Automated Personal Transit Network 198B Written Report

Team Member

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Abstract

During the course of designing and development, we were successfully able to complete our section of the project. The focus of our project was to design a 1/12 scale model of a sustainable transport system that would be able to run automatically. The goal of this project is to develop a personal rapid transit (PRT) system which can be used in most urban locations. The system will provide an alternative means of transportation for the community. The PRT will reduce wait time, travel time, and also have a positive impact on the environment as it will run completely on solar energy. The project involves various groups such as mechanical, civil, computer and electrical engineers who had to focus on various aspect of the project. As the electrical engineering group we had to focus on designing the power system that would be able to power the whole system. Our group's main task is harvesting and distributing enough solar power to the 1/12 scale model track to handle the load of three pods and its control. The second task given to us is to figure out a way to switch to an alternative source of power when the solar panels are not producing enough energy. Our final task is to design a third rail system which works as a transmission line to power all the components on the track. The team consists of four graduating seniors that have implemented their skills they learned at San José State University to come up with a design of the power system and successfully build and test it. The cost of developing and testing our prototype is covered by our team. Each task is assigned to capable members who have demonstrated exceptional efficiency and drive throughout the project.

Background:

The increase in population in large urban areas has resulted in increased traffic on our highways. The result of this increase in traffic is leading to an increase of pollution into our environment. With the advances in technology over the past century, it is now feasible to create an Automated Transit Network (ATN). An automated transit network is a mass transit system comprised of vehicles and guide ways which exhibit the following characteristics:

1. Automatically controlled vehicles which travel to their destination without human intervention.

2. On-demand service. A vehicle arrives when summoned, rather than on a predetermined schedule.

3. Supervisory safety and availability monitoring. The state of each vehicle in the system, and all of its subsystems are continually and automatically monitored for state and optimal function.

4. Non-stop service to the destination. Basically necessitates stations which are not on the main line of transit (called offline stations) .

5. A discrete guide way, separate from existing roadways.

   The goal of the project is to have a positive impact on society. This will benefit not only the people of the community, but it will also have a positive impact on the environment. The other benefits for Solar Powered Vehicles (SPV) are listed below:

- Because an SPV have few moving parts, repair costs are a smaller amount than for conventional means of transportation.

- Since there is no internal combustion engines, meaning there are no emissions.

- Electric vehicles put out very little noise.

- Additional emissions are not produced by power plants, since SPV's run only on solar energy.

- Efficient vehicles have traveled a mile on less energy than a 100-watt light bulb consumes in one hour. (For a gasoline-powered car to achieve comparable efficiency, it would need to get 500 miles per gallon.)

Cost

The cost of the project included purchasing components for the prototype and the final design. The team members all contributed to the purchasing all the component s needed to design the power system. Some of the equipment such as the solar panels was donated to the overall project.

Table 1: The table shows the breakdown of the number and cost of material needed to build the power system

description	number	cost
PCB	5	115.00
LM338K	3	15.00
Arduino Uno	1	23.00
LED display	1	15.00
Heat sink	1	5.00

fan	1	10.00
Capacitors	20	15.00
Diode	5	8.00
LM7812	1	1.00
LM7805	1	1.00
fuse	5	4.00
switch	2	5.00
relay	1	10.00
Current sensor	1	15
Total cost		232.00

The major cost in building the power system as can be seen above was having a external

company make the PCB. The reason why we took this path was because of time constraints and

we needed the final product to look professional.

Team management

Our group consists of four members and each member has their own way of approaching

to a problem and doing things. Each member had their own vision and idea on how to implement

and complete this project. We knew everybody have their own ways of doing things and our

main priority was to listen to each other's ideas and putting them together into one main idea to

achieve our goal. Each member had to make little bit of compromise to their ideas to achieve the

big goal which was to design the power system on time. Our team developed a timetable that

contains tasks for each week starting from the first week of the semester till the last week of the

semester. Starting of each week the tasks were divided equally between each member and our

goal as a group was to complete the assigned tasks by the due date.

During our first team meeting each member expressed their desire on which aspect of the

project they would like to be involved in. Each week during our team meetings we all worked

together on building the power supply circuitry and coding the microcontroller that will be used

to monitor the power system. During these meetings every member also shared new ideas from

the research they did each week on designing the power system. For any reason if any member of

the team missed the team meeting he was contacted and given update of the meeting. Our main

sources of communication were cell phone text and email. Communicating with each other was

the best solution for solving any disagreements within our team members. Attending weekly

team meeting was each member's first priority toward this project. Also each week one or two

member voluntary agreed to keep in touch and see the progress of the other engineering groups

involved in this project. This was helpful for our group to understand at what pace we should be

working on to keep up with the productivity of the whole project.

Skill set

All the members in our group have completed the critical courses required to graduate

with the B.S in electrical engineering up this point. Therefore we all possess some basic

knowledge learned from these courses. Apart from that Jiten and Raman who are currently

enrolled in EE134 which is a power system course that helped us with this project since we are

dealing with high power circuit. This course at San Jose State University provides the knowledge

of power system and power losses faced by high power transmission lines. Even though we are

not dealing with 3 phase voltage involved in the transmission lines, we still need the knowledge of power losses in system with high currents and voltages.

This project also requires knowledge provided in course such as EE122, and EE124 for designing circuits to output desire current or voltage. Course that involved designing the control system for the power system such as EE120, EE138 for C++ or EE124 which involved python gave us confident and helped us in understanding and writing the code required to build the digital part of the circuitry. Other basic skills such as reading and understand data sheets for components learned during course which involved labs helped us when we dealt with component that we never used in school before.

Design

The design for the power system had to meet a certain minimum requirements. This requirement was that it should output a steady 12V, with a maximum current of 5A and be able to have two sources of inputs going into it. The key component for the power supply was the circuitry that would regulate the input power and the control system that would monitor the two sources of power (the solar panel and power from the grid). The summary of the power system is shown below in the block diagram.
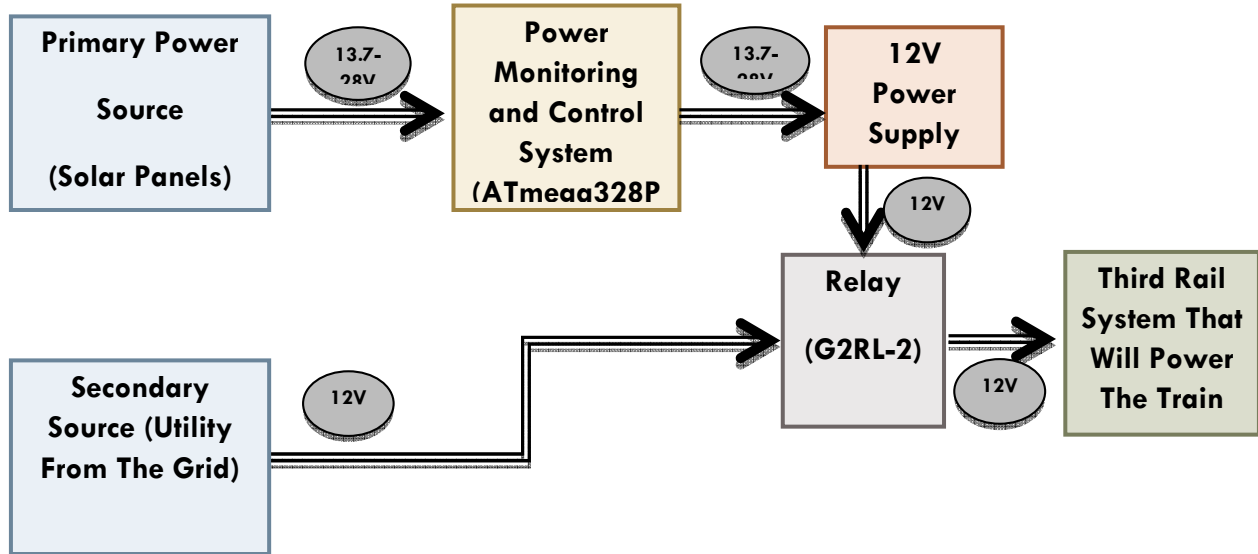
Figure 1: the figure above shows the block diagram of the power system

Control Functions:

The controls section of the circuit is designed to perform three main functions: (1) monitor

voltage and current being supplied by the solar panels using Analog to Digital Conversion, (2)

display voltage and current values from the solar panels in real time on a 16x2 LCD display

module, and (3) output a signal that triggers a relay switch when there is sufficient power

provided by the solar panels. For these functions we chose to use Atmel's ATmega328P low

powered microcontroller chip, along with the Arduino Uno R3 microcontroller based board to

communicate with it. Figure 2 shows the chip's pin names and diagram, along with their

corresponding Arduino functions.
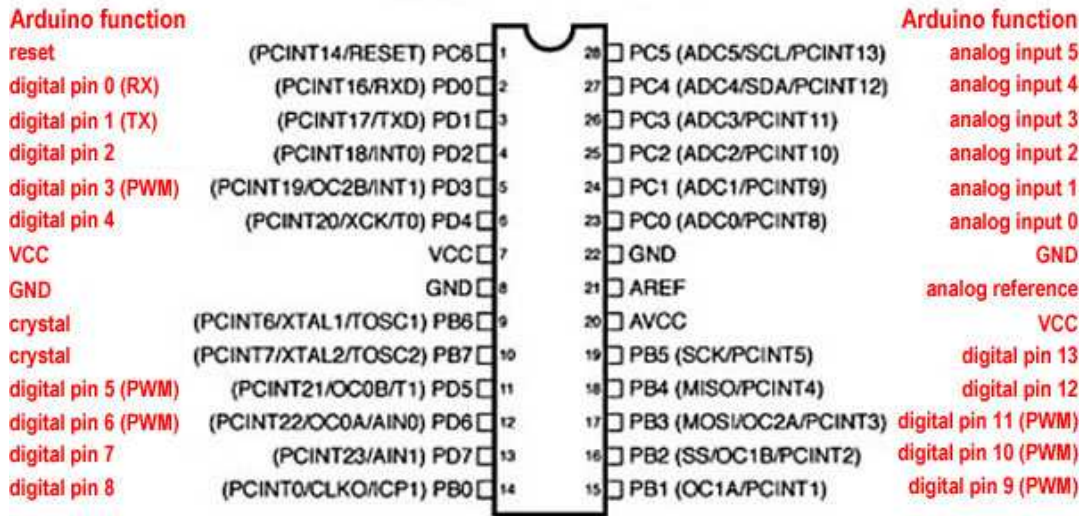
Figure 2: ATmega 328P pin mapping

Analog to Digital Conversion:

Analog to Digital Conversion (ADC) is done by reading an input voltage and assigning that

voltage value to a corresponding numerical value. This means that the microcontroller can read

an analog signal and save it with a digital number than can be used later. Figure 3 shows an

example of how this is done using 3-bit ADC. The black and blue lines represent the analog

input signal and the saved digital signal, respectively. The red points show where data was taken,

notice how at each point the corresponding digital data is rounded to the nearest 3-bit number.
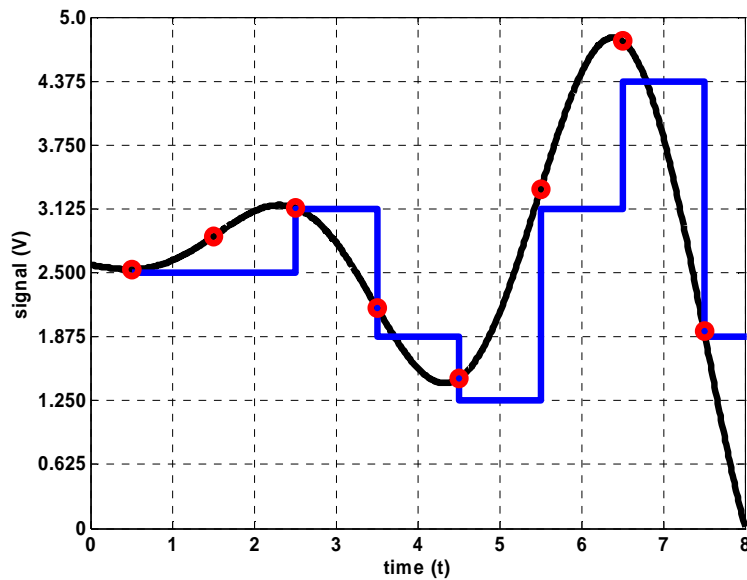
Figure 3: Analog to digital conversion

The ATmega328P is capable of 10-bit ADC with input signals ranging between 0 – 5 Volts. This

allows for a much more accurate reading than the 3-bits used in Figure 2. Instead of 0 – 5 Volts

being represented by a number 0 – 7, it is represented by a number 0 – 1023.

<u>Monitoring Voltage:</u>

The solar panel's large voltage range of 0 – 32 Volts presented a small problem for the

microcontrollers 5 Volt maximum input. The simple solution here was to use a voltage divider.

Choosing the right resistors we split voltage so that at 32 Volts, we read a corresponding 5 Volts

over the dividers smaller resistor. This Analog to Analog Conversion allows us to input a

readable analog signal to the ATmega328P, and then recalculate the larger voltage we want to

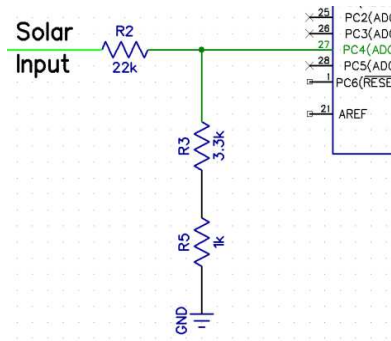monitor. Figure 4 shows this portion of the controls circuit.

Figure 4: voltage monitoring circuit

Monitoring Current:

To monitor the current running from the solar panels to the track we used a separate chip

designed to do exactly that. It is the ACS714 Current Sensor Board, Figure 5. The diagram in

Figure 6 shows how to connect the sensor to the microcontroller.
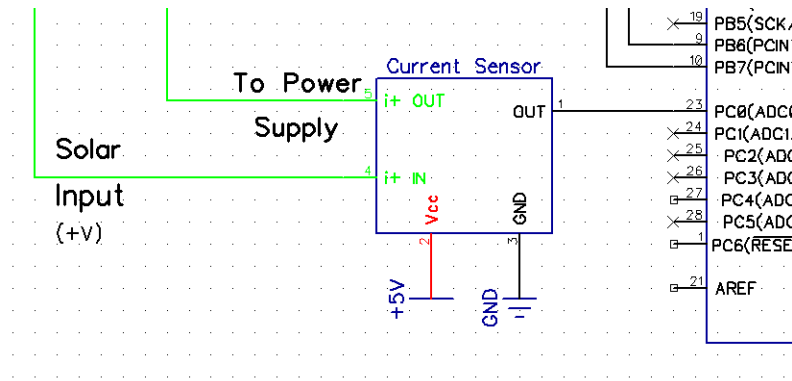

Figure 5: ACS714 Current Sensor Board

Figure 6: Current sensing circuit

The pins labeled i+ IN and i+ OUT are connected in series with the positive wire of the solar

panels before the LM338K regulator. The pin labeled OUT in Figure 6 is the chip's only data

output, which sends an analog voltage to another one of the ATmega328P'ss ADC pins. Just like

when reading voltage, the converted digital number from the ACS715 needs to be recalculated in

order to represent the correct current value. The ACS715 can read current between -30 Amps and

+30 Amps, corresponding to an output voltage of 0 – 5 Volts. This means that reading 2.5 Volts

from the sensor represents zero current. At low currents some accuracy is lost due to the sensor's

large range of readable current.

16x2 Character LCD Display Module:

Outputting characters to Microtivity's LCD module (Figure 7) is been made extremely simple by

the Arduino. The Arduino's programming software comes with a library called Liquid Crystal.

This library contains basic commands that convert characters from ASCII to a 4-bit signal that is

sent to the LCD module. With the module connected according to the provided connection

diagram in Figure 7, it will display the same characters from a keyboard that are typed into the

program's code.

Figure 7: Microtivity Arduino compatible 16x2 Character LCD module
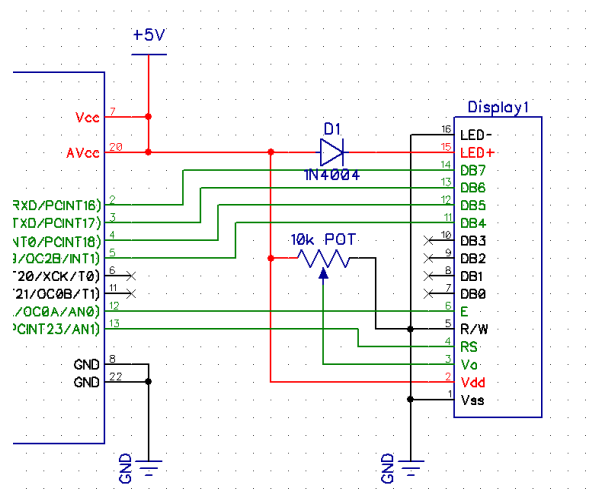

Figure 8: LCD Module Circuit

The diode in Figure 78provides protection to the LED backlight, and the potentiometer is used to

manually adjust the contrast of the characters.

Double Pole Double Throw Relay Switch:

Omeron's G2RL-2 Double Pole Double Throw Relay Switch (Figure 9) was chosen for this

project because during automatic switching between power sources, the grid power input and the

solar panel input are not able to share the same negative, or ground, wires. A relay's circuit is set

up just like a mechanical switch is, except that instead of manually flipping a physical switch, the

switch is activated through magnets when current passes through a wrapped coil generating a

magnetic field.

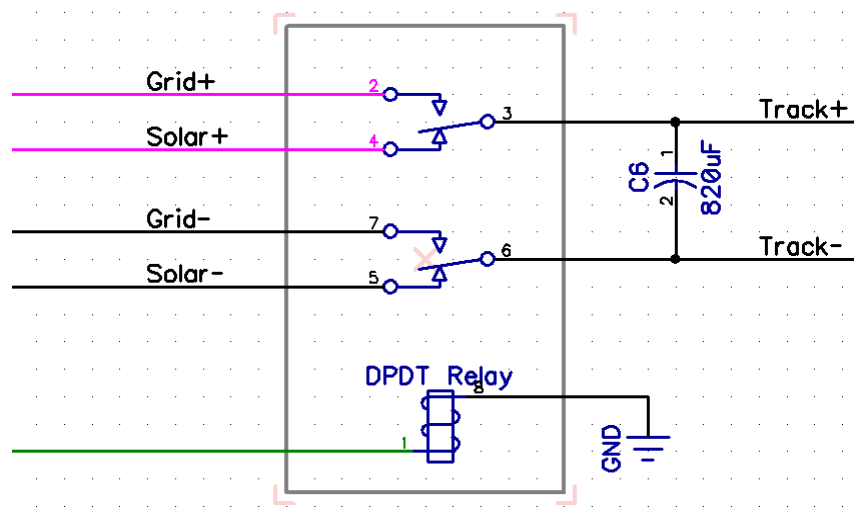**Figure 9**: Omeron's G2RL-2 Double Pole Double Throw Relay Switch

Figure 10: Relay Switch Circuit

Figure 10 shows the relay circuit with its input and output connections. Its two switch inputs are

connected directly to the grid through a 12 Volt transformer and to the solar panels, directly after

LM338K regulating circuit. The large capacitor over the output is there to discharge energy

during the few milliseconds of having an open circuit during a switch. Without this capacitor, all

the cars on the track would slow down for a brief moment every time a switch is made.

The signal to the relay's coil is generated by an output pin of the ATmega328P. This pin is set to

HI only when the solar panel voltage is above 13.7 Volts, and set to LOW otherwise,

reconnecting the track back to the grid. The ATmega328P knows when to send a signal to the

relay coil based on the ADC data collected by the voltage monitoring circuit. The greatest

advantage to using this type of switch is that it can be controlled using just one low powered

signal, but can withstand switching between up to 300 Volts and 8 Amps, far higher than our

maximum operating values.
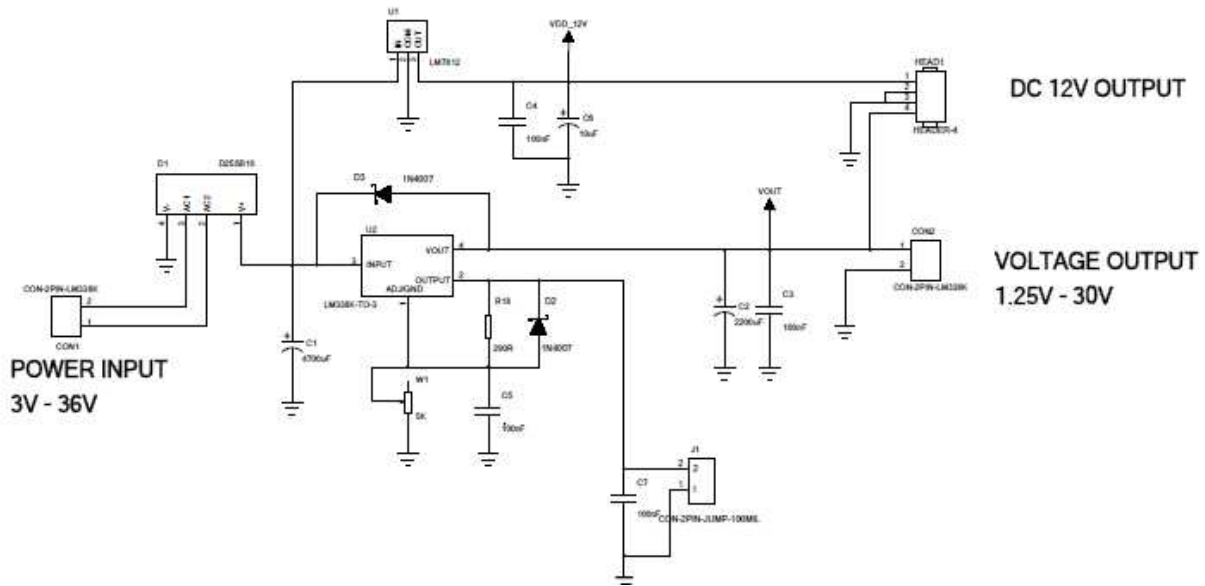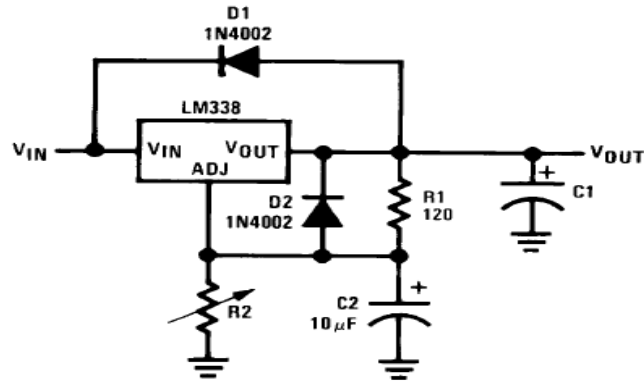
The Power

Supply:

Figure 11: schematic of the power supply of the power system

The power supply that is designed for the project requires it to be able to output maximum 5A

over a 1.2v to 32V output range. For this project requirement we will need 12V to be outputted.

The key component to the power supply is the LM338K regulator. The unique feature of the

LM338K is that it is a time dependent current limiting. The current limit circuitry allows peak

current of up to 12A to be drawn from the regulator for a short period of time, which allows it to

be used with heavy transient loads and speed start ups under full load conditions. This is ideal for

our design specification because if all three model pods start at the same time the power supply

will be able to handle the load for a short period of time. The LM338 is capable of providing

very good load regulation but a few safety measures are needed to get maximum performance.

The current set resistor connected between the adjustment terminal and the output terminal

(usually 240Ω) should be tied directly to the output of the regulator (case) rather than near the

load. This eliminates line drops from appearing effectively in series with the reference and

degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator

and load will have a load regulation due to line resistance of 0.05Ω × IL. If the set resistor is

connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case,

11.5 times worse. When external capacitors are used with *any* IC regulator it is sometimes

necessary to add protection diodes to prevent the capacitors from discharging through low

current points into the regulator. Most 20 μF capacitors have low enough internal series

resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough

energy to damage parts of the IC.

D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V \left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

Figure 12: the above diagram explains how the diode are used to protect the LM338

For the power supply we require a heat sink so that the LM338 regulator operates efficiently. We had to do some calculation to determine the correct size of the heat sink. We had to do some assumptions to do these calculations. The assumption where that that we operating in steady operating conditions, the transistor case is isothermal at 90°C and the contact resistance between the transistor and the heat sink is negligible. The peak power that the LM338 would output was 120W and the room temperature it would be operating was around 30°C

$$R = \frac{\Delta T}{Q}$$

$$R = \frac{90 - 30}{120} = \frac{0.5°C}{W}$$

From the value calculated thermal resistance we were able to look up a table that was available online to determine the correct size of the heat sink. For extra precaution we added a fan to the heat sink to cool the LM338 regulator.

The LM338K regulates power from two different inputs: the utility grid and a set of solar panels.

Our circuit must output power from the sources with the highest possible efficiency and at the

lowest possible cost. The basic design functions of our power supply are:-

Rectification –

 Convert the input AC voltage to DC voltage. For our circuit we used a full wave rectifier

Voltage transformation -

Adjust the supplied voltage to the required levels.

Filtering -

Smooth out the ripple of the supplied voltage.

Regulation -

Control the supplied voltage regardless of line, load and / or temperatures changes.

Isolation -

Electrically isolate the input voltage source from the output.

Protection -

Prevent any damaging power phenomena from reaching or take effect at the output.

The Third Rail System:

Our track was designed by civil and mechanical engineer from the previous semester, but

no consideration was made to how they would be powering the track. The track is supposed to

carry the 12V from the power supply (via the Solar cells or the grid power supply) that power all

the carts inside it. The design of the third rail system is based on how the electrical engineering

team wanted to power the track to ensure that we had conductivity throughout the whole track.

The third rail will consist of two separated power transmission lines which are ground and +12V

DC. Two conductive brushes will be connected to the bogie of the pods to transfer the power

from the track main power lines (3rd rail track) to support the operation of the pods. Some of the

track pieces are made of metal (Iron) and others, such as the turns, are made of acrylic. This

created two different issues for us to solve.

- Powering the plastic part of the track: The positives of having a plastic track is that we

    can place our connection where we need without worrying about having them shorting

    other connections. After trying different connections to the track we decided that the best

    way to implement the third rail on the acrylic side of the track is by applying Aluminum

    tape inside it (this will be our ground) and Aluminum tape in the bottom part of the track

    (to create a power line for the 12V DC inputs). Our final view of this part of the track is

    as shown in figure 13 below:
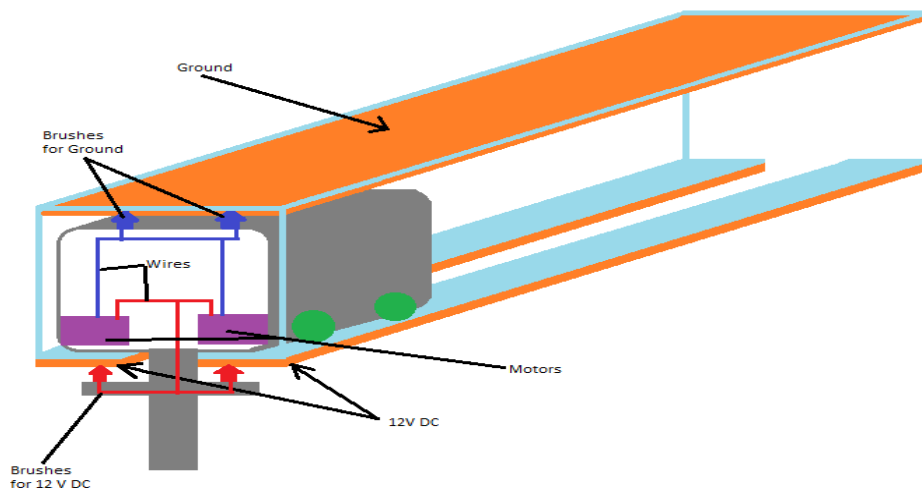
Figure 13: shows the plastic section of the track

As shown in figure 13, the two sides of the track are plastic (insulator) so there is no

chance of a short between them. The 12V DC power lines in the lower side of the track

are connected together supporting the same voltage from the same power supply. The

reason for having two connections instead of one is to maintain the power to the carts via

brushes that would run along both sides of the track when the cart would exit into a

station.

The installation of the lower connection was easy, simply by applying Aluminum tape on

that section and pressing it by hands. Although the ground connection on the top of the

track was not simple for having just a small access hole in the lower part of the track

where the bogie connects to the basket and also considering the track pieces are big

(about 2 Meters long each). For this we had to use certain tools to apply the Aluminum

tape.

- Powering the Metal part of the track: The positive of having a metal track is that there is

  no need to apply a ground to the track, instead we just used the track to be our ground.

  The idea of powering the metal track was similar to powering the plastic track to make

  them linear and so that the brushes will maintain the connection while moving between

  the plastic and the metal tracks. Connecting the 12V DC power line wasn't as simple for

  having to first insulate it from the track and then apply our Aluminum Tape. We tried

  using different insulators until we agreed on one to use with all the metal track pieces.

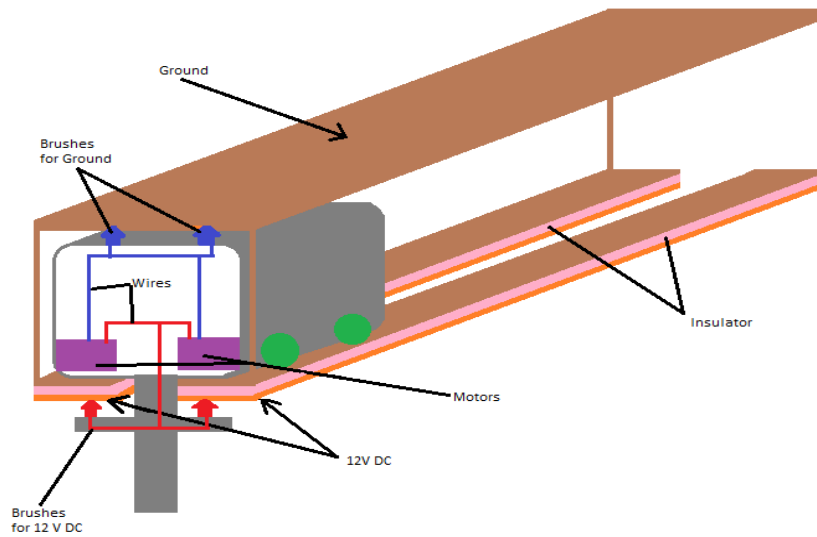 The connections of this section of the track are as shown in figure 14 below.

Figure 14: shows the metal section of the track

.

Connecting the plastic sections smoothly with the metal sections required some work to because they were both linked with a piece of metal as shown in figure 15 below. We used the same connection method as explained in the metal sections previously to continue linking the power line, but we added another insulation layer to the interior of the link to prevent it from touching the ground line.
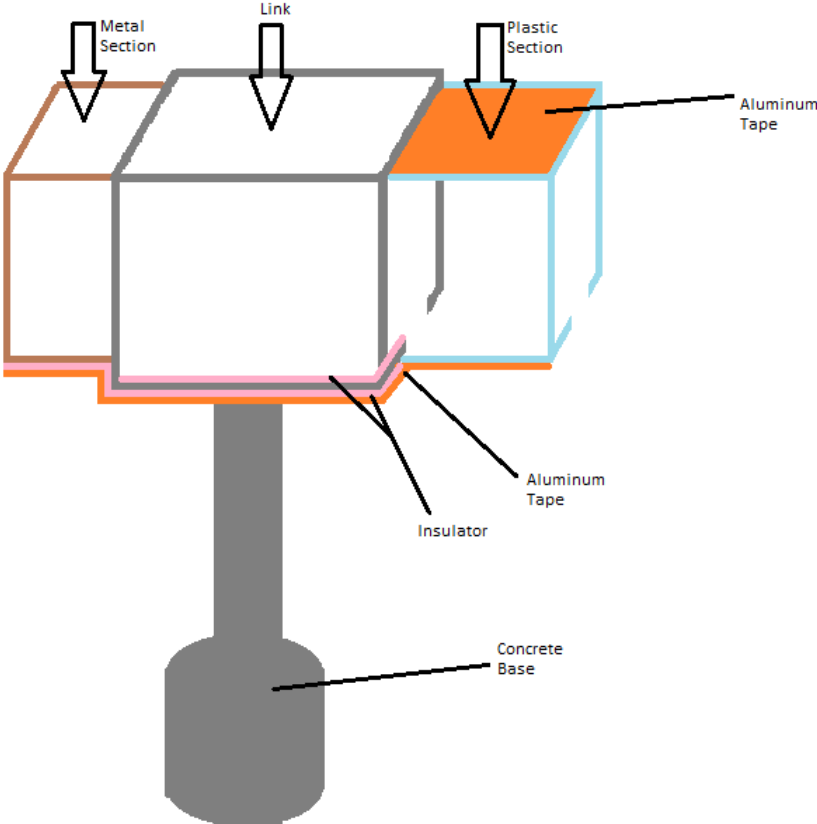
Figure 15: shows the link between the plastic and metal section

.

Figure 16: Actual track design

<u>Power Inputs:</u>

Solar Cells:

Our main power input for the project is solar cells which are one of the most interesting energy supplies yet. Those cells convert the solar energy into electrical current using semiconductors such as Silicon. Few years ago, this technology was only used to power low energy devices such as calculators, but now those cells are being used to power a lot of our electric devices such as the street lights, the cars charging stations, the swimming pools heaters etc.

An interesting fact is that on a bright day with a temperature of 25°C and an air mass of 1.g spectrum, the sun's rays give off about 1000 watts per square meter, and the solar cells industry is trying to collect most of this power and use it to provide us with clean and safe energy. Efficiency is the ratio between the amount of sunlight available to the cells to utilize and the actual power generated by the solar cells. Unfortunately the most efficient solar cell is about 20% efficient which would waste most of the sun energy it gets. The hope is to increase the

efficiency percentage and start depending on solar energy to power our homes to reduce the

pollution from the electric generators and the nuclear reactors.

How solar cells work:

Solar cells are also called photovoltaic (PV) cells which imply (Photo meaning "Light"

and voltaic means "voltage"). When light hit the solar cell, the semiconductor absorbed some of

it and with that energy it knocks out an electron loose creating electric current. Solar cells also

have electric field that force the electrons to flow in one direction. This current is being drawn

for us to use by placing two conducting plates over and under the cell.

Usually the silicon used in the solar cells manufacturing has impurities (doping), which

means other elements are added to it to make the solar cell better with emitting and receiving

electrons. One side of the solar cell is doped with phosphor creating an N-Type silicon. The

reason for adding phosphor is because silicone have 4 electrons in its outer shells which it uses to

share (bond) with another 4 silicon atoms. When adding phosphor with 5 outer electrons, one of

the phosphor's electrons will be free without a bond which makes it easier to break away from

the phosphor atom. The other side of the solar cell is doped with Boron creating a P-Type

silicon. Boron has only 3 outer Electron which makes it have a hole or a positive charge. The

procedure is shown in figure 1 A, B. The amount of impurity isn't high, about 1 phosphor atom
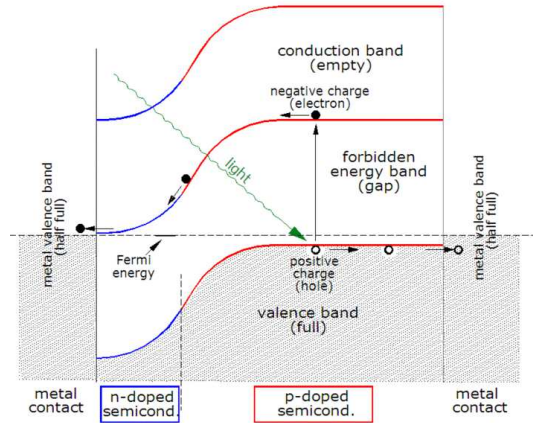
for every one million silicon atoms.

Figure 17: Shows the light and current flow in a solar cell with the N-Type and P-Type Silicon
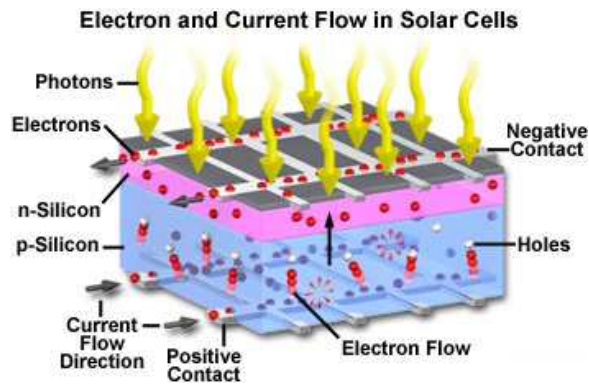

Figure 18: Shows the light and current flow in a solar cell with the N-Type and P-Type Silicon

Solar cells operate within what is called an IV curve (Current and Voltage Curve) as shown in figure 19 below. The short circuit current is the current maximum current a solar cell can provide with 0V which indicates that the Power of the cell at that moment is 0 watts too considering the power equation P=I X V. The open circuit voltage is the maximum voltage from a solar panel when the current is 0 which means that the power is 0watts again. The Maximum power point (MPP): is the point when that power is maximum with I X V = Maximum value.
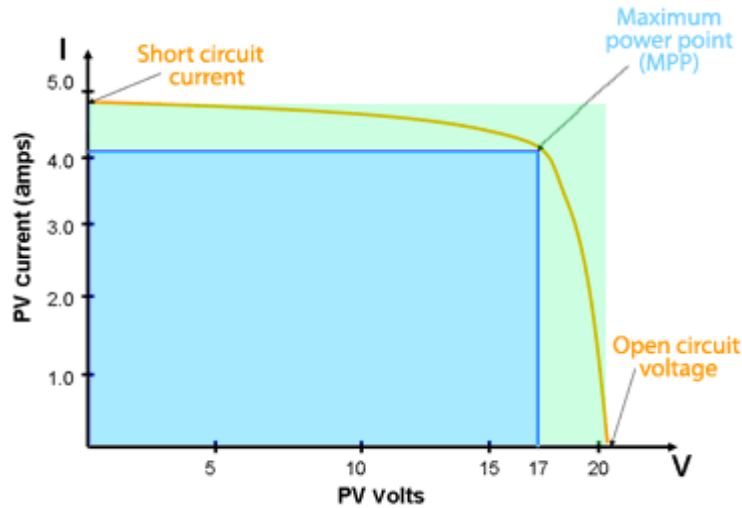
Figure 19: Shows an IV curve for a solar cell

This IV curve is interchangeable with the weather conditions. The maximum power and

the open circuit voltage decrease with the increase of the temperature as shown in Figure 20.

And the Short circuit current along with the maximum current decrease with the clouds when
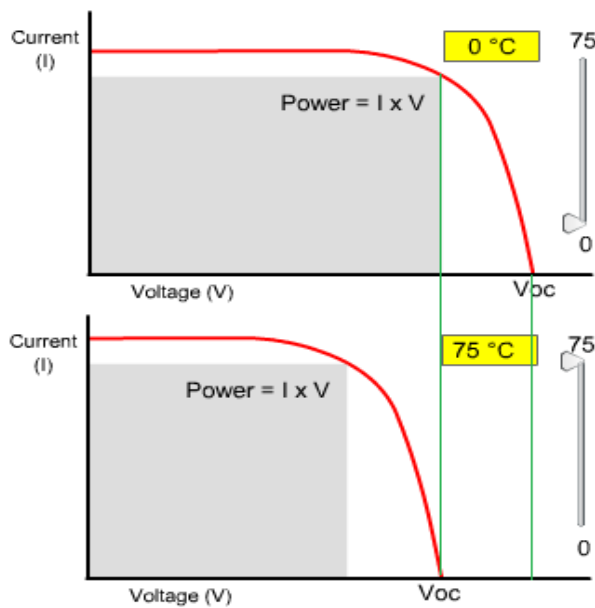
less light reaches the cells as shown in Figure 21.

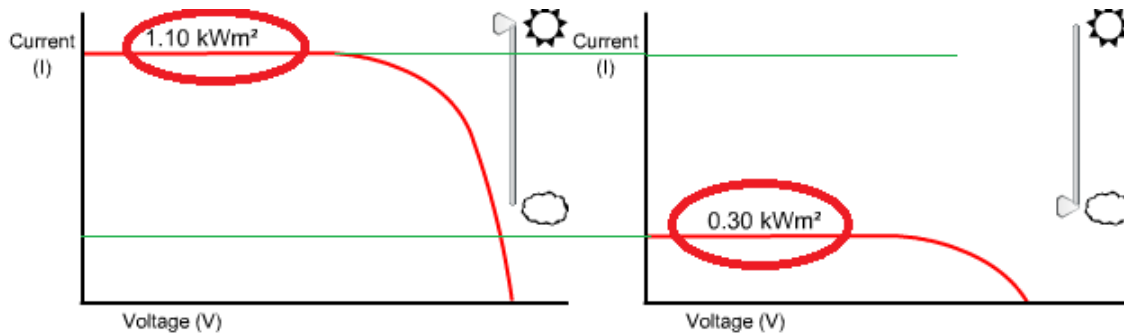**Figure 20**: the solar cell power changing due to the temperature

Figure 21: shows the solar cell power changing due to visibility

For our solar cells, we are getting about 25V, 3Amps output from the solar cell which is about 75W in clear weather and about 23.9°C temperature. This power is going to our power supply to be converted to 12V and about 5Amps.

1. Utility off the electrical grid

    For our secondary source of power we decided to have it go through the utility off the wall. The reason why we choose this was because we wanted a stable source of power if say the solar power was not sufficient to handle the load of the track. To be able to get 12V DC from the grid we require a step down transformer which will drop the voltage from 120V.

    A transformer consists of two coils wound around a common magnetic core. The coil of the primary circuit has N_1 turns and the secondary has N_2 turns. The primary coil is connected to an AC voltage source V_1 and the secondary is connected to a load. On the primary side of the transformer, the voltage source V_1 generates a current I_1 the primary

coil, which in turn establishes a magnetic flux Φ in the magnetic core. The flux and

voltage are related to Faraday law:

$$V = -N\frac{d\Phi}{dt}$$

The AC in this primary winding causes a varying magnetic flux in the iron rod (core)

which on its turn creates a varying magnetic flux through the secondary winding.

Because of electromagnetic induction a voltage is induced in the secondary winding. The

primary winding has more turns than the secondary winding which causes the secondary

voltage to be lower than the primary voltage. The diagram below illustrates a simple

transformer.
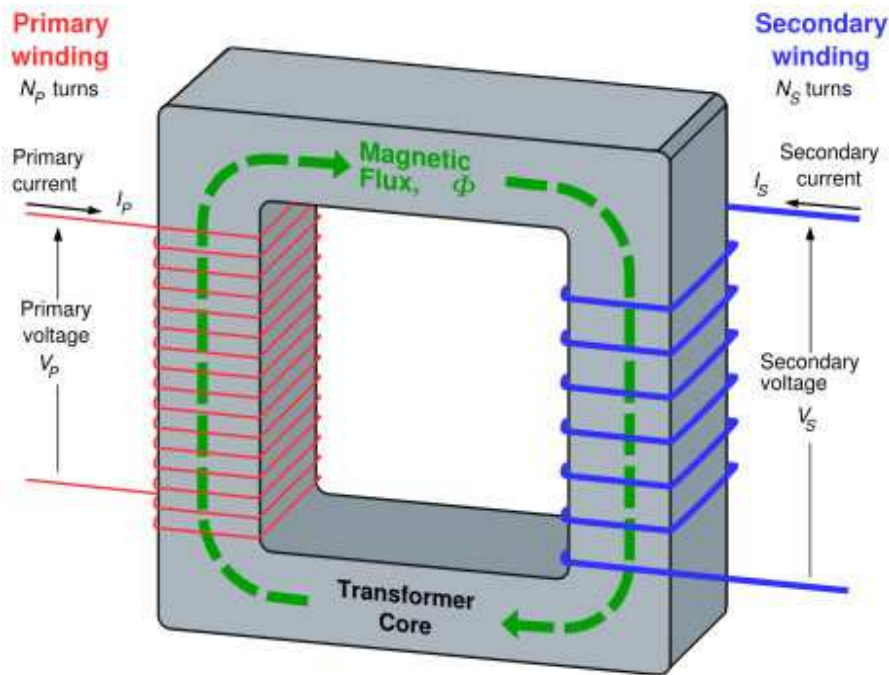
Figure 22: Basic transformer

The output from a transformer is going to be AC. To make it DC a circuit known as a full

bridge rectifier is required. using a rectifier as shown in Figure 23 which uses diodes to let the

input signal shown in Figure 6A pass the positive side only and block the negative side of the

sine wave creating a Half Wave Rectified signal as shown in Figure 6B then it continues to the

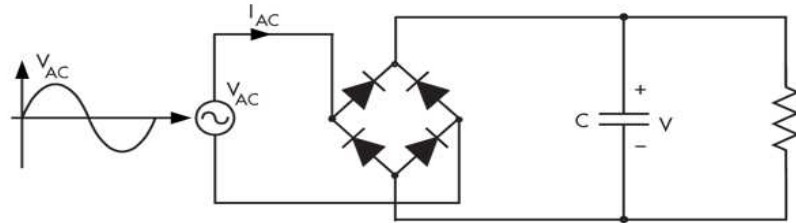high pass filter and outputs as a Full Wace Rectified shown in Figure 6C.
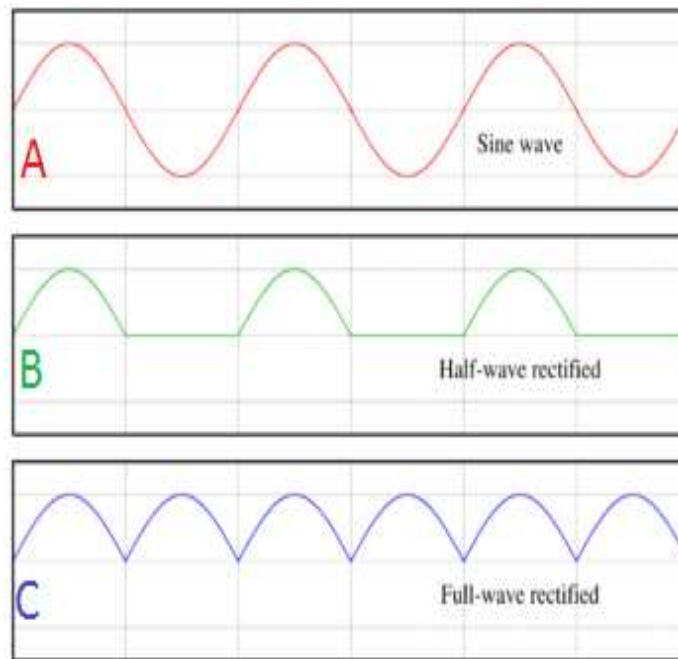

Figure 23: Bridge rectifier circuit

Figure 24: rectification of a sine wave

Figure 24A: Input Signal to the Rectifier (Sine Wave)
Figure 24B: Half Wave Rectified Signal
Figure 24C: Full Wave Rectified Signal

Specifications

Arduino Uno:

The Arduino Uno Board contains the ATmega328 chip inside. The image of the chip is shown below with its specifications. From pins 23 to 28, these are the ADC inputs needed to monitor power from the solar panels. The Arduino functions at 5V. Therefore, signals going inside the pin of the ADC have to have a voltage that is less than 5V to prevent damaging the Arduino Uno Board.
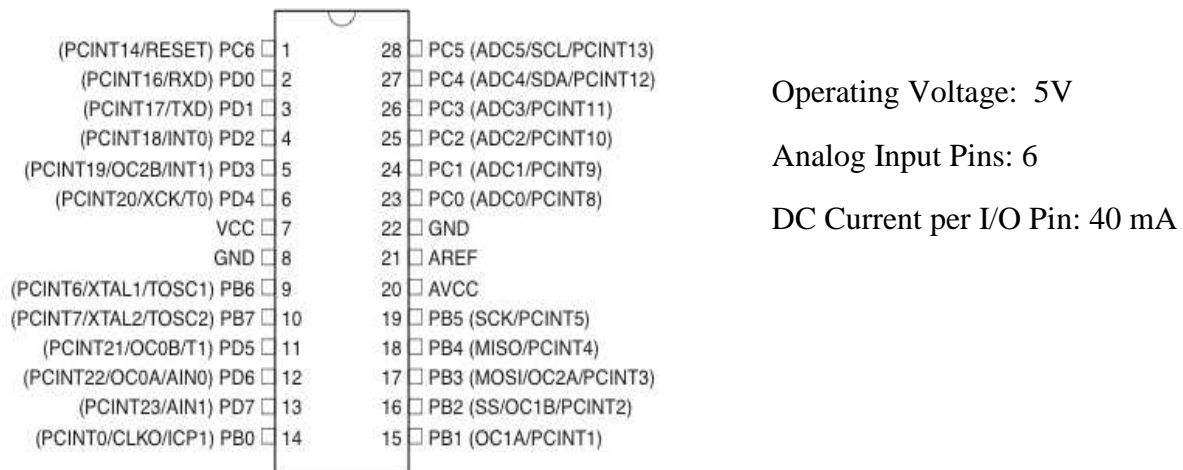

Operating Voltage: 5V

Analog Input Pins: 6

DC Current per I/O Pin: 40 mA

Figure 25: The Atmega328 Microcontroller with specifications

LCD Screen:

LCD screen is used in this project to be able to display the power coming from the solar panels. This type of screen can occupy 16 alphanumeric characters on each of the 2 lines. The specifications of this LCD screen are provided below in the figure. The VCC and GND are connected to the 5V and GND, respectively, of the Arduino Board.

Back light: Blue with White char color
Supply voltage: 5V
Pcb Size: 36mm×80mm
Contrast Adjust: 10k Potentiometer

Figure-26: LCD Module with specifications

DPDT Relay:

Rated Voltage	5 VDC
Rated Current	80.0 mA
Coil Resistance	62.5 Ω
Must operate voltage	70% max of the rated voltage
Must release voltage	10% min. of the rated voltage
Max. voltage	180% of rated voltage (at 23 degrees Celcius)
Power consumption	Approx. 400mW

Figure 27: Coil Rating for DPDT Relay Switch

Result

For our design of the power system we had to use Dip trace to create our PCB design. The figure

below shows all components in our circuit. In this circuit we have both the controls and the

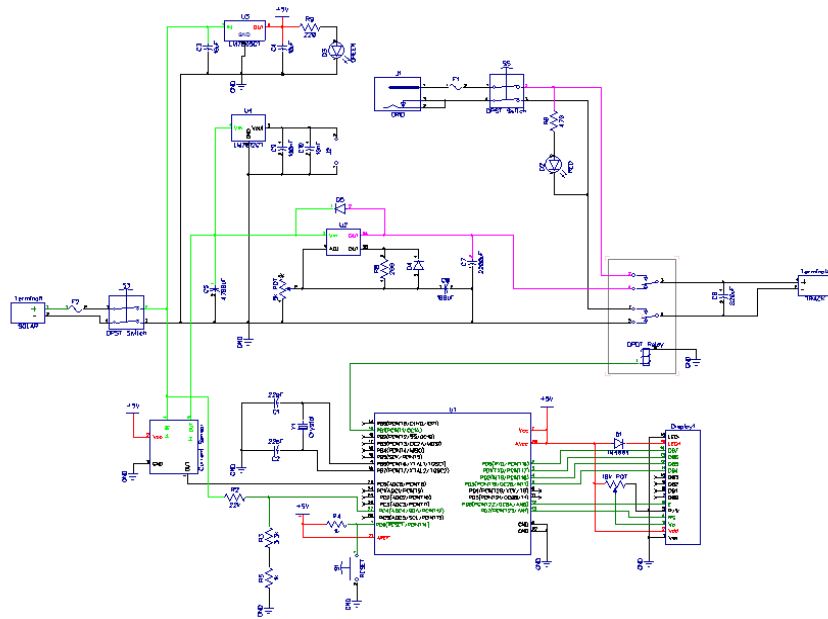power supply circuitry all on one single board, making the circuit as compact as possible.

Figure 28: Schematic design build in diptrace

Based on the schematic in figure above we came up with a proto type design of the circuit. For

convinence we built it on a breadboard so that we could trouble shoot any problems easily
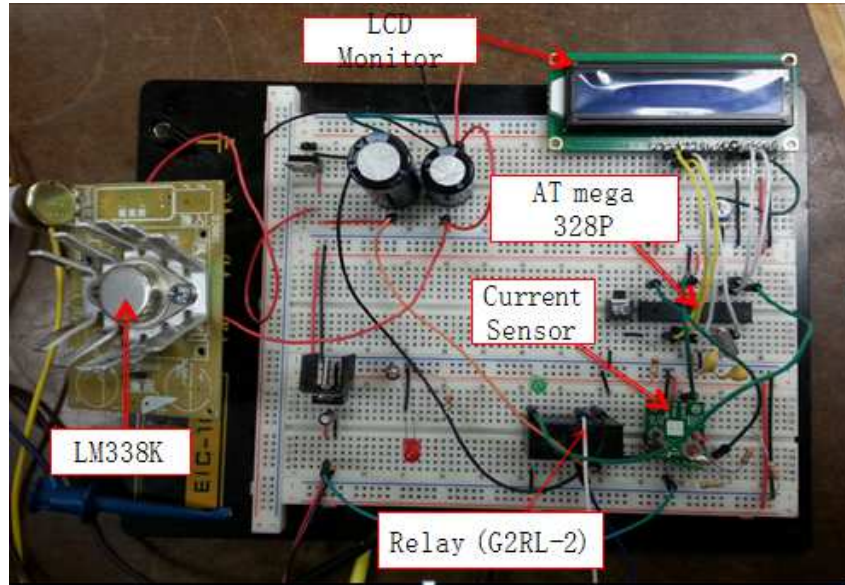
without soldering the components.

Figure 29: Prototype of the power supply build on breadboard

Finally once we had tested and verified our design we were able to come up with the final PCB

design which is shown below which was sent to the manufactures for fabrication.
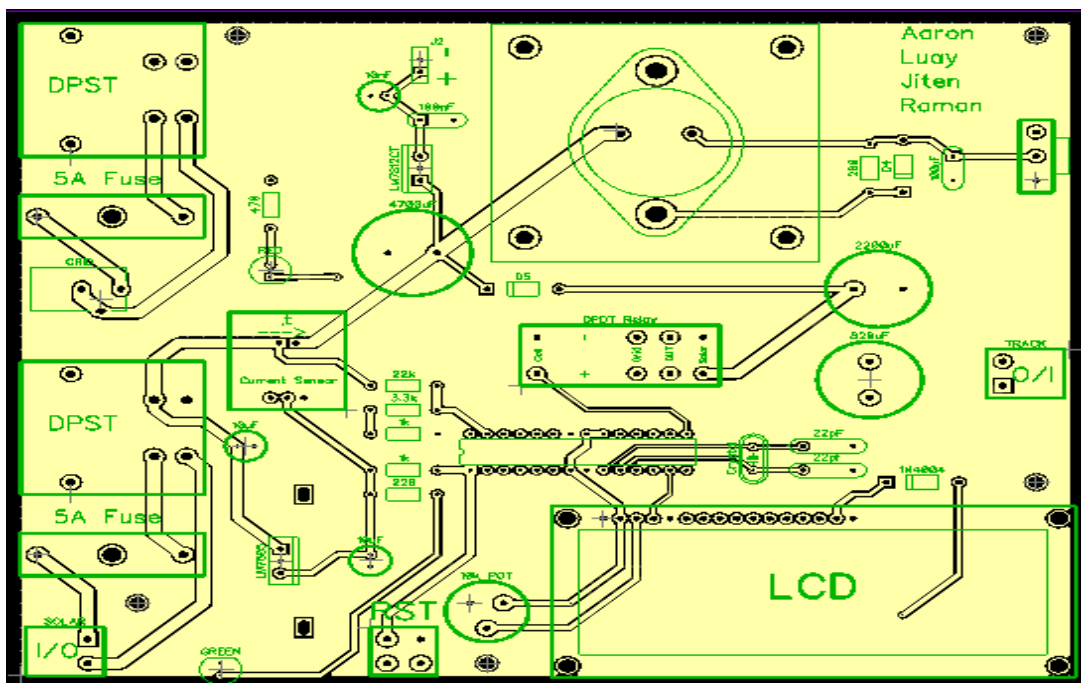

Figure 30: Final PCB design prepared for manufacturer

Conclusion

The project was a success as we were able to meet all the deadlines and accomplish the required tasks assigned to us:

- Build the power supply that could handle the loads of 3 pods and other necessary components.
- Build a control system that could switches between two power sources when needed.
- Setup a 3rd rail system to power the entire track.

The final prototype of the power supply system was able to produce enough voltage and current to handle 3 pods with ease. The power supply system was able to successfully power the third rail system via the solar panels and if say the voltage dropped below the required voltage, our on board control system on the power supply was able to switch to a secondary source of power to ensure that we had a constant 12V being supplied to the third rail at all time. Due to unforeseen constraints from the manufacture of our PCB we were unable to receive it on time because there was a problem with shipping. If the manufacture had returned our design on time as planed we could have had more time to design the power supply case. We also wanted to add features such as a system to collected unused extra energy produced by the solar panels to be used later on at night when solar panel cannot produce energy. After dealing with multiple short between 3rd rail and ground on the track during our first trial, now we would like to add short circuit detection sensor around the track to find out which portion of the track is shorted. Without such sensor the only way to detect which portion of the track is being shorted is to unassembled the track and test each portion of the track. With more time in hand, we would like to add one final feature to design a memory system to collect electrical data for data analysis.

The project also gave us the opportunity to show case several of our soft skills for us to be successful in the work place such as team work, meeting deadlines, work delegation and most importantly communicating with each other to ensure progress is being made. We can proudly say that we were able to complete the task that was assigned to us and, this gives us confidence in the future to undertake much larger projects.

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Appendix

Figures:

Tables:

Arduino Code:

```
#include <LiquidCrystal.h>


LiquidCrystal lcd(12, 11, 5, 4, 3, 2);  // initializes and configures LCD display


int relayPin = 9;                    // pin 9 controls relay
```

```
int analogInPin = A0;              // analog input pin that the current sensor board OUT pin is
connected to

int sensorValue = 0;               // value read from the carrier board

int outputValue = 0;               // output in milliamps

float amps = 0.0;                  // value displayed on LCD


int batMonPin = A4;                // input pin for the voltage divider

int batVal = 0;                    // variable for the A/D value

float pinVoltage = 0.0;            // variable to hold the calculated voltage

float batteryVoltage = 0.0;


float R1 = 22000.0;                // Resistance of R1 in ohms

float R2 = 4400.0;                 // Resistance of R2 in ohms

float ratio = R1 / R2;             // Calculated from R1 / R2


void setup() {
  lcd.begin(16, 2);                // initialize 16x2 Character LCD Module

  pinMode(relayPin, OUTPUT);       // sets the pin as output
}


void loop() {


  sensorValue = analogRead(analogInPin);      // reads voltage from OUT pin of current sensor
board

                                   // analogRead() converts the voltage to a number 0-1023

  batVal = analogRead(batMonPin);            // read the voltage on the divider
```

```
amps = ((float)(sensorValue-509)*5.0/1024.0)*1000.0/66.0;   // converts sensorValue to Amps

pinVoltage = batVal * 0.00595;              // calculate the voltage on the A/D pin

batteryVoltage =  pinVoltage * ratio;    //  Use the ratio calculated for the voltage divider
                              //  to calculate the battery voltage




/**************************************************************************
********

    CURRENT:

    ((long)sensorValue*5/1024) is the voltage on the sensor's output.

    There's a 509mV offset to subtract. The unit produces 66mV per amp of current,

    so divide by 0.066 to convert mV to mA.


    VOLTAGE:

    A reading of 1 for the A/D = 0.0048mV, so multiply the A/D

    reading by 0.00488 to get the voltage on the pin.

**************************************************************************
*******/


 if (batteryVoltage < 13.7) {

  digitalWrite(relayPin, LOW);

 }

 else {

  digitalWrite(relayPin, HIGH);

 }


 lcd.setCursor(0,0);                    // sets cursor on beginning of first line

 lcd.print(amps);                       // prints current value in Amps
```

```
lcd.print(" Amps ");

lcd.print(sensorValue);


lcd.setCursor(0,1);                    // sets cursor on beginning of second line

lcd.print(batteryVoltage);                 // prints voltage value in Volts

lcd.print(" V ");

lcd.print(batVal);


delay(100);                           // wait 100 milliseconds before the next loop

                                      // for the analog-to-digital converter to settle

                                      // after the last reading

}
```