Cost Effective Solar Powered Fan

A Technical Report submitted to the Department of Electrical and Computer Engineering

Presented to the Faculty of the School of Engineering and Applied Science
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In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Kelsi Loudenslager
Spring, 2020.
Technical Project Team Members
Hsing Chun Lin
Thu Tran

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Harry Powell Department of Electrical and Computer Engineering

Statement of Work:

Hsing Chun Lin - PCB Layout and Design
My primary responsibility is creating schematics and layouts. Based on the chips and loads that my teammates find, I design the peripheral circuits that are needed for the chips to run. In designing the peripheral circuits, I do calculations to make sure that the chips will run properly. Based on the Multisim schematic, I create the board layout and create the footprints.

Kelsi Loudenslager - Circuit Design and Motor Control
My primary responsibility is circuit design and motor control. For circuit design, my main work has been on component research. So far, I have found all necessary components to make our fan to function. These components include the solar panel, power management chip, buck-boost convertor, motor driver, motor, charge controller, and battery. Additionally, I have assisted in the board design. This work has been parallelized with the mechanical and prior to board design.

Thu Tran -Mechanical Lead
In addition to contributing to design discussions, I was primarily responsible for the mechanical design of the project. I did the primary research on what type of fan we were looking to implement. Before modeling the fan, I also did research on how many blades and the blade geometry to optimize our power. I decided on a three-blade fan with a swept tip blade design with a nearly constant chord. I modeled the fan in Solidworks, which was 3D printed by the Mechanical Engineering Department. I also constructed the fan housing and casing as well as being responsible for coding the MSP430 to run the motor driver. The tasks I performed was done in parallel with the electrical design.

Table of Contents

Table of Figures

Abstract

As the increased levels of greenhouse gases in the atmosphere continue to contribute to the imminent issue of global warming and climate change, it exacerbates the need for sustainable solutions for its detrimental consequences. The idea of a low-cost cooling solution was first proposed to us by Noah's Ark Ministries and immediately caught our attention. In metropolitan areas like Washington DC, the cost of consistently running an AC in the average household can accrue an electricity bill of over $200 per month. This is extremely unsustainable and strenuous on low income families looking to maintain comfortable living conditions within their home. This project tackles this issue through the research and design of a cost effective solar powered fan that is powered entirely on renewable energy whose cost of production is affordable in respect to similar products in the market.

Background

Environmental concerns have become a forefront issue worldwide as the detrimental consequences of climate change has exacerbated the need for sustainable solutions and efforts. As current trends in resource use and societal behaviors impact the environment in unsustainable ways, there is an increased pressure for communities to find solutions and invoke sustainable development. However, since the first international conference on environmental issues in 1972 [1], after four decades of efforts in sustainability, progress has been very unexceptional. Increased levels of greenhouse gases in the atmosphere continue to contribute to the imminent issue of global warming and climate change, and the problem of sustainable cooling and ventilation arises as society becomes more reliant on technology to provide adequate living conditions. Often overlooked, heating and cooling systems contribute to over 48% of residential energy with air conditioning releasing over 100 million tons of carbon dioxide yearly within the United States [2]. In addition to its carbon dioxide emissions, current cooling technologies rely on human made gases that are almost 10,000 times more potent than carbon dioxide in trapping heat [3]. Aside from its environmental impact, the lack of adequate cooling systems has serious detrimental effects on health, especially on the elderly, women, and children. Thermal comfort is also essential in productivity and performance as shown in a study done in Denmark where significant improvements in arithmetic and language tests were seen among students placed in an environment between 20-25 degrees Celsius [3].

In addition to being environmentally unsustainable, thermal conditioning has become financially unsustainable as well. In metropolitan areas like Charlottesville, the cost of consistently running an AC in the average household can accrue an electricity bill of over $245 per month [4]. This is extremely unsustainable and strenuous on low income families looking to maintain comfortable living conditions within their home. This issue of sustainable cooling was first brought to our attention by Noah’s Ark Ministries and really resonated with our group.

To tackle this issue this project proposes the design of a cost effective self-powered solar fan whose cost of production is affordable in respect to similar products currently in the market. The current market lacks a low-cost solar fan with energy storage, an essential feature for allowing operation of the fan when there lacks direct sunlight. We plan to fill this void in the market by adding a battery to store energy collected when the fan is not in use.

There are currently multiple commercial options for solar fans. These fans range in price, size, and design substantially. There are 16 to 20-inch fans that cost hundreds of dollars and smaller 8 inch fans which cost about 40 dollars. For example, the Western Harmonics 12-Inch Solar-Powered High-Velocity Fan which retails for $95 [5]. However, this fan lacks a battery system to store unused energy. There is a more expensive fan that has battery storage [6]. This fan is the Cowin Solar Fan System. Additionally, the Cowin fan may be plugged into an outlet to run. However, this fan retails for $180. Therefore, we plan to create a middle ground by creating a fan with a battery system for about $100.

There are also solar powered fans that are designed for users in underdeveloped countries. Bboxx is a for-profit company that creates solar systems to countries in Africa and the developing world. One of the accessories that can be plugged into their solar charging system is a fan. Mono Eco Green Energy is another organization that creates solar powered fans for African customers [7]. However, our application mainly focuses on metropolitan communities, so we don’t know if these products will be suitable for a different audience.

The main focus for the design will be reducing the production cost in order to increase accessibility to a sustainable cooling option. The design will also allow the fan to have the capability of running completely on renewable energy and without drawing any additional energy from the utility grid and will account for typical appliance safety standards. The fan will implement a three-blade axial flow fan design with swept tip blade geometry for aerodynamic efficiency. It will incorporate a 12V brushed DC motor for reliability and low initial cost as well as a 12V lead acid battery to implement the energy storage feature. A charge controller will be implemented as well to control the charging state and battery health. Challenges for this design will mainly surround maximizing energy efficiency with a minimal production budget.

This design will draw upon many of the different concepts from previous knowledge and coursework. This project will use the simulation and layout techniques as well as allow the implementation of core electrical concepts learned throughout the Fundamentals series. It will also implement MSP430 motor control drawing from coursework from the embedded courses. The team also will be implementing concepts from the power systems and photovoltaic courses as the project focuses on designing a solar powered system.

Constraints

Design Constraints

Acquiring the parts for our project was not difficult since our research showed that we can acquire all the components we anticipate to use on DigiKey and Amazon. The main constraint when acquiring components on DigiKey was the delivery time. Further our motor was from mouser which was more difficult to acquire.

Economic and Cost Constraints

Another parameter considered when acquiring parts was the cost of each part. Since we needed to make sure that our product is low cost price was a huge consideration when looking for parts. The end user of our product will not have the means to purchase an expensive solar powered fan so we must be mindful of cost all the time. When we talked to Brother Woodson about the goals for the product, he conveyed that the product should replace the AC unit entirely so our solar powered fan should cost less than around $150 a month to use. We also needed to consider the current market for solar powered fans and make sure that the market cost is below the cost of current solar powered fans on the market. The solar powered fans we found on Amazon were in the range of $20 to $260, so we needed to stay in that range to stay competitive [8].

External Standards

The solar fan can be classified as an electric fan and must be employed in accordance with the National Electrical Code, ANSI/NFPA 70, and be rated at 600V or less [9]. The solar fan will meet this standard and be operating with a 12V solar panel, battery, and motor. The UL Standard for Electric Fans also requires overheat protection for equipment possessing a motor, which may be caused by overload, or locking of the rotor [10]. The solar fan motor will be incorporating a motor controller to operate the motor, as well as provide protection against motor fault conditions.

According to the Occupational Safety and Health Administration exposed fan blades must be enclosed guards. All blades that are less than 7 feet above the floor need to be guarded [11]. The International Organization for Standardization has several standards for fans: ISO 3864:1984 (safety colors and safety signs), ISO 13852:1996 (safety distances to prevent danger zones being reached by the upper limbs), and ISO 14120 (design and construction of guards) [12].

To make sure the fan is effective in cooling and maintaining body thermal neutrality, the ASHRAE standard for thermal comfort was referred to. For fans it is recommended to have an airflow of between 50 and 100 cfm (cubic feet per minute) [13]. However, studies in acceptability of higher air velocities at higher temperatures have found that individuals tend to pick fan speeds lower than what is required to maintain their body's thermal neutrality. Therefore, to maximize battery usage and production cost, the solar fan will aim to meet the lower bound of the thermal comfort recommendation.

Currently, there are no efficiency standards for commercial or industrial fans [14]. However, because the solar fan will be drawing power from a battery when there is no access to sunlight, we will be making sure the solar fan is effectively using its power and will be aiming for a minimum of 85% fan static efficiency, which is the ratio of the fan power output to the power supplied to the fan [15].

Tools Employed

For the electrical design, the primary tools employed were Multisim and Ultiboard for simulation, design, and board layout. This project allowed the team to get significantly more familiar with designing and deploying prototype boards. We also learned how to include custom packages into the program, a skill not previously used in other EE courses.

For the mechanical design, Solidworks was used to model the fan blade. This tool allowed us to customize our fan design as well as become more familiar with 3D modeling and 3D printing.

To code the MSP430, Code Composer and the Launchpad were used to do preliminary debugging of the code to run the motor driver. The team also learned how to implement the JTAG onto the board for the first time, as well as how to use it to debug and upload the code onto the board as well.

Ethical, Social, and Economic Concerns

Environmental Impact

The solar panel is a major component in our design and it poses environmental issues. A major problem with solar panels is disposal. Solar panels last around 30 years and they are hard to recycle. This problem is getting worse and worse. By the end of 2016 there was an estimated 250,000 tonnes of solar waste in the world and that number could increase to 78 million metric tonnes by 2050. Solar panels also contain toxic chemicals such as lead or cadmium that can cause cancer. Most of a solar panel is composed of glass, but this glass cannot be recycled due to impurities such as plastic and toxic chemicals. Recycling is also costly because the value of the materials recycled is less than the cost of recycling the solar panels. Placing the burden of recycling on the producers has caused several photovoltaic companies to go bankrupt and this makes it even harder for existing customers of these bankrupt companies to recycle their solar panels [16].

Solar panel waste is the most harmful in underdeveloped countries where there is no standard for waste management [16]. This leads to the ethical question of whether or not we should introduce solar powered fans to underdeveloped countries. Introducing our product to these regions could solve the problem of inadequate cooling solutions, but not providing proper waste management for solar panels is irresponsible. Therefore, we need to consider making an instruction manual on how to properly dispose of the solar panel.

Sustainability

Our product could be considered sustainable, but it depends what parameters are being evaluated. The production of solar panels and batteries involve toxic chemicals which makes our product potentially unsustainable. At the same time, our product is reducing the use of AC which can depend on fossil fuels to run, making our product sustainable in the sense that we are reducing the use of fossil fuels. However, if AC units are powered by a grid that depends on renewable sources then our product would not be more sustainable than using AC units. More and more cities are relying on renewable energy as their main source of energy. In 2017, there were 570 cities that sourced 70% of their energy from renewable sources [17]. Therefore, we need to make sure that our product is more sustainable that AC units by making our fan more efficient than AC units.

Health and Safety

Using the solar powered fan does pose some potential health and safety risks, but there are also some benefits to using a fan over an AC unit. If the solar panel or battery catches on fire there is a risk of polluting the air with carcinogenic fumes. In order to mitigate this risk, we need to make sure that we properly wire the system and place fuses in the circuit in case of a power surge. The fan's blades could also be dangerous for a child if they put their hands inside the fan. Therefore, we need to make sure that the enclosure for the fan is tight enough so that a child cannot pry open the enclosure and that a child cannot insert their fingers into the enclosure. Using a fan instead of an AC unit could be safer because AC units are prone to being moldy and they could blow unsanitary air, but fans don't do that because they just recirculate the air.

Manufacturability

The product that we are making is easily manufacturable because the components we are using are pretty standard and the processes by which the components will be integrated are standard as well. All the test equipment and manufacturing equipment is easily accessible to us. To test and manufacture the product we will need test benches and 3D printers that are available in the NI Lab. Once the product has been manufactured, the operation of the device should be simple. There will be a couple of switches so the user can turn on the fan or charge the battery. In order to make sure that our product is usable by the user we need to use human centered design.

Ethical Issues

Though the project was designed using conventional ideas on the benefits of solar power and sustainability, further evaluating our project with the aforementioned research, have brought light on the ethical concerns of implementing this project. The project was designed to encourage a sustainable alternative, but due to its many environmental concerns, may be misleading to a consumer looking to live more sustainably. Promoting the use of solar panels within a community not fully equipped to manage them as a waste product, can have severe unintended consequences to the environment. This project has also brought to light the inefficiency of solar panels, as it does not seem to provide a substantial efficiency that would justify its cost, nor make it an economical choice to choose over conventional electrical fans. This would be a possible ethical concern as the solar fan promotes an energy source that is not justifiably better than using the power grid.

Intellectual Property Issues

Our project is not patentable due to the claims of multiple other patents. In a patent filed in 2001 by Hsin-mao Msiech, a solar fan a solar cell array electrically connected to an electric fan as to supply power when in sunlight is claimed [18]. This claim is the only independent claim within the patent. This claim directly conflicts with our design we connected our solar panel to power our motor. Additionally, in 2006 another patent was filed which claimed a portable solar powered fan with a rechargeable battery pack, an external switch for selectively delivering power, and a solar panel for harvesting solar energy and delivering it to the motor [19]. These claims are also all independent. This patent claims are very similar to the first, but the housing of these fans are different. Additionally, this patent included a rechargeable battery which our project also incorporated. Further, this patent claimed an external switch to choose the power driving the fan which was also incorporated in our design. Another similar patent which conflicts with our design was filed in 2007 [20]. This patent claimed a portable ventilation fan comprising of charging the battery by solar energy, running the motor within the housing through an electrical cord connected to both the battery and the fan motor, and rotating aerodynamic twisted blades by running the motor. The housing claimed in this patent includes encased blades, a telescoping mounting pole, and a solar panel mounted on a hand truck. Therefore, our design does not conflict with the housing claims although it conflicts with the fan running off both battery and solar power. Therefore, our simple design used for this project conflicts with many previous patents. If our design was altered to include unique housing it may be patentable, but in its current state it is neither unique nor novel.

Detailed Technical Description of Project

What it is

Our product is a low cost solar powered fan. The main components of our product are shown in the following block diagram.

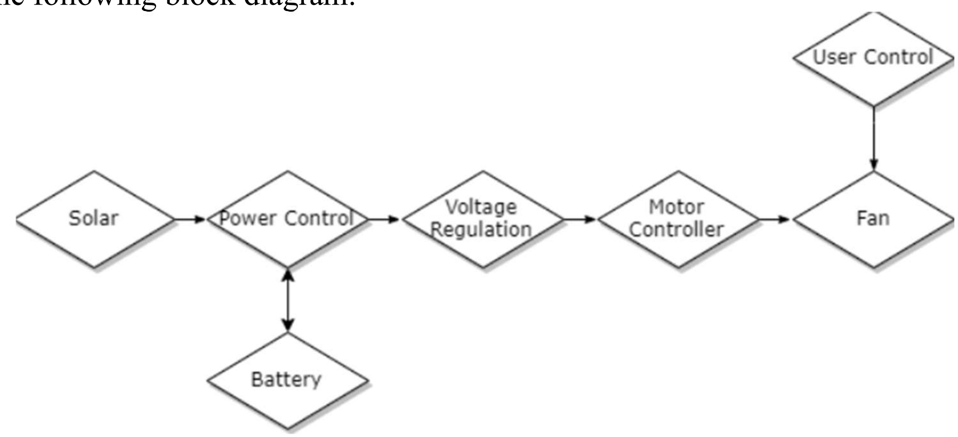


Figure 1 Product Block Diagram

Energy is harvested by the solar panel and that energy is switched between the battery and the load. Voltage regulation is used to step down the voltage from the solar panel to the motor controller. The motor controller then uses a PWM signal to control the speed of the motor that runs the fan blade. User control is used to turn the fan in the charging state or in the on state and LEDs give the user information about if the battery is charging or not.

How it works

The solar panel uses the photoelectric effect to harvest energy from the sun in order to generate the power necessary to run the fan. Switches are then used to switch between charging, using the solar panel to run the motor, or using the battery to run the load. If the user chooses to charge the battery then the power from the solar panel is directed to a charging circuit that makes sure the battery is charged properly. The battery charging circuit also indicates to the user whether or not the battery is charging and whether or not the battery is being faulty. If the user chooses to run the fan off the battery or the solar panel, then there is a buck voltage regulator that steps down the voltage to 12V to run the motor driver. The motor driver is given a PWM signal from the MSP430 microcontroller that controls the speed of the fan. The MSP430 is powered by a battery. The motor driver is connected to the 3D fan blade which is enclosed is a wire cage.

Mechanical Design

For the mechanical design of the fan, the fan will be a three-blade axial flow fan. A three-blade fan design was chosen because a fan with fewer blades is able to move faster and therefore move more air parallel to the motor shaft. The blade geometry was also designed with a swept tip design which rounds the leading blade of the fan, allowing for improved aerodynamic performance. A chord that increases toward the tip was also chosen for aerodynamic performance. At the base, the chord is at 50mm and increases to 280mm at the tip. The fan is modeled to have a 250mm diameter with considerations that the largest 3D printer we could find at UVA is 280mm by 280mm. The blades are slightly twisted hexily along the shaft at 10cm pitch and spans at .25 revolutions. The fan blades were modeled in Solidworks and isometric and orthogonal views of the design can be seen below. The design was 3D printed with PLA by the Mechanical Engineering Department at UVA.

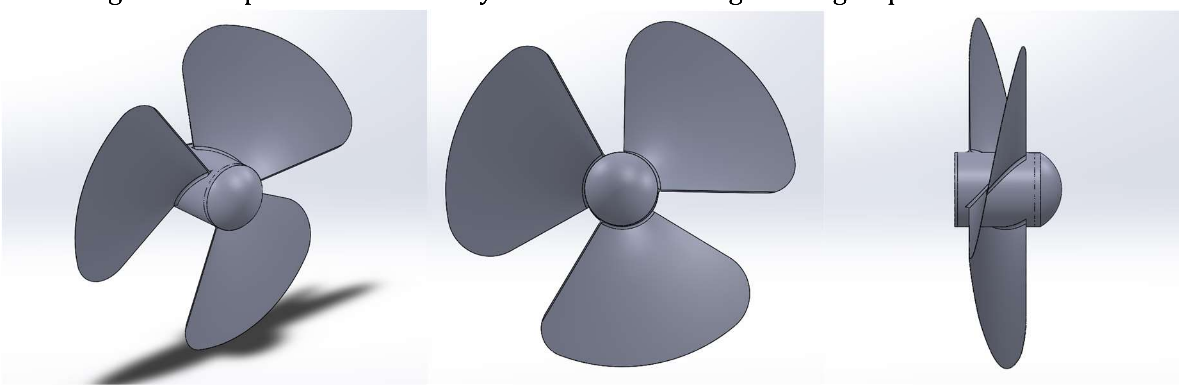


Figure 2 Isometric and Orthogonal Views of Fan Blades in SolidWorks

For the fan housing, a wooden box enclosure was used to house the battery and the circuit board. To mount the blades and motor, a wooden pedestal was used. For the fan grill, it was handmade by crimping 16-gauge galvanized steel wire.

Figure 3 Final Fan Design

Components Used

Reference	Manufacturer	Part Number
[21]	Microsemi IRE Division	1N914
[22]	Newpowa	NPA35S-12
[23]	Sha Yang Ye Industrial	IG220019X00015R
[24]	E-Switch	100SP1T1B4M2QE
[25]	On Shore	302-S141
[26]	AVX	1210YD107MAT2A
[27]	Phoenix Contact	1935161
[28]	Wurth Electronics	7443551111
[29]	Diodes Incorp	AZ1117EH-3.3TRG1
[30]	KEMET	C315C103M5U5TA7301
[31]	KEMET	C350C475M5U5TA
[32]	KEMET	C410C104M5U5TA7200
[33]	KEMET	C440C105M5U5TA7200
[34]	Vishay Dale	CMF5584K500FHEB
[35]	Central Semiconductor Corp	CMSH1-40M TR13 PBFREE
[36]	Central Semiconductor Corp	CMSH3-40MA TR13 PBFREE
[37]	United Chemi-Con	EKXG251ELL151MM25S
[38]	Broadcom	HLMP-1301
[39]	Broadcom	HLMP-1503
[40]	Vishay	HVR3700002324FR500
[41]	IDEAL	PowerPlug 5-Pack Orange Push-In Wire Connectors
[42]	TI	LM2674MX-12/NOPB
[43]	Linear Technology/Analog Devices	LT3652IMSE#TRPBF
[44]	Linear	LTC4419IDD#PBF
[45]	ON Semiconductor	MBR350RLG
[46]	ON Semiconductor	MBRS340
[47]	Yageo	MFR-25FBF52-1K74
[48]	Caddock	MP850-0.50-1%
[49]	Vishay	MRS25000C5762FCT00
[50]	TI	MSP430G2553IN20
[51]	Murata Electronics	NXRT15XH103FA1B030
[52]	Ohmite	OX473KE
[53]	Pulse Electronics Power	PE-53820NL
[54]	Murata Electronics	RCER71H106MWM1H03A
[55]	Stackpole	RNMF14FTD105K
[56]	Yageo	RSF100JB-73-910K
[57]	TE Connectivity Passive Product	SBL4R047J
[58]	Duracell	DURA12-7F
[59]	Nichicon	UPM1V121MPD6TD
[60]	Nichicon	UPW1J180MDD1TD
[61]	Vishay	VR37000001504FA100
[62]	Vishay BC Components	VR68000002703JAC00
[63]	Diodes Incorp	ZXBM5210-S-13

Figure 4 Components List

Design Decisions and Tradeoffs

One major design decision made was how much power we wanted to supply to our system. When researching components there were multiple options for solar panels. We decided to go for 35W which was one of the highest power inputs possible. We chose this option because we wanted the fan to be as large as possible. Therefore, we chose to use 12V motor. The motor chosen was a DC brushed motor because it was substantially cheaper than other options. There were very few options available when we looked for the proper motor. The only relatively cheap option found was a 12V motor with about 600 rpm. This speed was less than desired, but in order to keep the fan as large as possible it was the best option. The lower speed of our motor meant we needed a lightweight and efficient fan blade. Therefore, we decided to 3D print the blade ourselves. 3D printing the blade meant the largest possible diameter was 9.8 inches. Further, using the 35W solar panel meant our components needed to be rated for high current levels incase the solar panel reached its maximum power point. This meant the components used where slightly more expensive. This created a tradeoff between the power and the price. We chose to increase the power as we wanted the system to work even when the solar panel was less than ideal.

Schematics

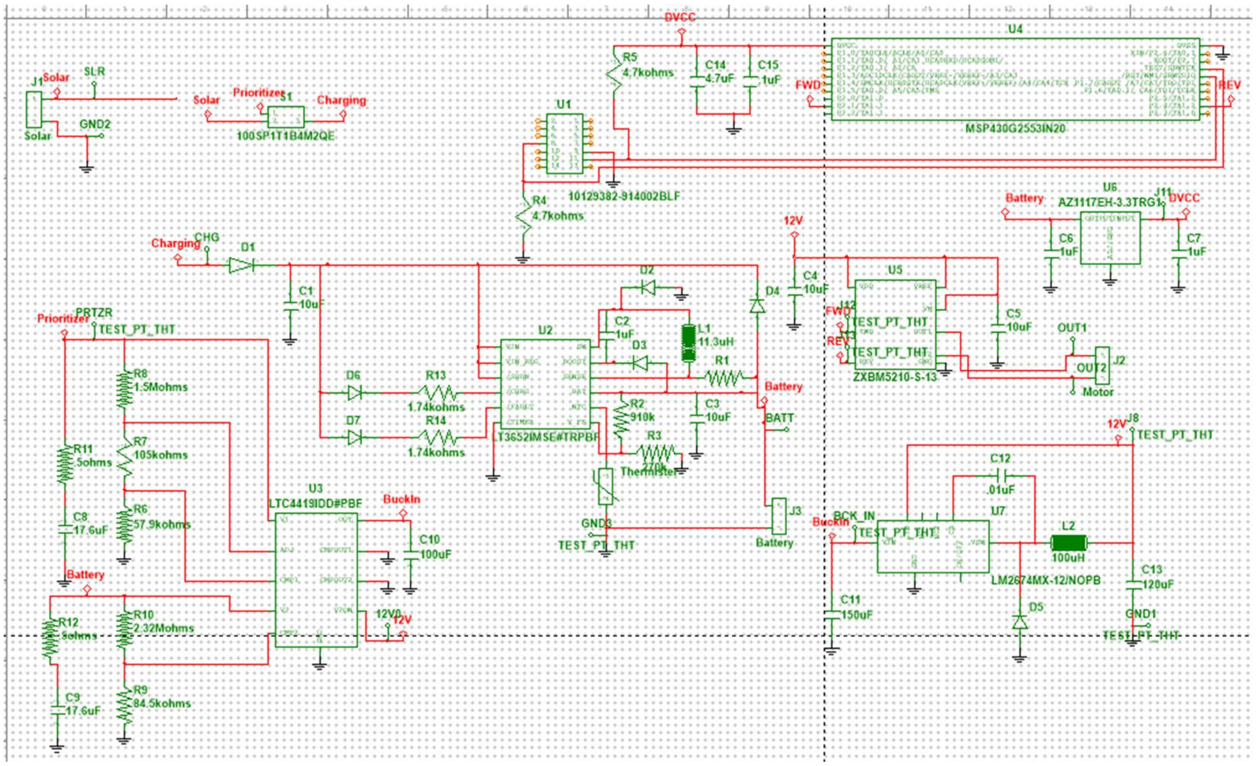


Figure 5 Entire Schematic

Shown above is the entire schematic. Below the various subsystems will be broken down and explained.

The first subsystem is the solar input subsystem.

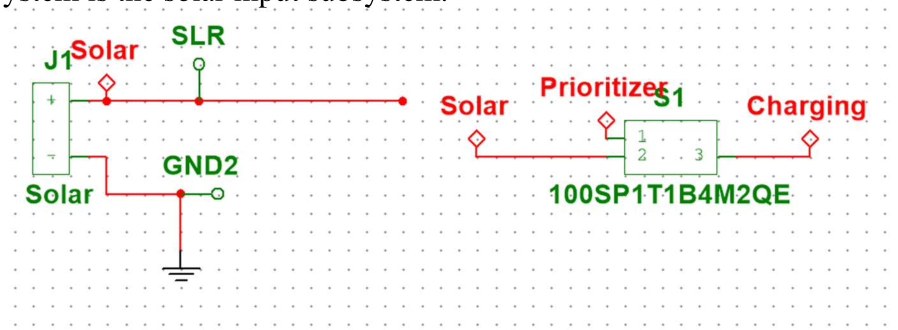


Figure 6 Solar Input

There is a connector that connects to the solar panel. This power from the solar panel can either be directed toward the prioritizer or the battery charging IC. The prioritizer decides whether to run the fan from the battery or the solar panel depending on the threshold set by the prioritizer.

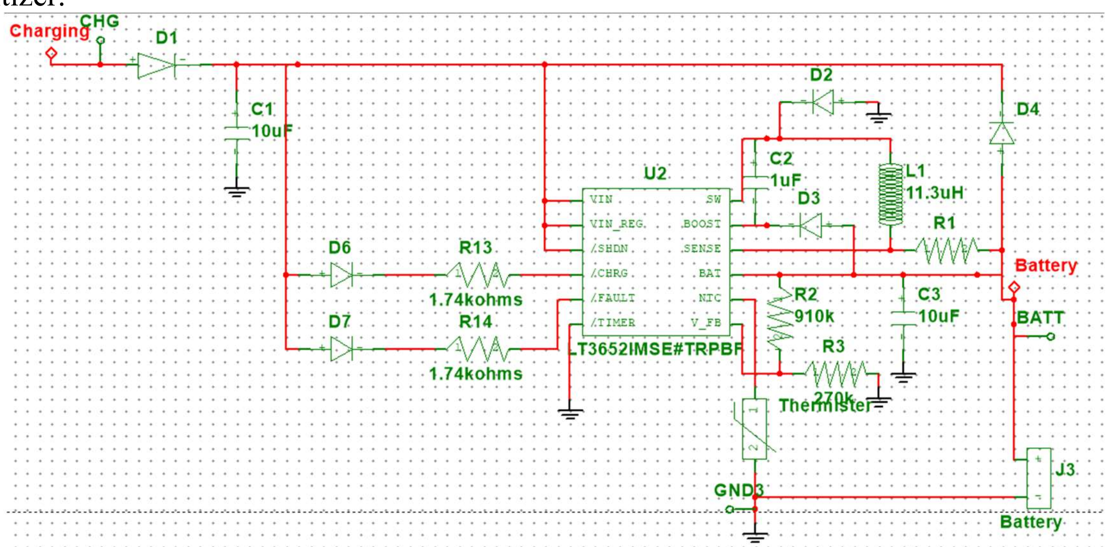


Figure 7 Battery Charging IC

The battery charging IC LT3652IMSE#TRPBF allows the battery to charge safely. There are two LEDs that gives the user an indication of whether the battery is charging properly. The following chart explains what the different colored LEDs indicate. One of the calculations that had to be done was a resistor value calculation in order for the charge controller to be compatible with a 12V battery. The charge controller has R2 between pin BAT and V_FB and R3 between pin V_FB and ground. R2=(V_batt_float*2.5*10^5)/3.3 and R3=(R2*2.5*10^5)/(R2-(2.5*10^5)). I want V_batt_float to be 12V which is the voltage rating of the battery. Therefore, R2 is approximately 910k ohms and R3 is approximately 270k ohms.

STATUS PINS STATE		CHARGER STATUS
CHRG	FAULT	
OFF	OFF	Not Charging — Standby or Shutdown Mode
OFF	ON	Bad Battery Fault (Precondition Timeout/EOC Failure)
ON	OFF	Normal Charging at C/10 or Greater
ON	ON	NTC Fault (Pause)

Figure 8 LED Chart

The green LED is on the CHRG pin and the red LED is on the FAULT pin and the combination of lit LEDs can tell the user there is something wrong with the battery or if it is full.

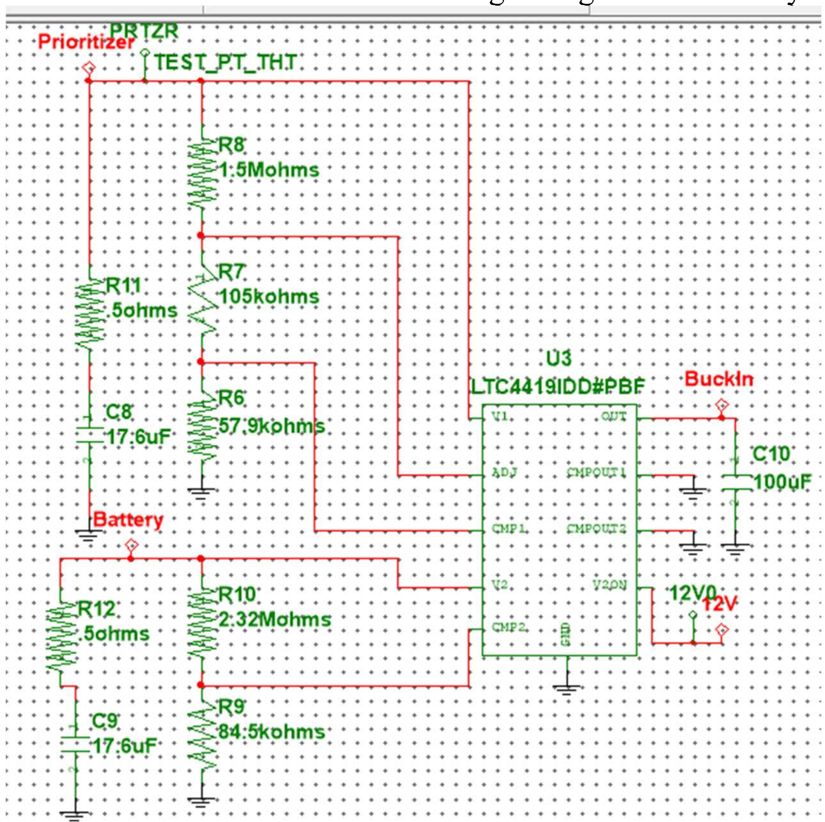


Figure 9 Prioritizer

If the load is being run, then the buck converter needs to make sure that the voltage supplied from the solar panel is stepped down to 12V. In order to set the switchover voltage for this circuit block, the proper resistor values must be selected for the voltage divider to provide proper input into the IC.

For our system, it is designed to prioritize between our solar panel, and 12V rechargeable lithium ion battery. The system is designed to switch to the battery source when the solar panel voltage drops below 11V.

First, we choose the total resistance in the resistive divider by dividing the max input of the solar panel by the divider current.

$$R1 + R2 + R3 = \frac{17.2V}{10uA} = 1720000$$

Our desired switchover voltage is 11V, therefore we can calculate R3 using the given equation for the switchover voltage given in the data sheet.

$$V_{SW1} = \frac{V_{THA}}{R1 + R2}\,(R1 + R2 + R3)$$

We are given the ADJ threshold in the datasheet to be V_{THA} = 1.047V. Therefore, rewriting the equation, we can then solve for R3.

$$R1 + R2 \;=\; \frac{(1.047)(1.72M)}{11V} = 163712.7$$

$$R3 \;=\; (1.72M \;-\; 163712.7) \;=\; 1556287.3$$

We can then solve for R1 using the equation given in the datasheet for the under-threshold voltage.

$$V_{V1UV} = \frac{V_{THC}}{R1}(R1 + R2 + R3)$$

Using the given value for V_{THC} = .387 in the datasheet and rearranging this equation gives us R1.

$$R1 \;=\; \frac{.387}{11.5}(1.72M) \;=\; 57881.7$$

R2 can be solved by plugging in R1 and R3 into the original equation for the total resistance, giving us R2 = 105831

A similar procedure is used to calculate R4 and R5, by first determining the divider current, and calculating the total divider resistance.

$$R4 + R5 \;=\; \frac{12V}{5uA} = 2400000$$

By using the given equation for the under-threshold voltage for V2, we can then calculate for R4 and R5.

$$V_{V2UV} = \frac{V_{THC}}{R4}(R4 + R5)$$

Rearranging the equation gives us R4.

$$R4 \;=\; \frac{V_{THC}(R4 + R5)}{V_{V2UV}} = \frac{(.387)(2.4M)}{11V} = 84436.36$$

Therefore, making R5 = 2315563.64.

Finally, we must solve for the value of C_{OUT} whose equation is also given in the datasheet.

$$C_{OUT} \geq \frac{(t_{PDA} \;\; + t_{SWITCH})(I_{load})}{100mV} = \frac{(7.3us \;+\; 2.5)(2)}{100mV} = .000196$$

Using standard component values, in summary, the system component values were determined as the following:

R1 = 57.9k
R2 = 106k
R3 = 1.5M
R4 = 84.5k
R5 = 2.3M
C_{OUT} = 2.3M

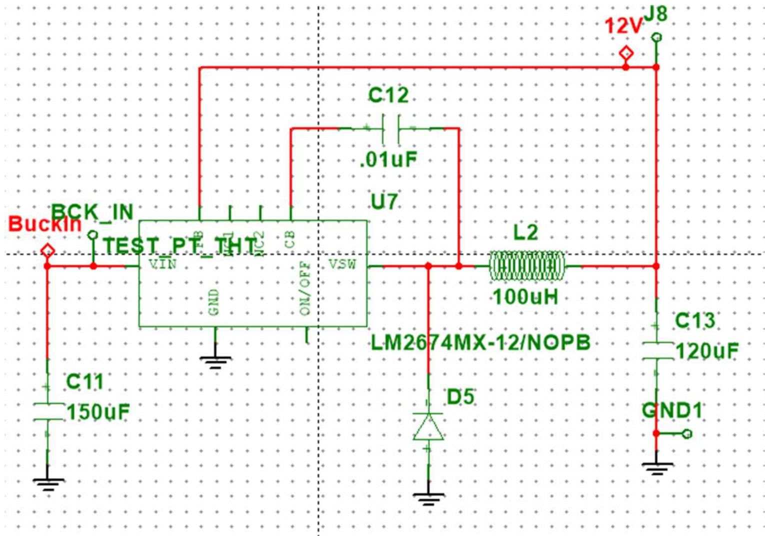


Figure 10 Buck Converter

The buck converter steps down the voltage from the solar panel to 12V because that is the voltage needed to run the motor. The values for the various components in the buck converter were determined by the required parameters of our circuit and charts given in the datasheet.

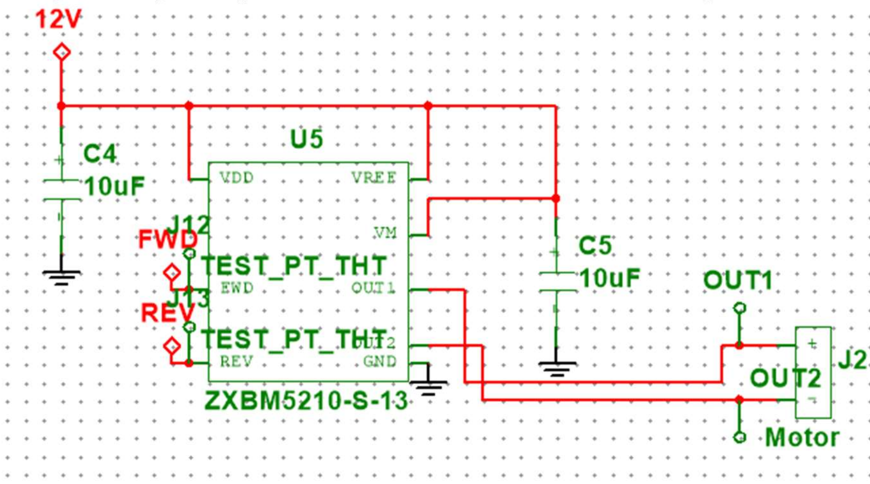


Figure 11 Motor Driver

The motor has inputs FWD and REV that are PWM inputs from the MSP430. The PWM signal can be changed to increase the speed or decrease the speed of the motor. The following chart shows how to vary the inputs into the FWD and REV pins to change the speed of the motor.

FWD	REV	V_{REF}	OUT1	OUT2	Operating mode
L	L	x	Open	Open	Standby mode – All switches are off
H	L	3V to V_{DD}	H	L	Forward mode – Current flows from OUT1 to OUT2; V_{REF} duty control
L	H	3V to V_{DD}	L	H	Reverse mode – Current flows from OUT2 to OUT1; V_{REF} duty control
H	H	x	L	L	Brake mode – Short circuit brake with low side switches on
PWM	L	V_{DD}	H	$\overline{PWM}$	Forward mode – Current flows from OUT1 to OUT2; PWM control mode
L	PWM	V_{DD}	$\overline{PWM}$	H	Reverse mode – Current flows from OUT2 to OUT1; PWM control mode
H	H	x	L	L	Brake mode – Short circuit brake with low side switches on

Figure 12 PWM Chart

We chose to operate in the two conditions outlined in red. That is why in the schematic, the VREF pin is connected to VDD. These two operating conditions were easy to operate in so that is why we chose them. Among the two outlined in red, we would choose one of them to actually use in our demo depending on which direction of the motor allowed more air to flow. The pin that had to be low would just be connected to ground.

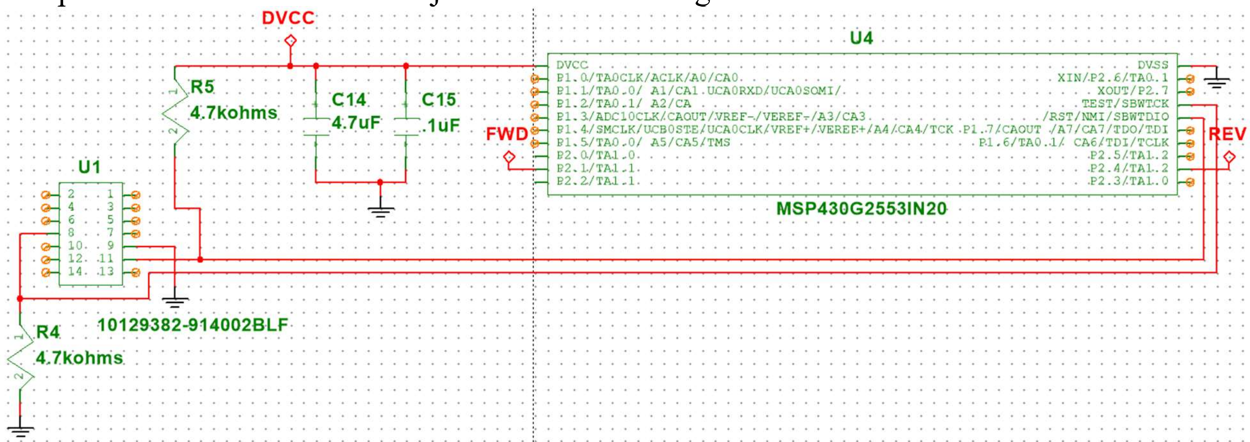


Figure 13 MSP430G2553IN20 with JTAG connector

Bypass capacitors were added to the DVCC pin of the MSP430G2553IN20 and the JTAG connector was connected. Originally, the JTAG that we were going to use was the MSP430-JTAG-TINY-V2 from Olimex, so we configured the connector to be compatible with that MSP430 debugger. That is why the 4.7K ohm resistors were added.

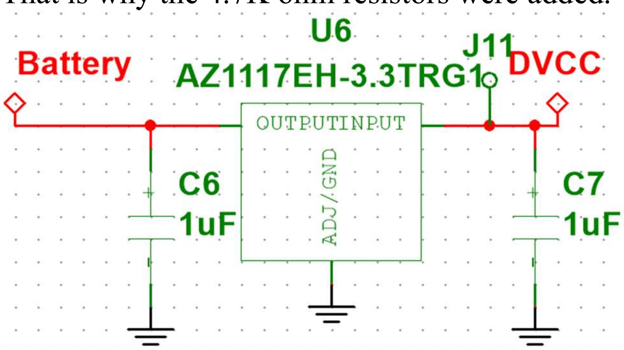


Figure 14 Buck Converter for the MSP430G2553IN20

A buck converter was needed to in order to step down the voltage from the battery to the MSP430G2553IN20. This is because the MSP430G2553IN20 needs a 3.3V supply but the battery is 12V. Bypass capacitors were added to the input and the output of the buck converter to make sure to reduce ripple.

Board Layouts

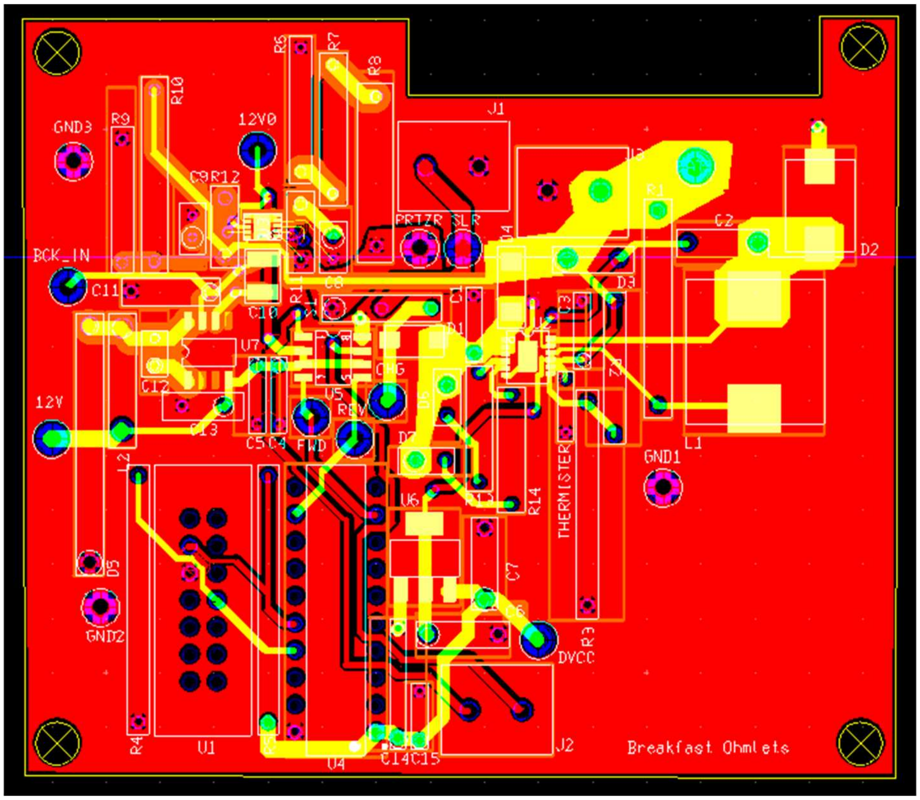


Figure 15 Overall Board Layout

As a general rule, we tried to keep traces pretty wide especially voltage traces. Several of the chips were really small so the traces that routed to those chips are pretty small. Most of the layout was based on design suggestions given in the data sheets.

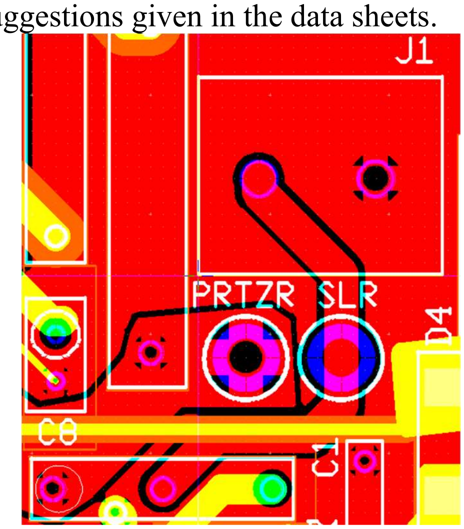


Figure 16 Solar Input and Switch Layout

The traces that connect the solar panel to the switch are pretty large since the voltage of the solar panel can get pretty high since it is a 35W solar panel. For the prioritizer node, I used a copper polygon since it is a trace that carries a supply voltage.

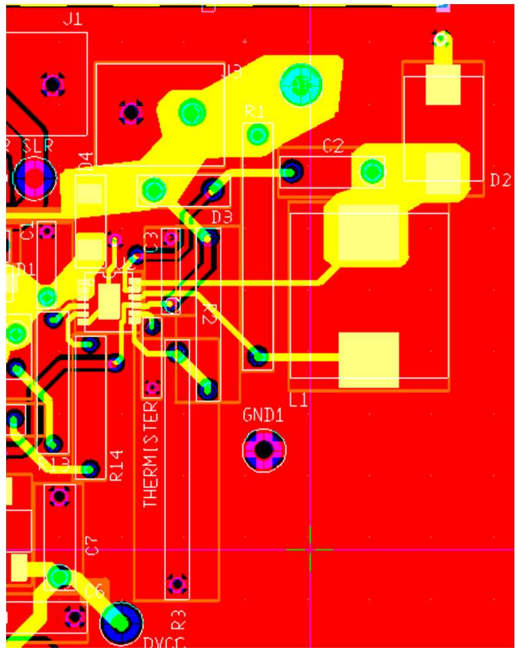


Figure 17 Battery Charging IC Layout

We used copper polygons on the traces that carried the voltage supplied. I also tried to keep the bypass capacitors as close as possible.

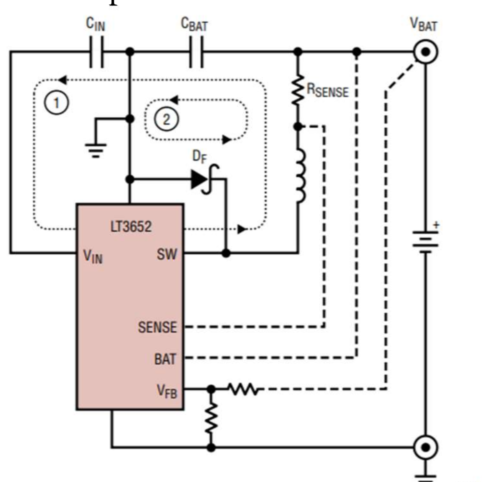


Figure 18 Layout Suggestions for the Battery Charging IC

We tried to place the components according to the suggested layout for the battery charging IC. In the board layout the diode is placed above the chip and the inductor is placed to the right of the chip just like it is shown in the suggested layout.

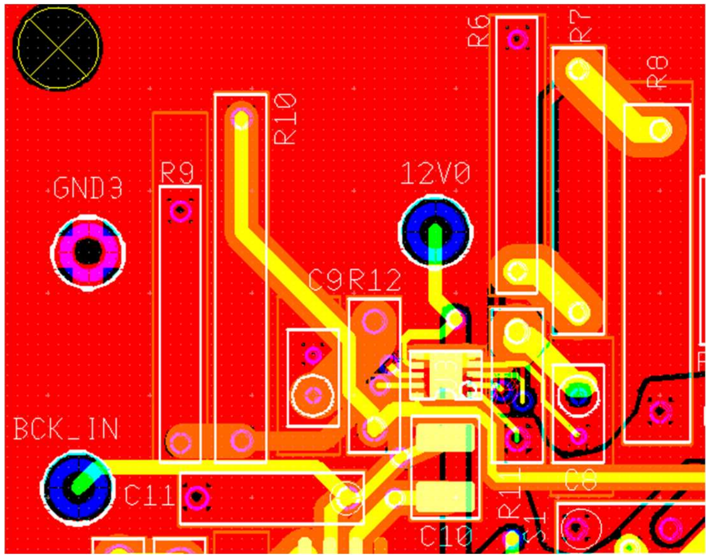


Figure 19 Prioritizer Layout

The components in the prioritizer were placed according to the layout given in the datasheet.

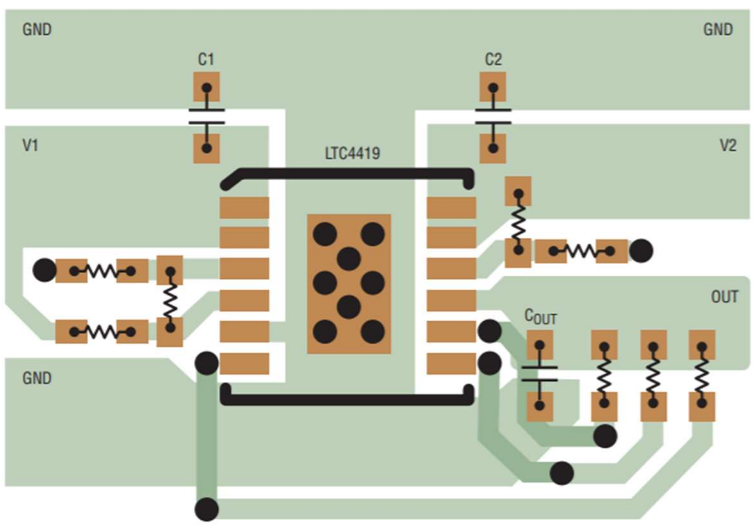


Figure 20 Prioritizer Suggested Layout

The components shown in the suggested layout are a lot smaller so copper polygons were feasible. In our layout, the components are a lot bigger so it was hard to play copper polygons according to the suggested layout. We tried to use large traces though. The bypass capacitors were placed as close to the chip as possible. The prioritizer is very small so small traces had to be used to route some of the components.

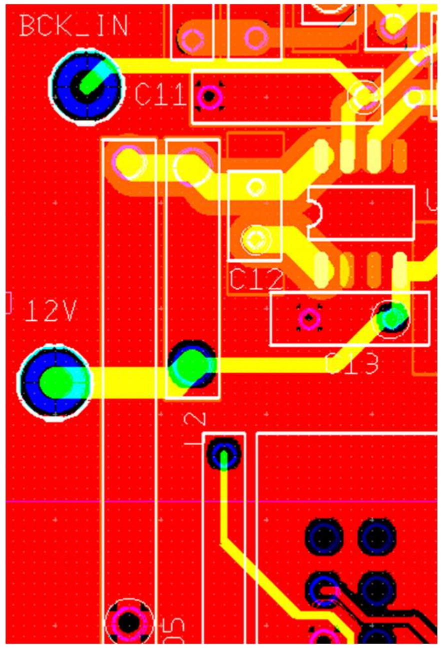


Figure 21 12V Buck Converter

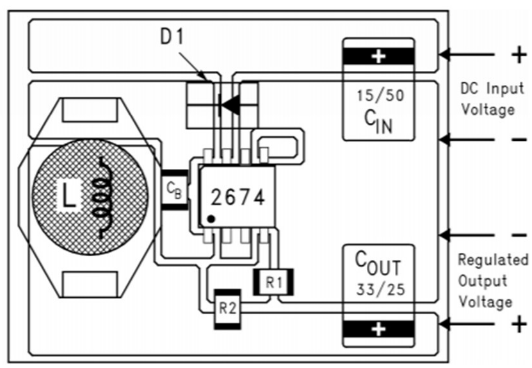


Figure 22 12V Buck Converter Suggested Layout

The placement of the components on the board are similar to placement of the components in the suggested layout. The bypass capacitors are placed close to the input and output pins. Since the components in the suggested layout are a lot smaller it seems like it is easier to place copper polygons. Therefore, I used large traces instead of copper polygons in the board layout.

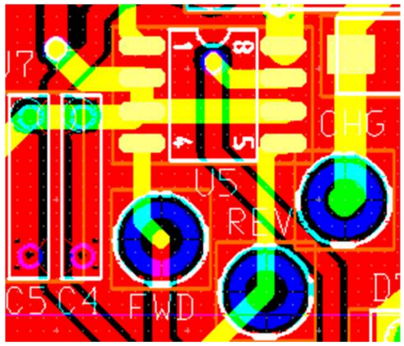


Figure 23 Motor Driver

The motor driver layout was relatively simple so I just tried to place the bypass capacitors close to the chip and use large traces for the supply voltages.

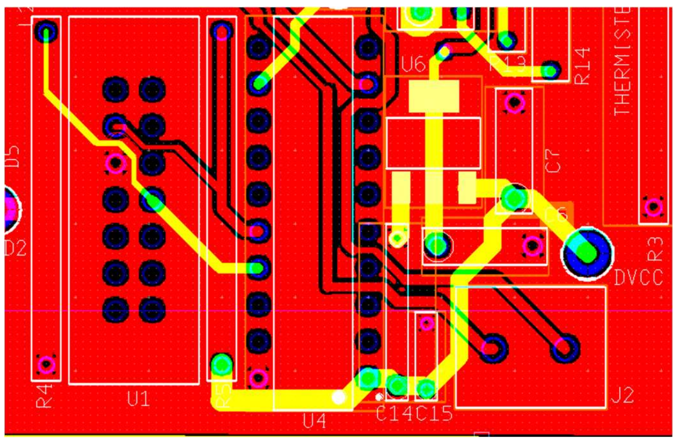


Figure 24 MSP430G2553IN20 Layout with JTAG Connector and 3.3V Voltage Regulator

The main consideration in laying out this part of the circuit was making sure the bypass capacitors were very close to the chips and the voltage rails had wide traces.

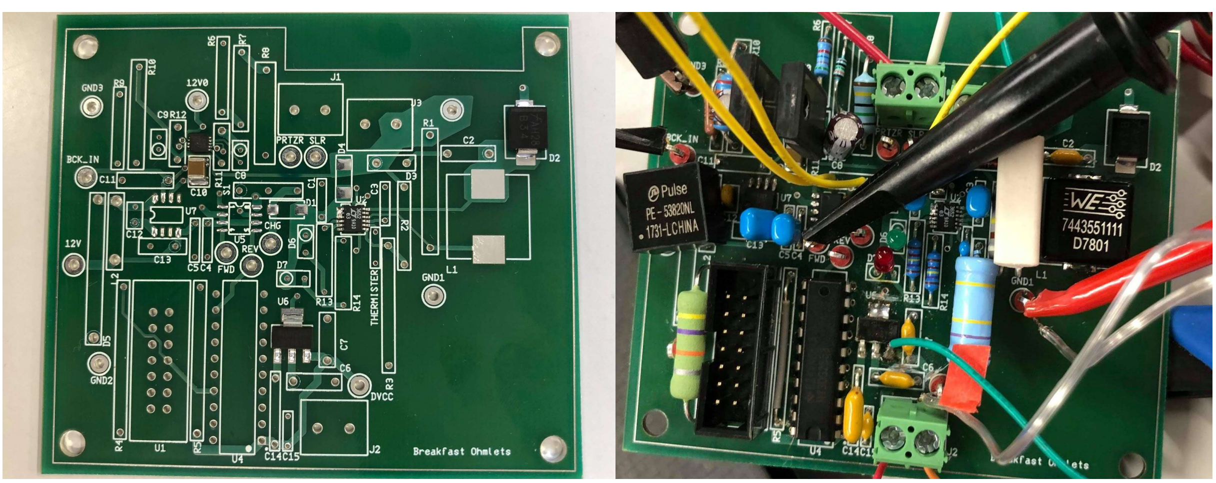


Figure 25 Final Board

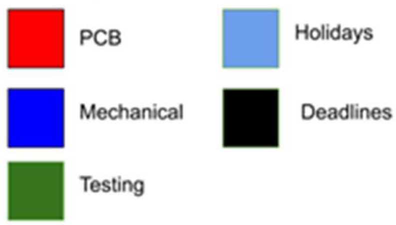
Problems and Design Modifications

In the testing phase of the project, there were several components that stopped working so we need to work around those challenges. The 3.3V regulator was laid out incorrectly. The input pins and output pins were switched so we had to cut traces and rewire the board. After traces were cut and wires were placed on the board to rewire the system, the voltage regulator outputted 3.3V. We tested if the board would output 3.3V again and then we realized that the board was not outputting 3.3V. The output voltage of the regulator kept dropping and regulator started to current limit. We determined that there had to be a short in the circuit, but after much testing we still could not find the short. Therefore, we decided to get rid of the 3.3V buck converter and use 2 AA batteries instead. The downside of using the AA batteries is that the system is less self-sufficient and the batteries may need to be replaced often if the product is continually in use.

The prioritizer decides whether the solar panel or the battery should be used in order to power the load based on the power supplied by each power source. During the debugging phase, the prioritizer in our circuit did not work and the miniature size of the prioritizer made it hard to debug problems. Therefore, we decided to remove the prioritizer and use switches instead to control whether to use the solar panel or the battery to power the load. This places more pressure on the user to determine which energy source will be adequate to run the fan.

Project Timeline

Our original and updated Gantt charts can be seen below.



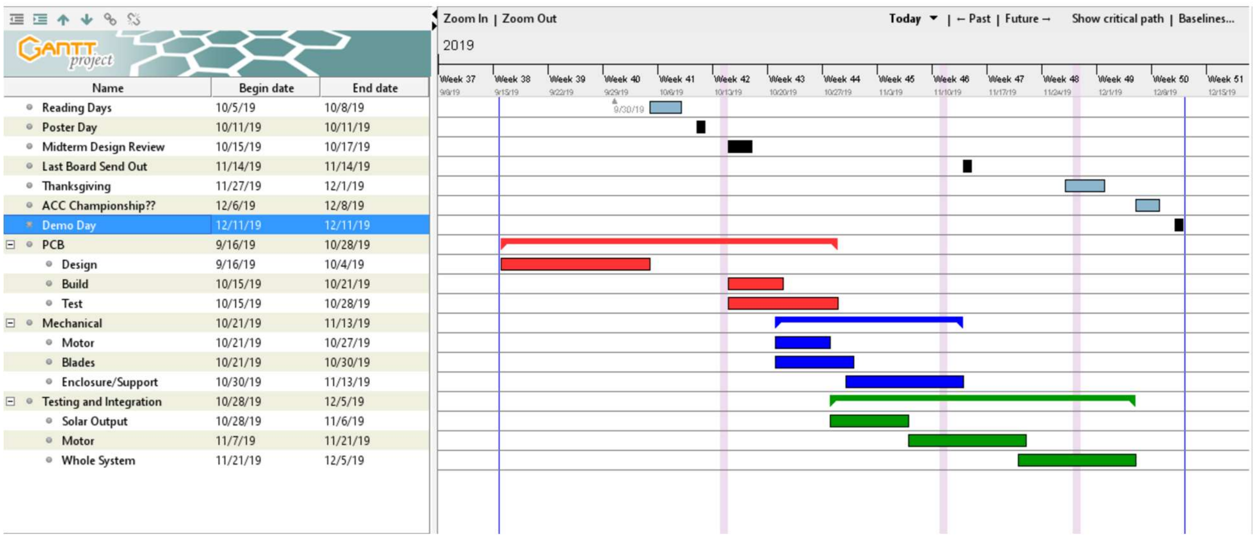


Figure 26 Original Gantt Chart

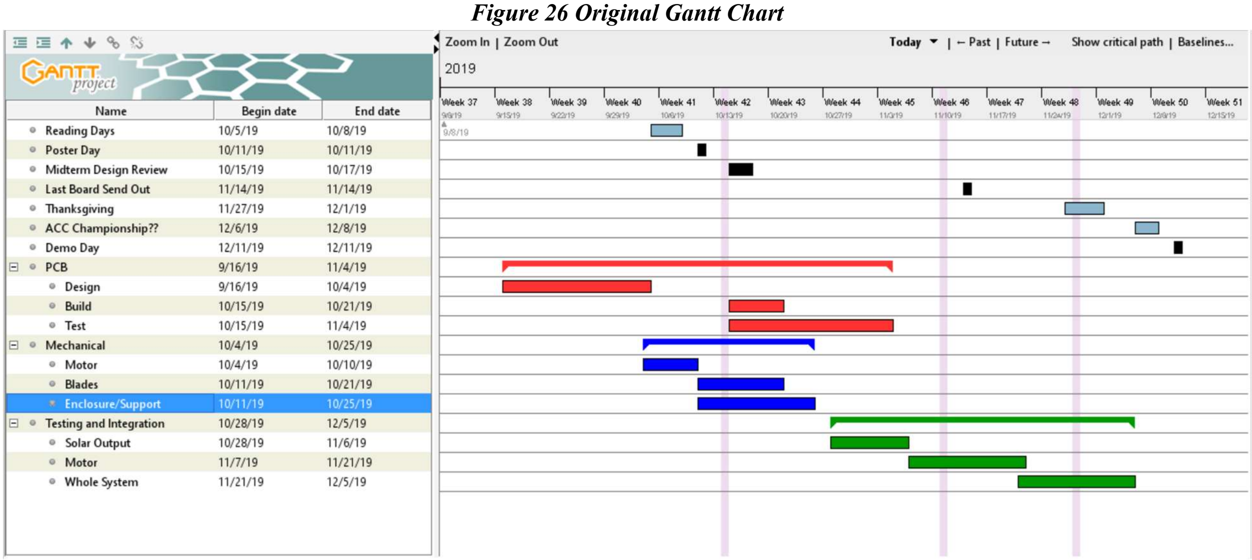


Figure 27 Final Gantt Chart

Our Gantt chart was comprised of three major sections: PCB, Mechanical, and Testing. We first designed our PCB. Then we were able to build in test the project in parallel. Different teammates tackled each section of the project. The major change in our timeline was extending the time for PCB design. In our original plan we hoped to have the final board completed by the second send out date. We later pushed this back as we underestimated the time needed to find and layout all of our components. Additionally, the mechanical design was started and completed earlier than anticipated. Moving the mechanical up allowed us to focus on testing once the boards were completed. Lastly, we extended our testing section as debugging our project took much more time than anticipated.

The design of the PCB was completed primarily by Hsing with assistance from Kelsi. Hsing was chosen for board design due to her summer intern experience with board layouts.

Thu acted as the primary for the motor enclosure and blades for the fan. Kelsi acted as the primary for incorporating the motor with Thu's help. Further, Hsing acted as the secondary on the enclosure of the motor and Kelsi acted as the secondary on the blades for the fan.

The testing will cover the entirety of the project and will be performed by all members of the team in order to double check the work of the other teammates.

Test Plan

Our project was divided into the subsystems shown in the flowchart below. The major sections to be tested were the motor controller, voltage regulation, and power control. The original test can also be seen below. The idea of testing subsections was continued however we worked in a different order than originally planned. The order of the test plan was changed in order to make sure our fundamental system was functional before the demo.

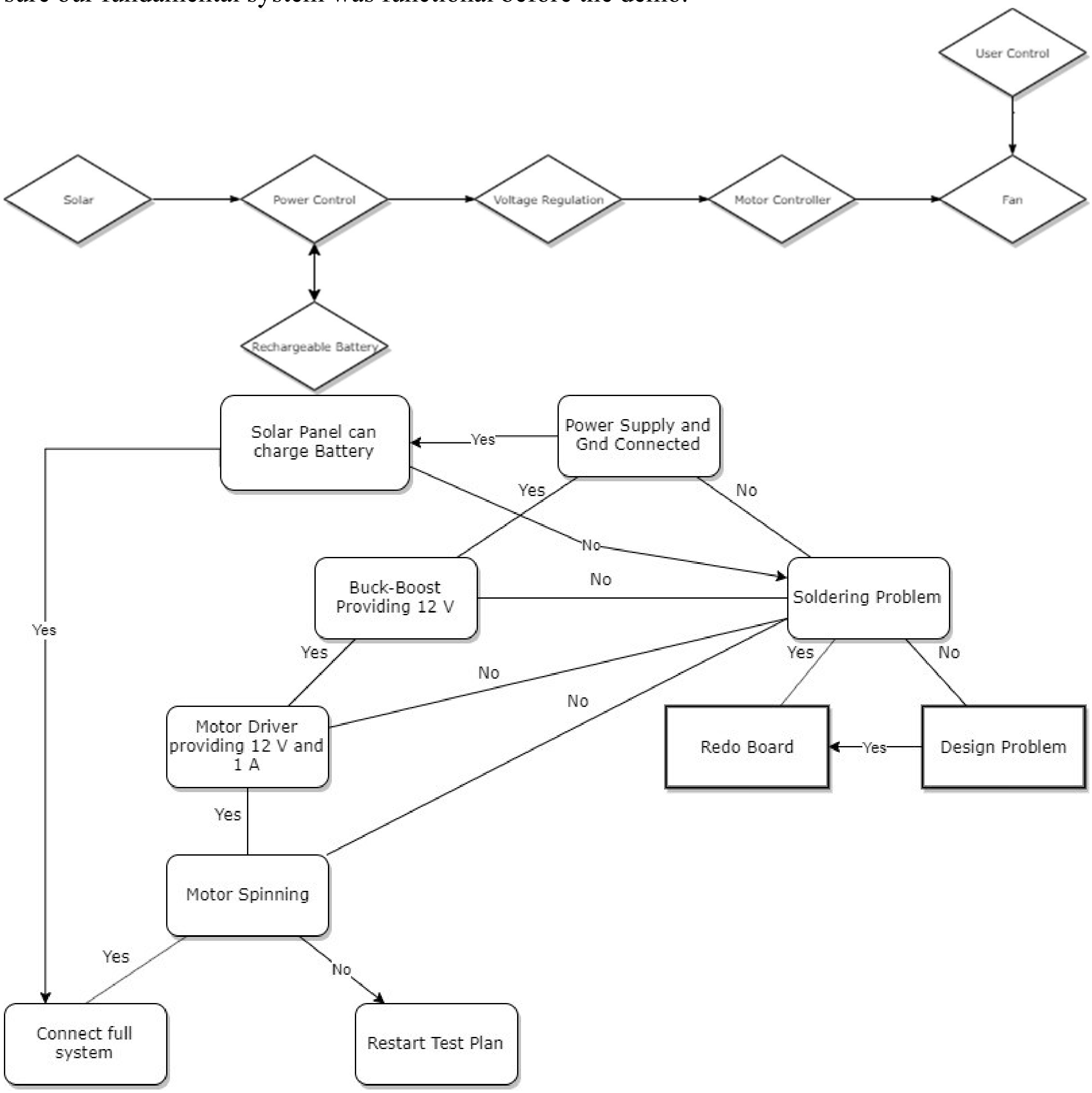


Figure 28 Test Plan

The voltage regulation was tested first. This subsystem was comprised of a buck convertor. Once the components were installed on the board, we input voltages ranging from 12V to 20V using the virtual bench. We then read the output which was fed into the motor controller to verify a steady 12V output. We found that when 12V were inputted the output was slightly less than 12V; however, the voltage drop was not significant enough to heavily impact the speed of the fan.

Further, the solar panel was tested with no load and produced an average of 17V when placed in sunlight so we concluded the voltage regulation worked as anticipated.

Next, the motor controller was built and tested. First, we provided the motor driver with 12V and a square wave pwm using the virtual bench. Then we flashed our pwm code onto an MSP430. The MSP was then tested to verify a steady pwm output at 90% duty cycle. Once the MSP430 was connected to the motor driver we attached the motor to verify its functionality. This subsystem also behaved as planned. One problem we ran into in this stage was the voltage regulator for the MSP430. Originally, we had a voltage regulator that stepped the 12V input down to 3.3V for MSP; however, we discovered the output and input were placed on the wrong pins. In order to rectify this problem, we first cut the traces and rerouted them using jumpers. However, we found this created a short in our system. Therefore, we removed the regulator and decided to run the MSP430 off of a separate battery pack with provided 3.2V via two AA batteries. This solution was far from ideal however it provided the voltage needed in order for our motor to behave normally. We then attached this subsystem to the previous and verified that they worked together. These two systems together formed our basic fan design and we verified the motor ran off the battery input the buck convertor and the solar panel input to the buck convertor.

The next step taken was testing the battery charging system. Our battery charger took the input from the solar panel and diverted power to a charging IC. First, we soldered the components onto the board. Then we input 12V into the circuit and observed the LEDS that indicated the charging status. This system worked as intended.

The last section tested was the power control. The IC chip used took the solar and battery inputs and decided which one to use. After installing the components, we input 12V into the solar input using the virtual bench to make sure it could pass through the chip. When we did this, we did not receive an output. We then discovered a problem as we debugged. This problem was the limited access to the chip due to the large components on either side of it. Due to the size and mobility constraints we were unable to identify the problem. Therefore, we did a redesign. This redesign added an additional switch which allowed us to choose whether the solar power or battery power where inputted into the voltage regulator subsystem. This additional switch allowed us to work around the power control system, but took away a level of automation we originally planned to have. Once the switches were installed all subsystems were tested together. In the end the system lacked some of the automation we originally designed, but met our goal of creating a solar fan.

Final Results

The criteria proposed can be seen in the chart below.

Grade	Criteria
A	• Device is successfully powered by solar panel • Device recharges battery when motor is not running • Motor and fan blades are enclosed • Motor spins at a reasonable speed for a fan
B	• Device does not perform one of the tasks required for an "A"
C	• Device does not perform two of the tasks required for an "A"
D	• Device does not perform three of the tasks required for an "A"

The completed solar fan met our original criteria. The device ran at a reasonable speed when powered through the battery. The fan ran at the same speed when tested with the solar panel in direct sunlight. Additionally, the battery was successfully recharged using the solar panel. Our design also features an enclosure for safety. Although this criterion was met there were problems with our design. First our voltage regulator for our MSP had to be replaced with an additional battery pack. The replacement added maintenance to the design as these batteries would need to be replaced at some point. Further, the power control system was replaced with a switch. This addition took away from the original intended automation of fan and replaced it with user control. These changes allowed us to meet the criteria set by the proposal although the ideal functionality was changed.

Costs

The manufacturing cost for our fan was $236.60. A detailed breakdown of this cost can be seen in the appendix. The costliest products in our design are the solar panel and battery. If 10,000 units were produced the approximate cost per unit is $175.76. This cost may further decrease as the current design enclosure was composed of premade wooden boxes. If the fan were to be mass produced the enclosure cost would most likely decrease dramatically. Additionally, the assembly of the enclosure may be automated. Further, the installation of components on the pcb may be automated. This automation would increase manufacturing costs, but would decrease labor costs. If the fan were to be mass produced it may be beneficial to seek out cheaper components that can only be ordered in large quantities as the current components were chosen due to their availability and minimum order quantity. Our original goal was to create a fan costing less than $150 to manufacture. With a few components changes this goal may be achieved, but the current components used bring the fan to $15 over budget. However, this fan is below the cost of a typical electric bill in a hot summer month so it is still cost effective for the consumer.

Future Work

The two major problems with our design where the voltage regulator for the MSP and the power control system. The voltage regulator could be fixed by rerouting the input and output on the PCB. The power control system would need to be altered as the chip we chose was too small to find the error. Therefore, one major pitfall of our design was the size of the board created. If the board was slightly larger debugging would have been much easier. Additionally, we did not anticipate how difficult it would be to achieve direct sunlight. In order to demo our design, we had to provide many lamps to receive very little power from the solar panel, but in sunlight the design worked as intended. Therefore, one useful addition to the project may be to create a bracket to hang the solar panel from a window. Further, a second method of charging the battery by plugging the fan into the wall may be useful as the battery will not charge is the solar panel does not have sunlight. Lastly, the fan may be more efficient in cooling large spaces if the design was used to create a ceiling fan.

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Appendix

Cost Table 1

PCB Components					33	33
	Description	Quantity	Price	10,000	Cost	Cost 10,00
	MyParts, ZXBM5210-S-13	1	1.13	0.47902	1.13	0.47902
	MyConnectors, TERM BLK 2POS	3	0.43	0.3035	1.29	0.9105
	MyBasic, MRS25000C5762FCT0	1	0.29	0.0396	0.29	0.0396
	MyBasic, RNMF14FTD105K	1	0.1	0.0121	0.1	0.0121
	MyBasic, VR37000001504FA10(	1	0.59	0.1386	0.59	0.1386
	MyBasic, CMF5584K500FHEB	1	0.58	0.1485	0.58	0.1485
	MyBasic, HVR3700002324FR50	1	0.54	0.10839	0.54	0.10839
	MyBasic, 1210YD107MAT2A	1	4.57	2.8738	4.57	2.8738
	MyBasic, MP850-0.50-1%	2	11.35	6.4328	22.7	12.8656
	MyBasic, UPW1J180MDD1TD	2	0.36	0.09439	0.72	0.18878
	MyConnectors, 100SP1T1B4M2	1	2.9	1.62945	2.9	1.62945
	MyBasic, CMSH1-40M TR13 PBI	1	1.71	0.80114	1.71	0.80114
	MyBasic, RCER71H106MWM1H	4	2.5	1.17426	10	4.69704
	MyDiodes, MBRS340	1	0.49	0.14253	0.49	0.14253
	MyBasic, C440C105M5U5TA72(	3	0.41	0.10707	1.23	0.32121
	MyDiodes, CMSH3-40MA TR13	1	0.65	0.21	0.65	0.21
	MyBasic, 7443551111	1	3.27	2.649	3.27	2.649
	MyBasic, 1N914	1	0.1	0.0174	0.1	0.0174
	MyBasic, SBL4R047J	1	1.64	0.59877	1.64	0.59877
	MyBasic, RSF100JB-73-910K	1	0.32	0.03644	0.32	0.03644
	MyBasic, VR68000002703JAC0(	1	0.78	0.38924	0.78	0.38924
	MyBasic, NXRT15XH103FA1B03	1	0.7	0.24304	0.7	0.24304
	MyBasic, C350C475M5U5TA	1	1.87	0.66339	1.87	0.66339
	MyBasic, C410C104M5U5TA72(	1	0.27	0.0534	0.27	0.0534
	MyParts, LTC4419IDD#PBF	1	7.65	4.2	7.65	4.2
	TestPoints, TEST_PT_THT	15	0.35	0.1434	5.25	2.151
	MyMCU, MSP430G2553IN20	1	2.69	1.1843	2.69	1.1843
	MyBasic, UPM1V121MPD6TD	1	0.56	0.26	0.56	0.26
	MyDiodes, MBR350RLG	1	0.51	0.22092	0.51	0.22092
	MyBasic, EKXG251ELL151MM2!	1	2.32	0.92616	2.32	0.92616
	MyBasic, C315C103M5U5TA73(	1	0.26	0.06279	0.26	0.06279
	MyBasic, OX473KE	2	1.74	0.7056	3.48	1.4112
	MyParts, LT3652IMSE#TRPBF	1	8.54	4.6865	8.54	4.6865
	MyBasic, PE-53820NL	1	3.06	1.47755	3.06	1.47755
	MyParts, LM2674MX-12/NOPB	1	3.28	1.488	3.28	1.488
	MyParts, AZ1117EH-3.3TRG1	1	0.42	0.09036	0.42	0.09036
	MyBasic, MFR-25FBF52-1K74	2	0.1	0.01057	0.2	0.02114
	MyDiodes, HLMP	2	0.18442	0.14165	0.36884	0.2833
					97.02884	48.68016
					97.03	48.69
Motor						
	290-006	1	19.99	19.99		
Solar Panel						
	Newpowa 35W	1	38.58	38.58		
Enclosure						
		1	15		203.6	155.26
Battery						
		1	33	20.5		
Total Cost					236.6	175.76