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14. ABSTRACT The intent of our project is to increase awareness of solar cells as source of energy. Solar power use is commonly recognized for residential use such as artificial roof shingles that can trap the sun rays to heat a house. In return, the resident will enjoy monthly savings on their electric bill when it arrives in mail. However, we would like to show others how solar energy can be incorporated within electronics as well.  <del>Our project is based on the DESIGN and construction of a solar powered DC vehicle. This process also requires</del>
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**REPORT DOCUMENTATION PAGE (SF298)**  
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**Continuation for Block 13**

Proposal/Report Number: 59045.25-EL-REP

Report Title: Design of Solar Powered Remote Controlled Vehicle

Report Type: Technical Report

## 1. Introduction

The purpose of this project is to show how solar energy can be harvested and channeled to power a vehicle. Our project is to demonstrate how rays of sunlight can be trapped by the solar cells and converted to electrical voltage or current for electronics. In the area of Semiconductor technology, solar cells are vital because of the electrical properties that they can possess. (See figure 1 for a basic theory) In accordance of our project, the solar cells will be providing the energy to recharge the battery pack on the remote controlled vehicle. The standard voltage in a remote controlled vehicle's battery pack is 7.2 volts. Also, we will be using the microprocessor called Raspberry Pi which will be the steering system for our project. (See figure 1) In an era where natural resources are becoming scarce, it is imperative to discover new ways for energy. As a result, this same logic can be applied for electronics as well. Our project will also show future electrical engineers an alternate way to supply power, voltage, and/or current to electronics. Applications that we foresee include but not limited to solar-powered fiber optics, machinery, weaponry, communications and etc. Finally, this project is to show how engineering in general, incorporates the dedication of group planning, research, design, and critical thinking skills before putting these characteristics to use in the professional world.

## 2. Design Project Tasks Timeline

Table 1. January 2015 Tasks Timeline

Here is our project task timeline for January. Its schedule is based on one week due to the fact that we were having a very difficult time getting a project approved, finding an adviser, and other departmental issues as well.

	January 2015													
	Week 1							Week 2						
	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Abstract due						x								
Timeline due						x								
Progress Report 1 due											x			
Advisor meeting				x					x		x			
Group meeting		x	x	x		x			x	x	x		x	
Identify and order parts to complete project													x	
Holiday		x												

Table 2. February 2015 Tasks Timeline

This is the project task timeline for February. It includes our final itemized list of parts along with the setting up the specifications on the remote controlled vehicle as well. Also, we will set up the microprocessor Raspberry Pi so that we can have a steering control system to incorporate into our design. In the meanwhile, we have group and adviser meetings accordingly while doing research.

February 2015																												
Week 3							Week 4							Week 5							Week 6							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mid-term																												
Advisor meeting		x		x					x		x					x		x						x		x		
Group meeting		x	x	x		x			x	x	x		x			x	x	x		x				x	x	x		x
Set up car						x																						
Test cars basic controls									x	x	x	x	x															
Develop control Accelerometer/Servo and associated software																x	x	x	x	x								
Develop transmitter and associated software																								x	x	x	x	x

Table 3. March 2015 Tasks Timeline

Here is our project task timeline for March. It includes the integration of the Raspberry Pi microprocessor along with the testing of the solar cells and creating a panel to incase the cells into. Also, March task timeline includes more group and adviser meetings and hopefully a mini-testing of the project.

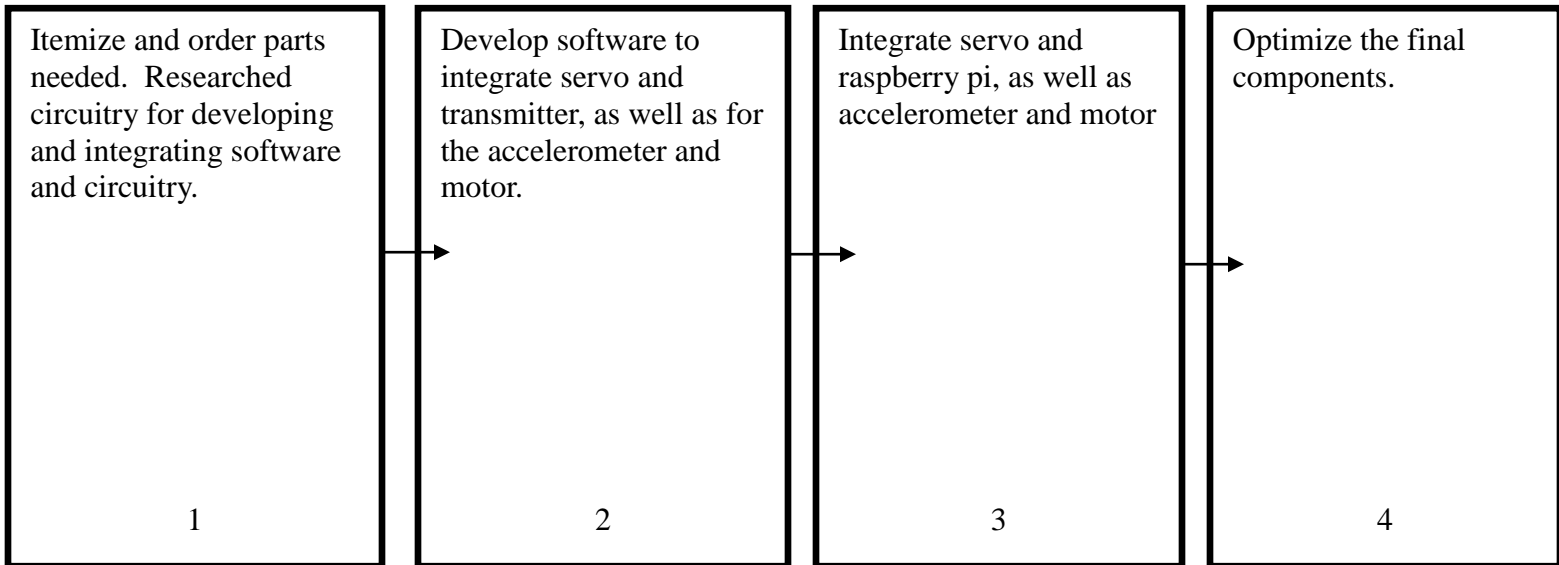
March 2015																												
Week 7							Week 8							Week 9							Week 10							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Progress Report 2 due																x												
Progress Report 3 due																										x		
Advisor Meeting		x		x					x		x					x		x						x		x		
Group Meeting		x	x	x		x			x	x	x		x			x	x	x		x				x	x	x		x
Integrate Accelerometer and transmitter software		x	x	x	x	x																						
Integrate Servo and Sensor									x	x	x	x	x															
Integrate control boards																x	x	x	x	x								
Holiday								x	x	x	x	x	x	x	x													

Table 4. April 2015 Tasks Timeline

Here is the final month of our project task timeline which is April. At this point, the project should be nearly (if not completely) finished with a solar powered remote controlled vehicle. A final group meeting and adviser meeting will be conducted to smooth out all details. Finally, a demonstration of the project will be on display for the class.

	March		April 2015																										
	29	30	Week 11				Week 12					Week 13					Week 14												
	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
Final Presentation														x															
Final Demonstration																x													
Final Report																										x			
Advisor Meeting		x		x					x		x			x		x					x					x			
Group Meeting		x	x	x		x				x	x	x		x				x							x	x	x		x
Integrate Software and Car		x	x	x	x	x				x	x	x	x	x															
Holiday																													

### 3. Design Procedure Block Diagram



## 4. Results

The work completed so far is that we have chosen our advisors, although that delayed our project timeline for three weeks. Nevertheless, we and the Electrical Engineering Department of Tuskegee University have gotten that solved. Next, we tested our solar panels for compatibility using the HP5545A machine in the Semiconductor Lab. After, finding experimental values, we attached a miniature bread-board on the back of the vehicle along with a suitable adapter to connect to the Lipo battery pack. Finally, we categorize our design parts and incorporated them into the vehicle. The project turned out to be successful not only in practical application but in completing the objectives mentioned in the “abstract” section of this report.

## 5. Solar Cells

Solar cells or photovoltaics are large diodes when not supplied voltage. They take advantage of the electrical phenomenon of the p-n junction. A p-n junction are two semiconductor materials, p type and n type, who characteristics cause a charge due to the nature of the material. N type electrons diffuse over the junction leaving positively charged ions called donors. Simultaneously p type holes diffuse across the junction leaving negatively charge ions called accpetors

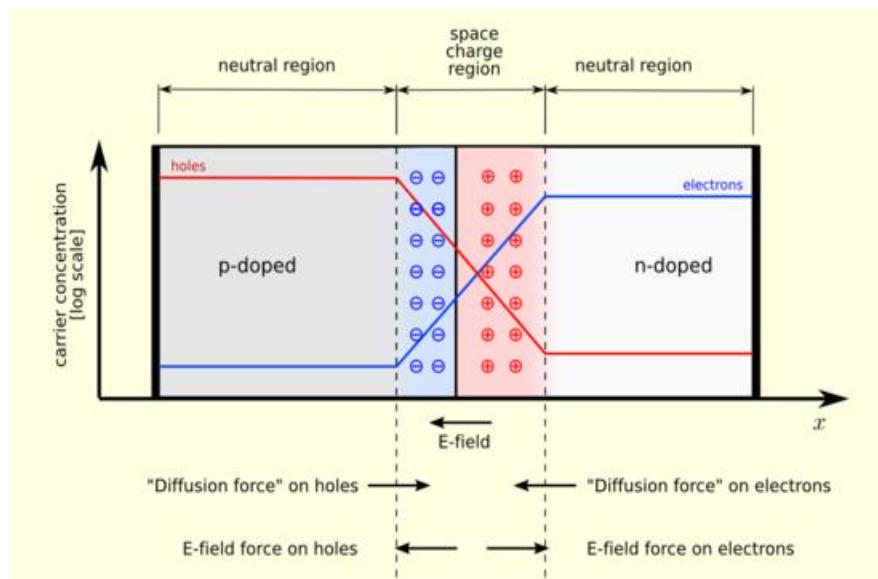


Figure 1. P-N junction with no external power supplied

The charge supplied can be viewed in an I-V curve which holds the current on the y-axis and the voltage on the x-axis. The curve shifts exponentially in the fourth quadrant as the power increases. For sake of clarity the I axis is inverted so that the curve shift is directly proportionate. The short circuit current is the maximum current supplied when the voltage is zero. Open circuit voltage is the maximum voltage supplied when the current is zero. The largest area rectangle that fits within this curve is known as the fill factor is an important component of efficiency. And efficiency is the ratio of the fill factor times the area of the short circuit current and open circuit voltage rectangle to the input power supplied.

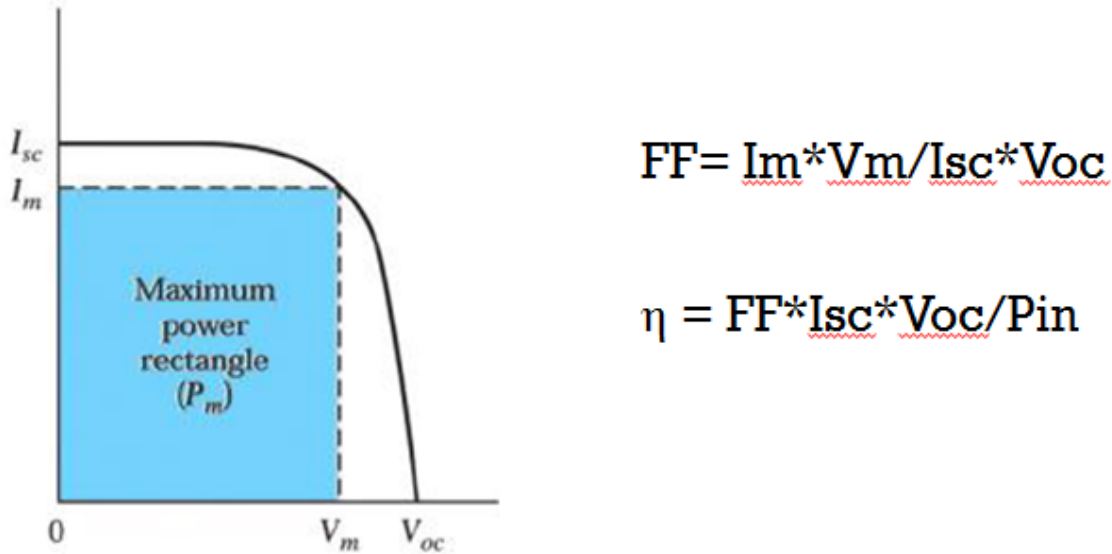


Figure 2. I-V curve with fill factor equation and efficiency equation

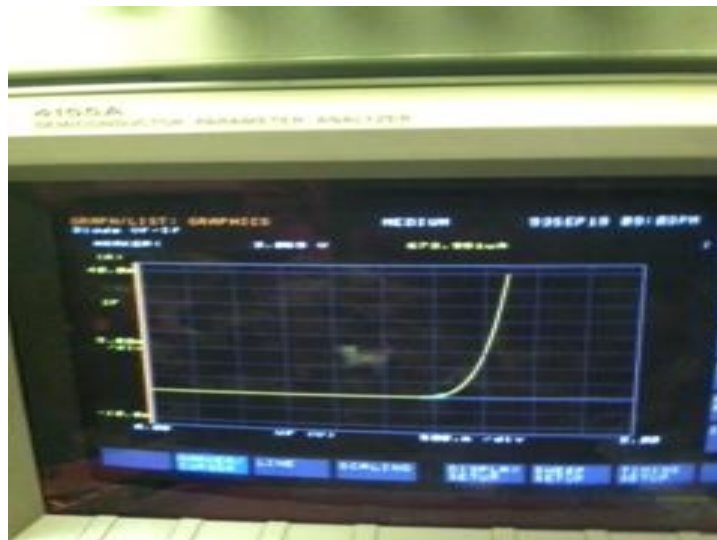


Figure 3. I-V plot of solar panel using the HP4155A parameter analyzer

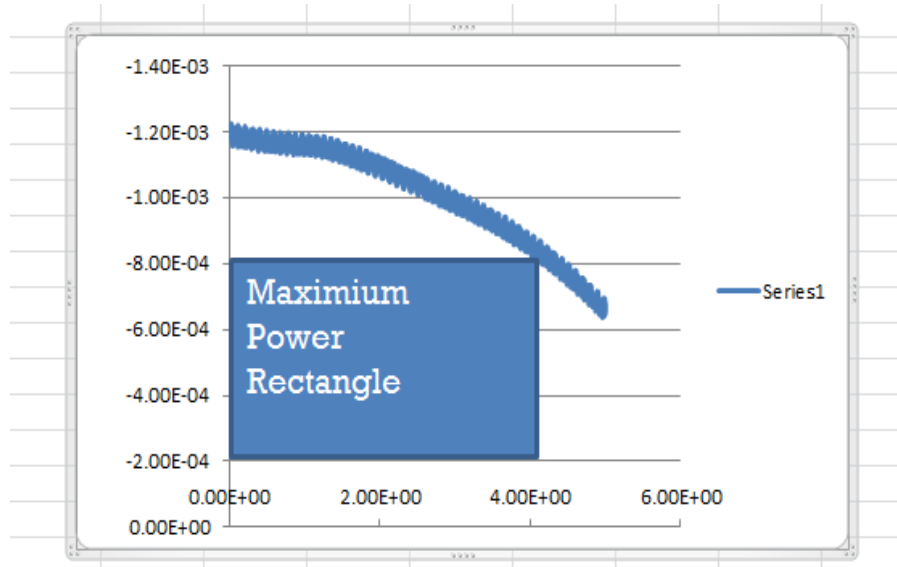


Figure 4. I-V solar panel curve imported to Microsoft Excel from LabVIEW

Given these parameters we were able to calculate efficiency. Taking  $I_m$  and  $I_{sc}$  at 0.8 and 1.2 mA respectively; and taking  $V_m$  and  $V_{oc}$  as 4kV and 6kV respectively were able to calculate fill factor at 0.44 which at a 8.7W power input gives us a efficiency of 0.36.

We tested the solar cell connection to see what output we can expect from a 1k ohm resistor the first trial was done in series yielding the following results:

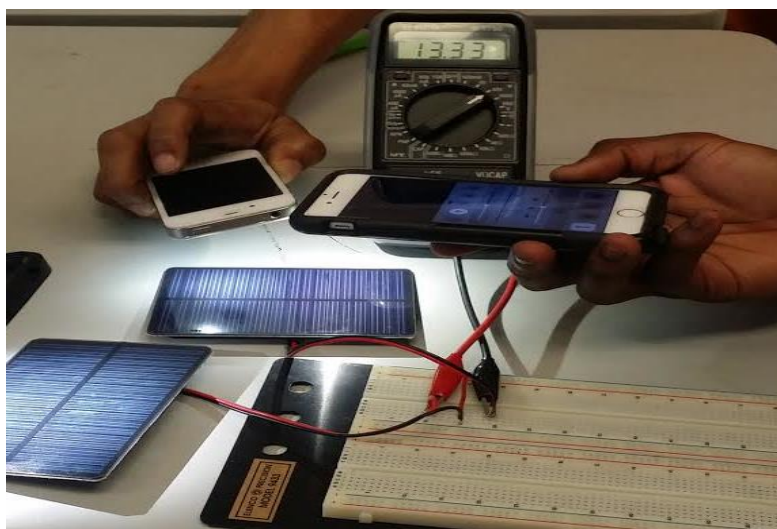


Figure 5. 13.5 mA without load



Figure 5. Solar cells connected in series 5.5 mA with load

The cells were then connected in parallel to see what values we would attain:



Figure 6. Solar cells connected in parallel 6.5 mA without load



Figure 6-1. Solar cells connected in parallel with 2.0 mA with load

We then took the experiment outside to see what values we would attain from a natural light source:



Figure 7. Outside solar cell testing in series and parallel

Parallel

-10.1mA without load

-10.3 mA with load  $1k\Omega$

Series

-20 V without load

-18 V with lo

## 6. Raspberry Pi

The Raspberry Pi was programmed to its default settings and updated to recent firmware for use. The default settings included the initial start-up interface in which we chosen the window environment. This simply means when the Raspberry Pi is powered up, it will interface with the user in a command line mode. This means instead of double clicking a folder to access a file/program, the user would type in a string of characters or word to access files. Just to mention, the actual operating system of the microcontroller is based off the older Linux software. Other settings included various programs that can be installed such as a media center for music, movies, pictures and other related files. However, we did not need to proceed any further than the Raspian program. After finalizing default settings, we connected an Ethernet cable for internet access. This allowed us to update the Raspberry Pi by using the LX Terminal program on the Raspberry Pi. Inputting the command “sudo apt-update” and “sudo apt-upgrade” the Raspberry Pi began to upload the files necessary to update itself to the recent firmware available.

After updates, we configure the Raspberry Pi to open a serial port so that the Servo Board can interface with the GPIO pins of the Raspberry Pi. Typing the command, “stty -F /dev/ttyAMA0 9600” pulse signals are able to travel to the servo board. Next we ran a test program on the raspberry pi that sent pulse signals to the servo board at steps of -1000 ms to 1000ms. Finally we implemented this into our vehicle by selecting the appropriate values that responded to the vehicle’s electronic speed controller.

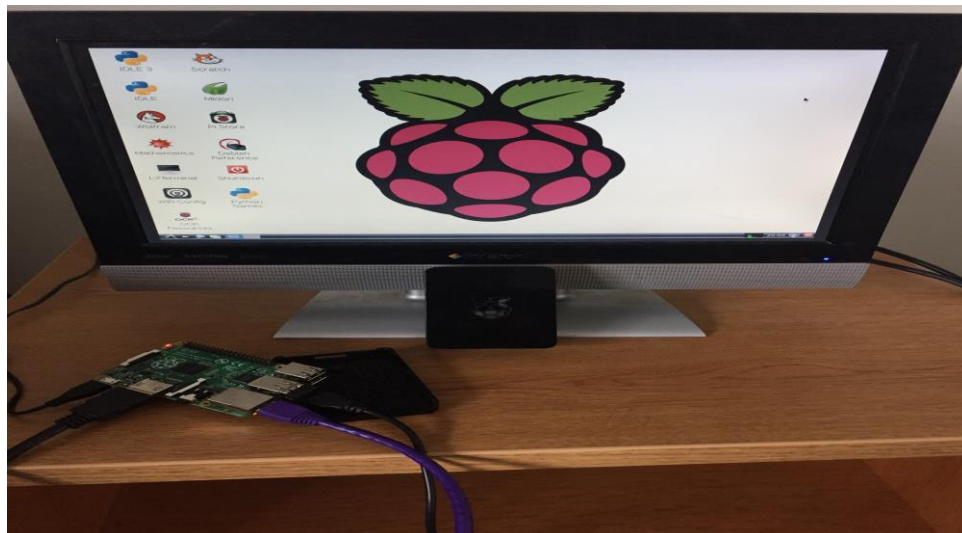


Figure 8. Raspberry Pi Update using window environment

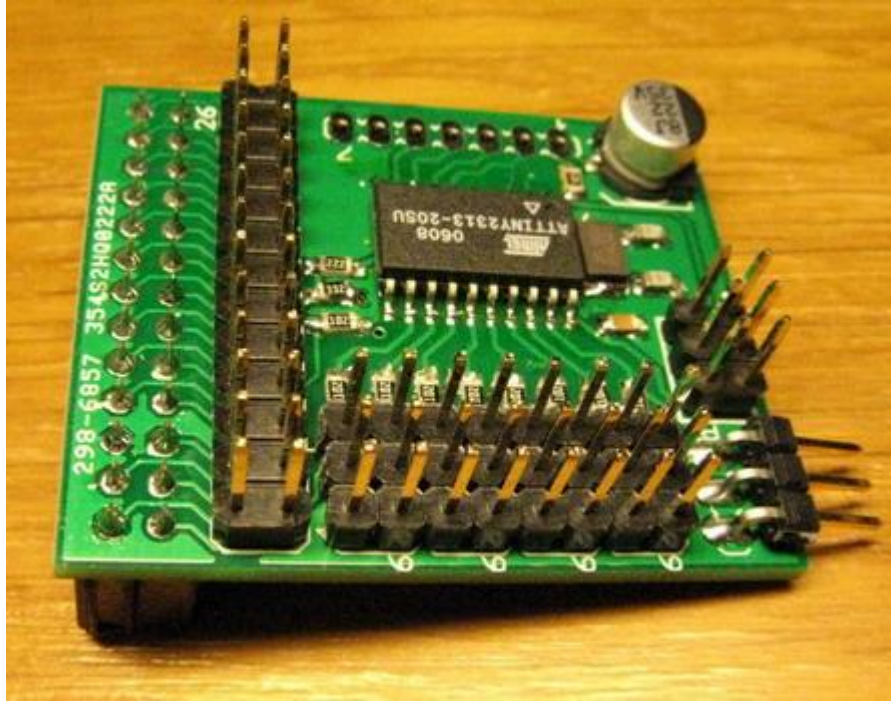


Figure 9. Raspberry Pi Servo Board

## 7. Vehicle

We have received our vehicle and assembled the appropriate pieces for modification. The vehicle has certain wiring that will be listed and explained.

- Battery Negative – Black Wire
- Battery Positive – Red Wire
- Motor Connection A – Black Wire
- Motor Connection B – Blue Wire
- Motor Connection C – White Wire
- GND – Black Wire
- 5V power – Red
- Signal (Arbitrary) – White

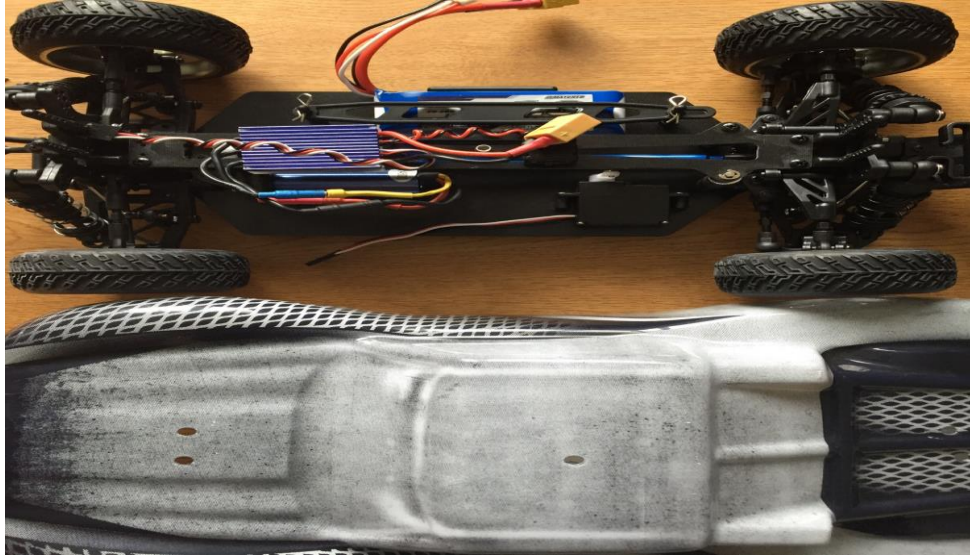


Figure 10. Vehicle Assembly Specifications

The Turnigy 7.4V 2S 20-30C 1300mAh Lipo pack constitutes a two cell 3.7V with a 20-30C charge rate. The equations for charge and discharge are as follows:

<b>Rate of charge*</b>	$\text{mAh} \times \text{charge C rate}/1000$
<b>Constant discharge rate*</b>	$\text{mAh} \times \text{min. charge C rate}/1000$
<b>Peak discharge rate*</b>	$\text{mAh} \times \text{max. charge C rate}/1000$

Figure 11. Battery charge/discharge equations

## 8. Economic Consideration

The following is an itemized list of parts with prices. Our budget was projected to be around \$300 however we were a little bit under the budget.

### Parts List:

Turnigy 1/16<sup>th</sup> 4x4 Mini Trooper SCT (ARR) - \$76.87

Turnigy 1300mAh 2S 20C Lipo Pack- \$6.64

Canakit Raspberry Pi Ultimate Starter Kit.- \$64.99

Solar Panels/Cells- \$20.00 and pending

Raspberry Pi Servo Board- \$13.00

Bluetooth Adapter- \$14.00

Aluminum Heatsink for Raspberry Pi- \$3.33

JST-XH adapter and cables- \$6.25

Figure 12. Itemized parts list

## 9. Ethical Consideration

Our project takes in account four of the IEEE Code of Ethics:

IEEE code #3: To be honest and realistic in stating claims and estimates based on available data. We displayed this by doing research on our vehicle specifications, selecting the appropriate solar cells and testing them.

IEEE code #6: To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training and experience or after full disclosure of pertinent limitations. We completed this by accepting this project with cross-disciplinary engineering concepts although the emphasis is on the semiconductor technology.

IEEE code #7: to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors and to credit properly the contributions of others. We displayed this by accepting this criticism of our peers and especially the comments of our advisors/instructors.

IEEE code #9: To avoid injuring others, their property, reputation, or employment by false or malicious acts. We completed this by doing our research about the lithium polymer battery pack and its limitations.

## **10. Discussion**

Our project has been given timely thought and procedure although we have had some issues. There were complications in communicating efficiently with the department for resources, yet we still thrived in becoming thorough in our research and development. We ultimately resulted to using the solar cells as a recharge utensil which supplies alternative energy to our battery. We would like to have had more lab experience but view our project a sufficient due to the amount of effort put forth by each of our groups members.

From our research we have observed that solar cell technology, though one of the best renewable energy sources in existence isn't that prevalent as it should be considering global warming and the depletion of the world's natural resources. So to shed light on how much the world needs this clean energy source, to advance the awareness of solar cell technology, and to apply all of the electrical engineering knowledge that we have acquired as seniors we choose this project to hopefully make a difference.

The solar cell industry today is responsible for about 60 to 70 GW of power being produced each year which has seen a 30% increase from the previous years before. To stress how much power that is, one billion watts of power is equivalent to one GW which compared to one nuclear reactor that produces about 1.3 GW of electricity per year you start to see the difference that could be made in the world with solar energy. One of the biggest markets that solar technology is really making waves in is in utilities. Divided into about a third of what makes up the solar cell industry; residential rooftops, from commercial buildings like hotels or malls, and from utility plants connected to the grid make up the majority of total installed Photo Voltaic units.

In connection with our project, we hope that the application of solar cells in our project will ultimately raise awareness about this awesome technology by showing people how easy it is to use with common items. By achieving this goal, more and more people are encouraged to buy, support, and create their own solar power devices. As a result the whole world will become a cleaner and more energy efficient planet.

## **11. Future Work**

Considering the resources available at the time of our project, there are a couple of suggestions that we would like to mention in this section. Firstly, there are various ways to for vehicle control. Applications such as a smartphone or Bluetooth signal are creditable for steering and movement. In addition, coding programs such as Matlab, C++, Javascript, and etc. can be used for autonomous control as well. The microprocessor, Raspberry Pi worked very well for our design. However, there are better microprocessors such as the Intel Galileo or Arduinio Uno which may be faster for the command to the vehicle design. Finally, the use of efficient miniature solar cells is a great commodity; they provide a better fit when incorporating into the vehicle design. Also, they may provide a higher charge rate for the battery pack.

## **12. Conclusion**

We would like to advise any future semiconductor majors to pursue lab experience before entering this course. The lack thereof has made our project very limiting. Absent this fact, we are very proud of our production. We shifted course from our initial plan of charging the whole system via solar cells to recharging our installed battery with our photovoltaic system. This design provided a more consistent charge while maintaining the use of our solar cells. We gained relevant knowledge of charge production from solar cells and how to manipulate current and voltage output through circuitry connection. Additionally we furthered our knowledge of microprocessors and wireless communication. Communications being a vital division of electrical engineering, we valued our gained knowledge. Throughout this process we were able to maintain our schedule according to our initial tasks timeline and our design procedure block diagram. It was a pleasure working in our group and we look forward to continuing our critical thinking and problem solving in our future endeavors courtesy of our Tuskegee University Electrical Engineering education.

### 13. References

- [1] "2V 200mA Encapslated Solar Cell." *VE-SOLA* -. N.p., n.d. Web. 27 Jan. 2015.
- [2] Butler, Shaun. "Awesome Raspberry Pi iPhone WiFi Radio Controlled Car Toy with POV Video." *YouTube*. YouTube, 16 June 2013. Web. 19 Jan. 2015. \*Three part video
- [3] Cook, David. "Simple Solar Power Circuit with Rechargeable Battery Backup." *Solar Panel Charging Rechargeable Batteries*. N.p., n.d. Web. 19 Jan. 2015.
- [4] "CanaKit Raspberry Pi B+ Ultimate Starter Kit (Over 40 Components: Raspberry Pi B Plus + WiFi Dongle + 8GB SD Card + Case + Power Supply and Many More)." *Amazon.com: : Computers & Accessories*. N.p., n.d. Web. 26 Jan. 2015.
- [5] Kent, Barnaby. "Pi-Cars Factory - Tool Kit." *PiCars*. N.p., 23 Jan. 2013. Web. 23 Jan. 2015.
- [6] "Less than \$1 a Watt DIY MAKE YOUR OWN SOLAR PANEL (PART 1)." *YouTube*. GreenPowerScience, 3 June 2011. Web. 23 Jan. 2015.
- [7] "Turnigy 1/16 4x4 Mini Trooper SCT (ARR)." *HobbyKing Store*. N.p., n.d. Web. 26 Jan. 2015.
- [8] "Turnigy 1300mAh 2S 20C Lipo Pack." *HobbyKing Store*. N.p., n.d. Web. 26 Jan. 2015.
- [9] "Thread: Lipo Charge Time and Charger?" *Lipo Charge Time and Charger?* Web. 20 Mar. 2015. <<https://traxxas.com/forums/showthread.php?8976562-Lipo-charge-time-and-charger>>.
- [10] "RPI Servo Board Manual." Web. 20 Mar. 2015. <[http://electronics.chroma.se/RPi\\_servo\\_board\\_manual.pdf](http://electronics.chroma.se/RPi_servo_board_manual.pdf)>