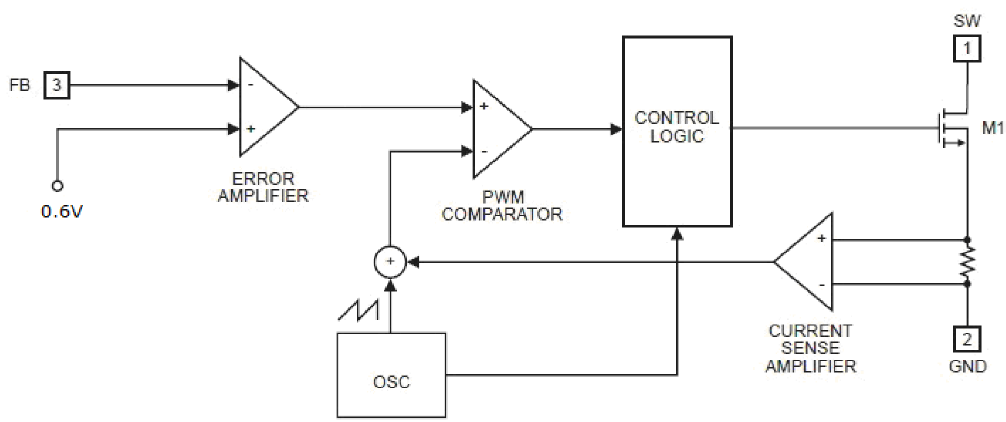
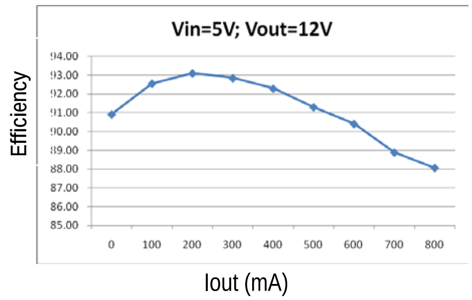


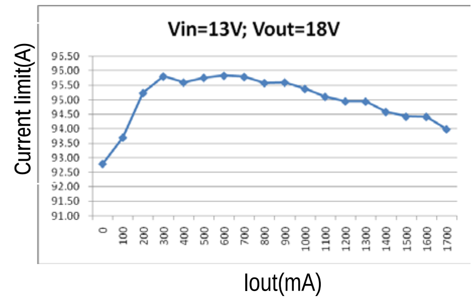
Figure 3. Functional Block Diagram

TYPICAL OPERATING CHARACTERISTICS

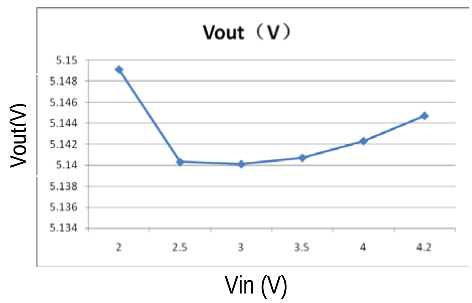
Efficiency Curve



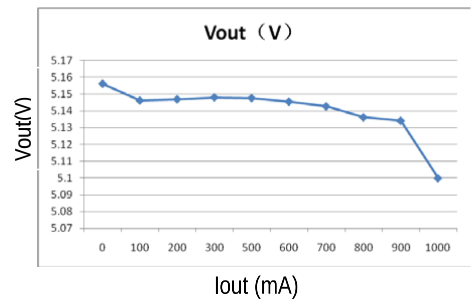
Efficiency Curve



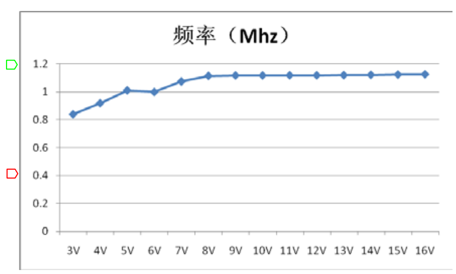
line Regulation



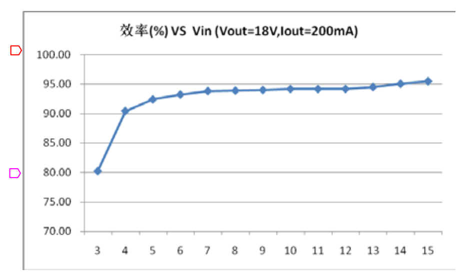
Load regualation



Freq VS Vin



Efficiency VS Vin



APPLICATION INFORMATION

Setting the Output Voltage

The internal reference VREF is 0.6V (Typical).The output voltage is divided by a resistor divider,R1 and R2 to the FB pin. The output voltage is given by

$$V_{OUT} = V_{REF} \times (1 + \frac{R_1}{R_2})$$

Inductor Selection

The recommended values of inductor are 4.7 to 22μH. Small size and better efficiency are the major concerns for portable device, such as MT3608 used for mobile phone. The inductor should have low core loss at 1.2MHz and low DCR for better efficiency. To avoid inductor saturation current rating should be considered.

Capacitor Selection

Input and output ceramic capacitors of 22μF are recommended for MT3608 applications. For better voltage filtering, ceramic capacitors with low ESR are recommended. X5R and X7R types are suitable because of their wider voltage and temperature ranges.

Diode Selection

Schottky diode is a good choice for MT3608 because of its low forward voltage drop and fast reverses recovery. Using Schottky diode can get better efficiency. The high speed rectification is also a good characteristic of Schottky diode for high switching frequency. Current rating of the diode must meet the root mean square of the peak current and output average current multiplication as following :

$$I_D(RMS) \approx \sqrt{I_{OUT} \times I_{PEAK}}$$

The diode' s reverse breakdown voltage should be larger than the output voltage.

Layout Consideration

For best performance of the MT3608, the following guidelines must be strictly followed.

- Input and Output capacitors should be placed close to the IC and connected to ground plane to reduce noise coupling.
- The GND should be connected to a strong ground plane for heat sinking and noise protection.
- Keep the main current traces as possible as short and wide.
- SW node of DC-DC converter is with high frequency voltage swing. It should be kept at a small area.
- Place the feedback components as close as possible to the IC and keep away from the noisy devices.

PACKAGE DESCRIPTION

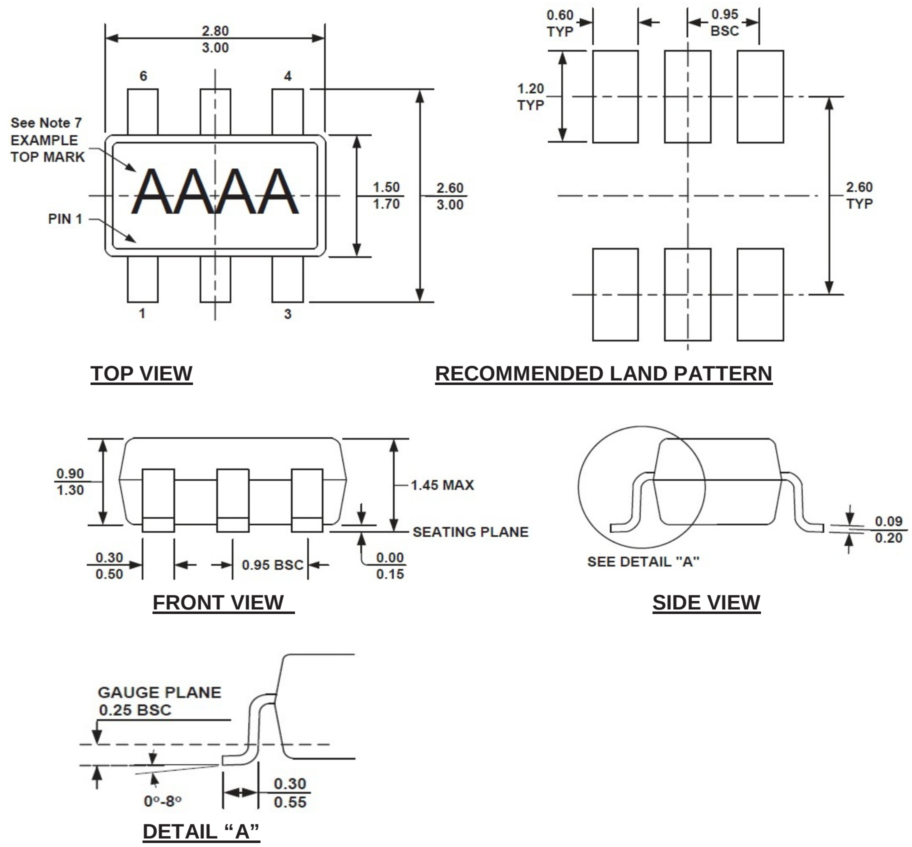


Figure 4. TSOT23-6/SOT23-6 Physical Dimensions

NOTE:

1)ALL DIMENSIONS ARE IN MILLIMETERS.

2) PACKAGE LENGTH DOES NOT INCLUDE MOLD FLASH,PROTRUSION OR GATE BURR.

3) PACKAGE WIDTH DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION.

4) LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.10 MILLIMETERS MAX.

5) DRAWING CONFORMS TO JEDEC MO-193, VARIATION AB.

6) DRAWING IS NOT TO SCALE.

7) PIN 1 IS LOWER LEFT PIN WHEN READING TOP MARK FROM LEFT TO RIGHT, (SEE EXAMPLE TOP MARK)

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Datasheet

DW01A

One Cell Lithium-ion/Polymer Battery Protection IC

Fortune
SEMICONDUCTOR CORPORATION

Fortune Semiconductor Corporation
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www.ic-fortune.com

1. General Description

The DW01A battery protection IC is designed to protect lithium-ion/polymer battery from damage or degrading the lifetime due to overcharge, overdischarge, and/or overcurrent for one-cell lithium-ion/polymer battery powered systems, such as cellular phones.
The ultra-small package and less required external components make it ideal to integrate the DW01A into the limited space of battery pack. The accurate ±50mV overcharging detection voltage ensures safe and full utilization charging. The very low standby current drains little current from the cell while in storage.

2. Features

- **Reduction in Board Size due to Miniature Package SOT-23-6.**
- **Ultra-Low Quiescent Current at 3μA (Vcc=3.9V).**
- **Ultra-Low Overdischarge Current at 3μA (Vcc=2.0V).**
- **Precision Overcharge Protection Voltage 4.3V ± 50mV**
- **Load Detection Function during Overcharge Mode.**
- **Two Detection Levels for Overcurrent Protection.**
- **Delay times are generated by internal circuits. No external capacitors required.**

3. Ordering Information

DW01A-G

PACKAGE TYPE
SOT-23-6(G stands for Green-Package)

TEMPERATURE RANGE
-40°C~+85°C

OVERCHARGE PROTECTION
4.3V± 50mV

4. Applications

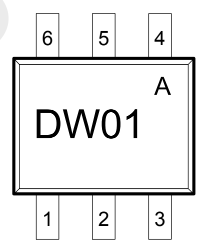
- **Protection IC for One-Cell Lithium-Ion / Lithium-Polymer Battery Pack**

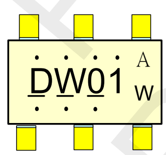
5. Product Name List

Model	Package	Overcharge detection voltage [VOCP] (V)	Overcharge release voltage [VOCR] (V)	Overdischarge detection voltage [VODP] (V)	Overdischarge release voltage [VODR] (V)	Overcurrent detection voltage [VOI1] (mV)
DW01A	**SOT-23-6**	**4.300±0.050**	**4.100±0.050**	**2.40±0.100**	**3.0±0.100**	**150±30**

6. Pin Configuration and Package Marking Information

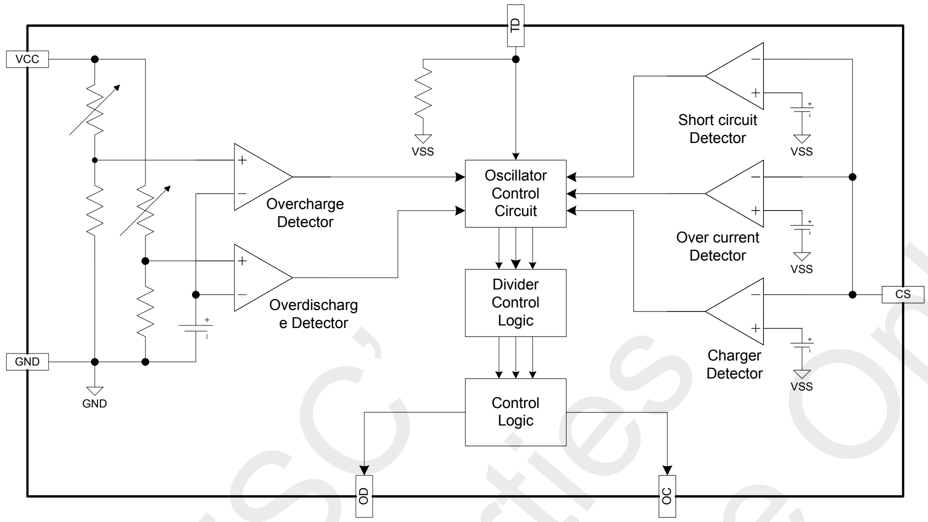
Pin No.	Symbol	Description
1	OD	MOSFET gate connection pin for discharge control
2	CS	Input pin for current sense, charger detect
3	OC	MOSFET gate connection pin for charge control
4	TD	Test pin for reduce delay time
5	VCC	Power supply, through a resistor (R1)
6	GND	Ground pin



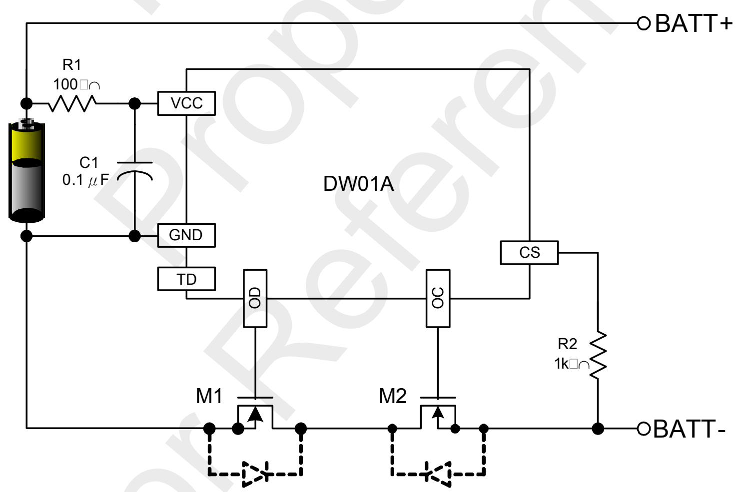


Top Point and Under_line：Lot No.
Bottom Point：Year
w : week, A~Z & A ~ Z

7. Functional Block Diagram



8. Typical Application Circuit



9. Absolute Maximum Ratings

(GND=0V, Ta=25˚C unless otherwise specified)

Item	Symbol	Rating	Unit
Input voltage between VCC and GND *	VCC	GND-0.3 to GND+10	V
OC output pin voltage	VOC	VCC -24 to VCC +0.3	V
OD output pin voltage	VOD	GND-0.3 to VCC +0.3	V
CS input pin voltage	VCS	VCC -24 to VCC +0.3	V
Operating Temperature Range	TOP	-40 to +85	˚C
Storage Temperature Range	TST	-40 to +125	˚C

Note: DW01A contains a circuit that will protect it from static discharge; but please take special care that no excessive static electricity or voltage which exceeds the limit of the protection circuit will be applied to it.

10. Electrical Characteristics

(Ta=25˚C unless otherwise specified)

PARAMETER	TEST CONDITIONS	SYMBOL	Min	Typ	Max	UNIT
Supply Current	VCC=3.9V	ICC		3.0	6.0	μA
Overdischarge Current	VCC=2.0V	IOD		1.5	3	μA
Overcharge Protection Voltage	DW01A	VOCP	4.25	4.30	4.35	V
Overcharge Release Voltage		VOCR	4.05	4.10	4.15	V
Overdischarge Protection Voltage		VODP	2.30	2.40	2.50	V
Overdischarge Release Voltage		VODR	2.90	3.00	3.10	V
Overcurrent Protection Voltage		VOIP（VOI1）	120	150	180	mV
Short Current Protection Voltage	VCC=3.6V	VSIP（VOI2）	1.00	1.35	1.70	V
Overcharge Delay Time		TOC		80	200	ms
Overdischarge Delay Time	VCC=3.6V to 2.0V	TOD		40	100	ms
Overcurrent Delay Time (1)	VCC=3.6V	TOI1		10	20	ms
Overcurrent Delay Time (2)	VCC=3.6V	TOI2		5	50	μs
Charger Detection Threshold Voltage		VCHA	-1.2	-0.7	-0.2	V
OD Pin Output “H” Voltage		VDH	VCC-0.1	VCC-0.02		V
OD Pin Output “L” Voltage		VDL		0. 1	0.5	V
OC Pin Output “H” Voltage		VCH	VCC-0.1	VCC-0.02		V
OC Pin Output “L” Voltage		VCL		0.1	0.5	V

11. Description of Operation

11.1 Normal Condition

If VODP<VCC<VOCP and VCH<VCS<VOI1, M1 and M2 are both turned on. The charging and discharging processes can be operated normally.

11.2 Overcharge Protection

When the voltage of the battery cell exceeds the overcharge protection voltage (VOCP) beyond the overcharge delay time (TOC) period, charging is inhibited by turning off of the charge control MOSFET. The overcharge condition is released in two cases:

The voltage of the battery cell becomes lower than the overcharge release voltage (VOCR) through self-discharge.

The voltage of the battery cell falls below the overcharge protection voltage (VOCP) and a load is connected.
When the battery voltage is above VOCP, the overcharge condition will not release even a load is connected to the pack.

11.3 Overdischarge Protection

When the voltage of the battery cell goes below the overdischarge protection voltage (VODP) beyond the overdischarge delay time (TOD) period, discharging is inhibited by turning off the discharge control MOSFET.

The default of overdischarge delay time is 10ms. Inhibition of discharging is immediately released when the voltage of the battery cell becomes higher than overdischarge release voltage (VODR) through charging.

11.4 Overcurrent Protection

In normal mode, the DW01A continuously monitors the discharge current by sensing the voltage of CS pin. If the voltage of CS pin exceeds the overcurrent protection voltage (VOIP) beyond the overcurrent delay time (TOI1) period, the overcurrent protection circuit operates and discharging is inhibited by turning off the discharge control MOSFET. The overcurrent condition returns to the normal mode when the load is released or the impedance between BATT+ and BATT- is larger than 500kΩ. The DW01A provides two overcurrent detection levels (0.15V and 1.35V) with two overcurrent delay time (TOI1 and TOI2) corresponding to each overcurrent detection level.

11.5 Charge Detection after Overdischarge

When overdischarge occurs, the discharge control MOSFET turns off and discharging is inhibited. However, charging is still permitted through the parasitic diode of MOSFET. Once the charger is connected to the battery pack, the DW01A immediately turns on all the timing generation and detection circuitry. Charging progress is sensed if the voltage between CS and GND is below charge detection threshold voltage (VCH).

12. Design Guide

12.1 Selection of External Control MOSFET

Because the overcurrent protection voltage is preset, the threshold current for overcurrent detection is determined by the turn-on resistance of the charge and discharge control MOSFETs. The turn-on resistance of the external control MOSFETs can be determined by the equation: RON=VOIP/ (2 x IT) (IT is the overcurrent threshold current). For example, if the overcurrent threshold current IT is designed to be 3A, the turn-on resistance of the external control MOSFET must be 25mΩ. Be aware that turn-on resistance of the MOSFET changes with temperature variation due to heat dissipation. It changes with the voltage between gate and source as well. (Turn-on resistance of MOSFET increases as the voltage between gate and source decreases).

As the turn-on resistance of the external MOSFET changes, the design of the overcurrent threshold current changes accordingly.

12.2 Suppressing the Ripple and Disturbance from Charger

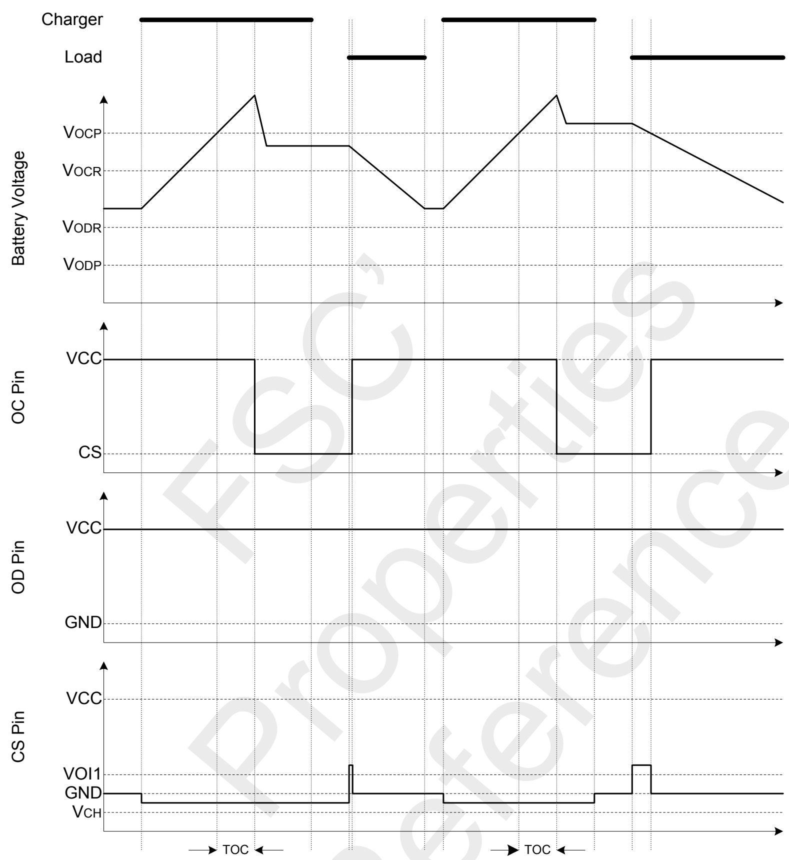
To suppress the ripple and disturbance from charger, connecting R1 and C1 to VCC is recommended.

12.3 Protection the CS pin

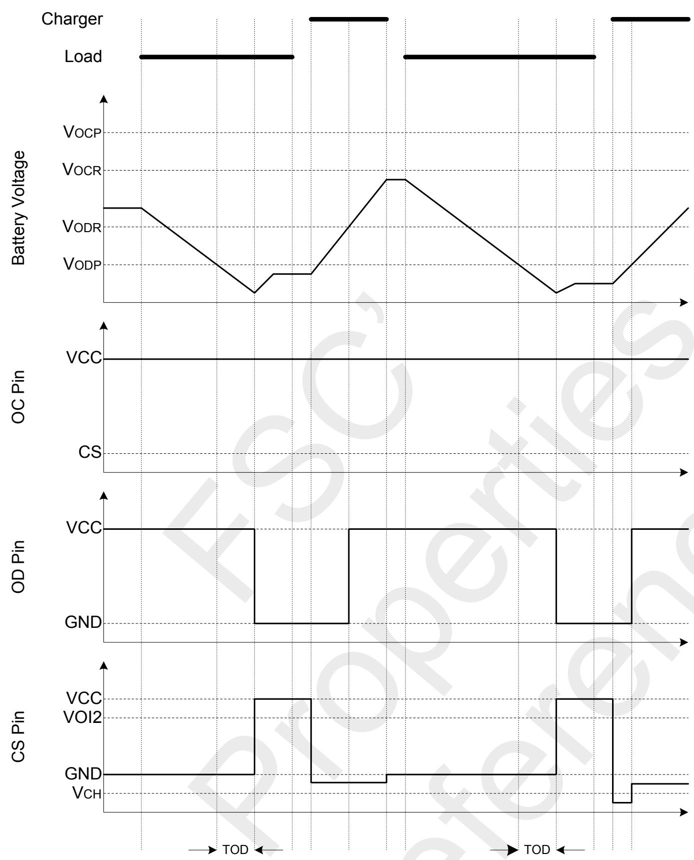
R2 is used for latch-up protection when charger is connected under overdischarge condition and overstress protection at reverse connecting of a charger.

13. Timing Diagram

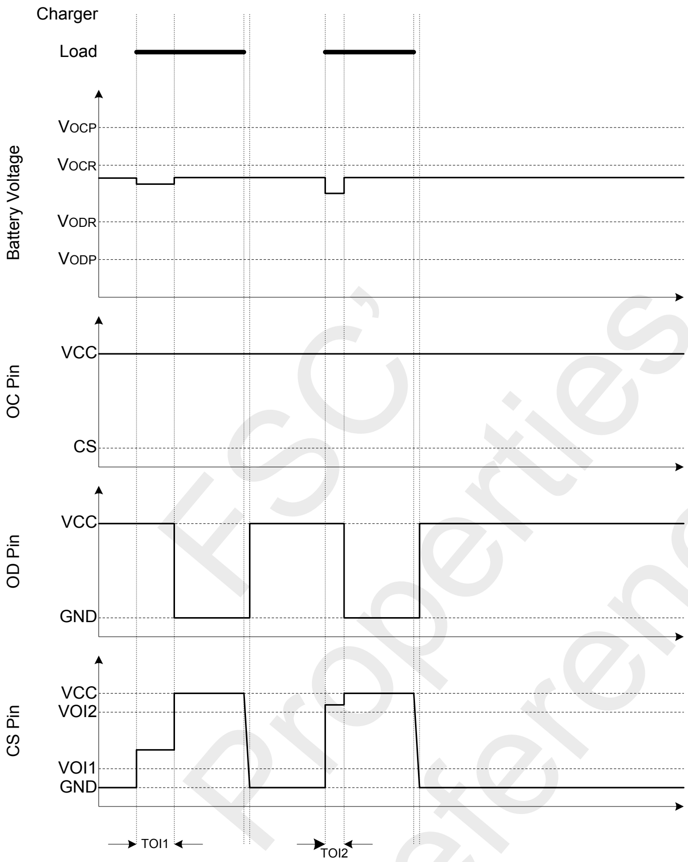
13.1 Overcharge Condition →Load Discharging → Normal Condition



13.2 Overdischarge Condition → Charging by a Charger →Normal Condition

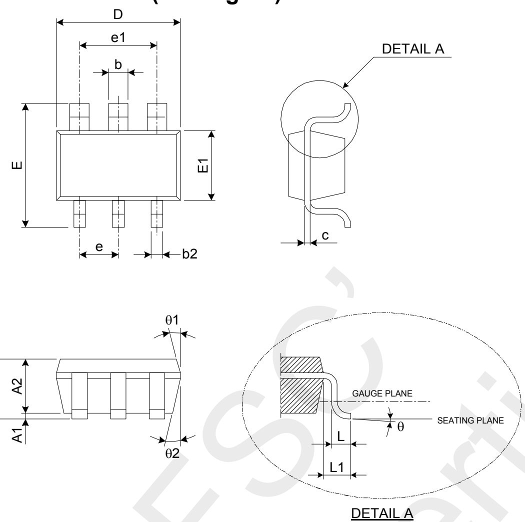


13.3 Over Current Condition → Normal Condition



14. Package Outline

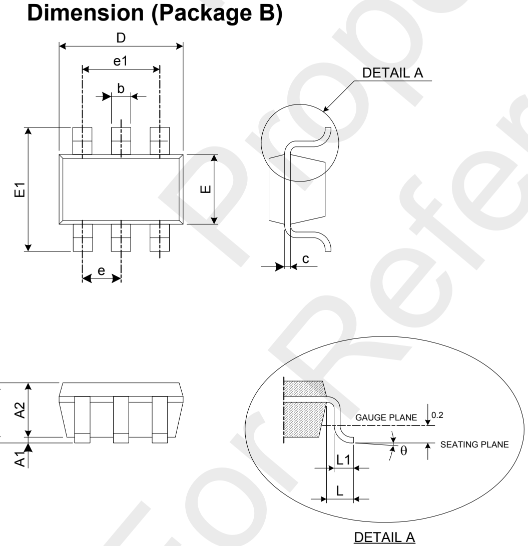
Dimension (Package A)



Unit : mm

SYMBOL	MIN.	TYP.	MAX.
A	1.05	-	1.35
A1	0.05	-	0.15
A2	1.00	1.10	1.20
b	0.40	-	0.55
b2	0.25	-	0.40
c	0.08	-	0.20
D	2.70	2.90	3.00
E	2.60	2.80	3.00
E1	1.50	1.60	1.70
L	0.35	0.45	0.55
L1	0.60 REF.		
e	0.95 BSC.		
e1	1.90 BSC.		
θ	0°	5°	10°
θ1	3°	5°	7°
θ2	6°	8°	10°

Dimension (Package B)



Unit : mm

SYMBOL	MIN.	TYP.	MAX.
A	1.050	-	1.250
A1	0.000	-	0.100
A2	1.050	-	1.150
b	0.300	-	0.400
c	0.100	-	0.200
D	2.820	-	3.020
E	1.500	-	1.700
E1	2.650	-	2.950
e	0.950 TYP		
e1	1.800	-	2.000
L	0.700REF		
L1	0.300	-	0.600
θ	0°	-	8°

15. Revision History

Version	Date	Page	Description
1.0	2009/06/24	ALL	New release

Datasheet

FS8205

Dual N-Channel Enhancement Mode Power MOSFET

Fortune SEMICONDUCTOR CORPORATION

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1. Features

1.1 Low on-resistance

1.1.1 $R_{DS(ON)}$ = 28 mΩ MAX. (V_{GS} = 4.5V, I_D = 4A)

1.1.2 $R_{DS(ON)}$ = 37 mΩ MAX. (V_{GS} = 2.5V, I_D = 3A)

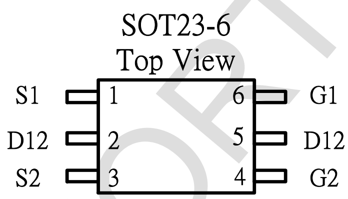
2. Applications

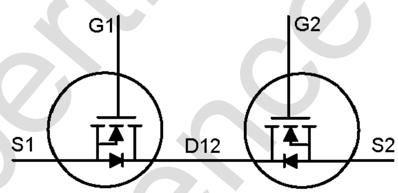
- Li-ion battery management applications

3. Ordering Information

Product Number	Description	Package Type	Quantity/Reel
FS8205	SOT23-6 package version	SOT23-6	3,000

4. Pin Assignment





5. Absolute Maximum Ratings

Symbol	Parameter	Rating	Units
VDS	Drain-Source Voltage	20	V
VGS	Gate-Source Voltage	±12	V
ID @TA = 25℃	Continuous Drain Current3	6	A
ID @TA = 70℃	Continuous Drain Current3	5	A
IDM	Pulsed Drain Current1	25	A
PD @TA = 25℃	Total Power Dissipation	1	W
	Linear Derating Factor	0.008	W/℃
TSTG	Storage Temperature Range	-55 to 150	℃
TJ	Operating Junction Temperature Range	-55 to 150	℃

6. Thermal Data

Symbol	Parameter	Value	Unit
Rthj-a	Thermal Resistance Junction-ambient3	Max. 125	℃/W

7. Electrical Characteristics

Electrical Characteristics @T_j = 25℃ (unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
Static Characteristics						
BV_{DSS}	Drain-Source Breakdown Voltage	V_{GS} = 0V, I_D = 250uA	20	-	-	V
$\Delta BV_{DSS}/\Delta T_j$	Breakdown Voltage Temperature Coefficient	Reference to 25℃, I_D=1mA	-	0.1	-	V/℃
$R_{DS(ON)}$	Static Drain-Source On-Resistance[2]	V_{GS} = 4.5V, I_D = 4A	-	23	28	mΩ
		V_{GS} = 2.5V, I_D = 3A	-	30	37	mΩ
$V_{GS(th)}$	Gate Threshold Voltage	V_{DS} = V_{GS}, I_D = 250uA	0.45	-	1.2	V
I_{DSS}	Drain-Source Leakage Current (T_j = 25℃)	V_{DS} =16V, V_{GS} = 0V	-	-	1	uA
	Drain-Source Leakage Current (T_j = 70℃)	V_{DS} =16V, V_{GS} = 0V	-	-	25	uA
I_{GSS}	Gate-Source Leakage	V_{GS} = ±10V	-	-	±0.1	uA

8. Source-Drain Diode

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
I_S	Continuous Source Current (Body Diode)	V_D = V_G = 0V, V_S = 1.2V	-	-	0.83	A
V_{SD}	Forward On Voltage[2]	T_j = 25℃, I_S = 1.25A, V_{GS} = 0V	-	-	1.2	V

Notes：

1. Pulse width limited by Max. junction temperature.
2. Pulse width ≦ 300us, duty cycle ≦ 2%.
3. Surface mounted on 1 in^2 copper pad of FR4 board；208℃/W when mounted on Min. copper pad.

9. Typical Characteristics

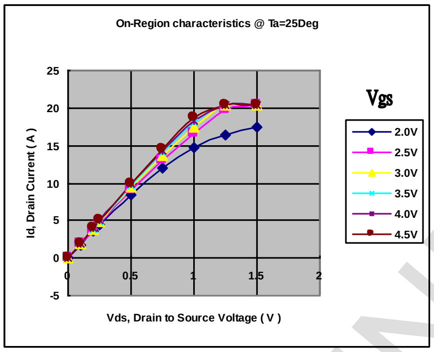


Fig 1. Typical Output Characteristics

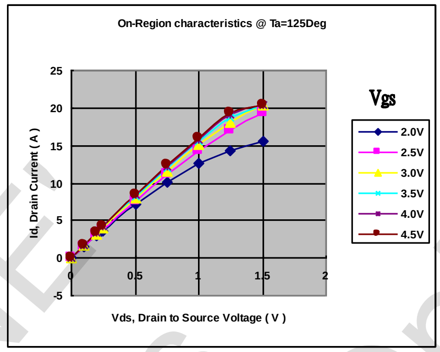


Fig 2. Typical Output Characteristics

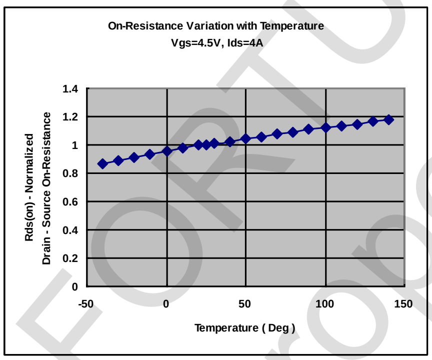


Fig 3. Normalized On-Resistance

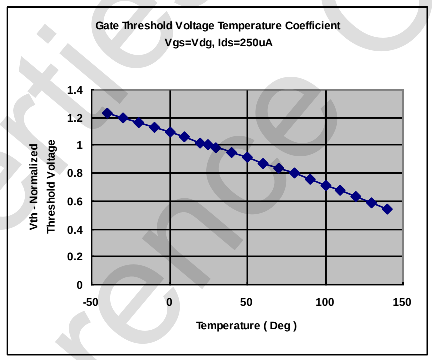


Fig 4. Gate Threshold Variation with Temperature

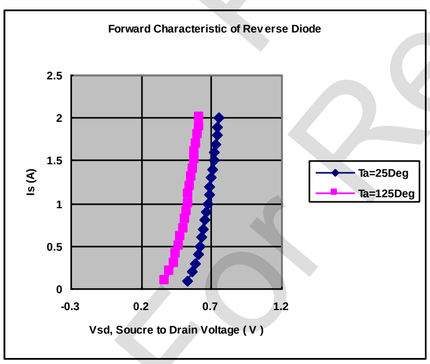
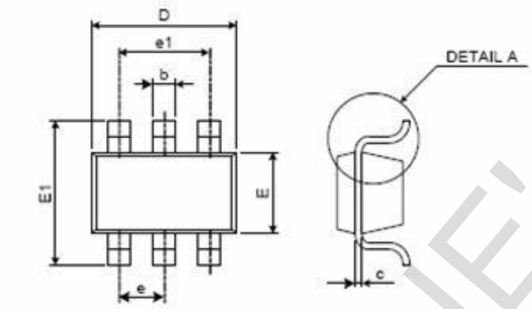
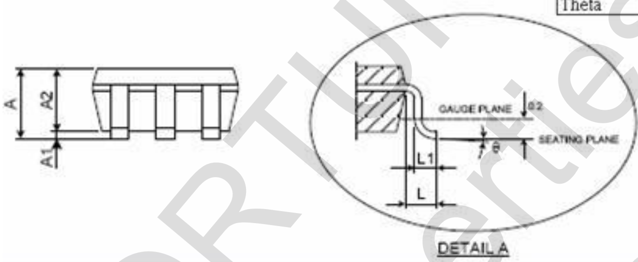


Fig 5. Forward Characteristic of Reverse Diode

10. Package Information



	Min.	TYP.	Max.
A	-	-	1.45
A1	0	-	0.15
A2	0.90	1.15	1.30
b	0.30	-	0.50
c	0.08	-	0.22
D	2.75	2.90	3.05
E	1.45	1.60	1.75
E1	2.60	2.80	3.00
e	0.95 BSC		
e1	1.90 BSC		
L	0.60 REF		
L1	0.30	0.45	0.60
Theta	0	4	8



11. Revision History

Version	Date	Page	Description
1.0	2009/08/17	-	Version 1.0 released
1.1	2010/01/26	3	Rds25 TYP 28mohm MAX 36mohm Rds45 TYP 22mohm MAX 26mohm
1.2	2010/06/02	3	Rds45 TYP 23mohm MAX 27mohm
1.3	2010/06/10	4	IDSS Test Conditions：VDS=16V VGS=0V
1.4	2010/08/31	3	Revise Pin Assignment
1.5	2010/04/27	4	Rds25 TYP：30mohm MAX：37mohm Rds45 TYP：23mohm MAX：28mohm VGS(th) MIN：0.45V MAX：1.2V IGSS MAX：±0.1uA
1.6	2011/09/08	6	Revise Package Outline
1.7	2011/11/02	3	Revise Pin Assignment