12-2015

Solar Powered Picnic Table for Charging Cellphones and Other Small Devices

Casey B. Potts
East Tennessee State University

Solar Powered Picnic Table for Charging Cellphones and Other Small Devices

---

A thesis

presented to

the faculty of the Department of Business and Technology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Technology

with a concentration in Engineering Technology

---

by

Casey B. Potts

December 2015

Dr. J. Paul Sims, Chair

Dr. Mohammad Moin Uddin

Dr. Hugh Blanton

Keywords: Solar Power, Green Energy, Sustainable Energy, Picnic Table

ABSTRACT

Solar Powered Picnic Table for Charging Cellphones and Other Small Devices

by

Casey B. Potts

Solar panels are used in many different applications for generating sustainable energy. Many countries use solar power as a power generation method. It is also, an excellent option for getting power to difficult areas. There are three main systems used when generating solar power: grid-tied, battery banked, and direct driven systems. Most systems use a combination of grid-tied and battery banked so any unused power can be fed back into the main grid for compensation. The solar power application suggested in this thesis will provide USB power to a picnic table enabling students to charge cellphones and other small devices while at the table. The solar panel will be mounted on the top of the picnic table or on a canopy as shading for the table. These locations along with the power generation systems were researched and tested to find the best option.

DEDICATION

This thesis is dedicated to my loving parents and Elizabeth. You have supported me and encouraged me to be my best, inspiring me to always do better. You have let me fail a few times along the way, to teach me how to get back up. You have always been there to lend a helping hand when I needed it. I love you all very much and hope to show my love for you each day. God, thank you most of all, through which all of this was possible.

– Casey

TABLE OF CONTENTS

Page:

ABSTRACT 2

DEDICATION 3

LIST OF ACRONYMS 6

LIST OF TABLES 7

LIST OF FIGURES 8

Chapter:

1. INTRODUCTION 9

2. BACKGROUND 10

Similar Products on the Market 10

Objective 12

Literary Review 12

3. SCOPE 20

Equipment 20

Kyocrea PV Solar Panel 20

Kimdrox Dual Power Adapter 21

PortaPow USB Power Monitor 22

Tenma DC Power Supply 23

Fluke 87V Multi-meter 24

Designs 25

Table Types 25

Solar Panel Locations 30

System Design Options 31

Safety of the Design 31

Advantages and Tradeoffs 34

Final Design 37

Bill of Materials 39
4. PROCEDURE 40
Implementation 40
Initial Test Plan 40
Equipment 41
Testing Procedure 41
Initial Test Findings 42
Modified Test Plan 45
Equipment 45
Testing Procedure 46
Modified Test Findings 47
Final Test Plan 50
Equipment 50
Testing Procedure 51
5. RESULTS 52
Analysis of Final Results 54
6. CONCLUSIONS 55
Recommendations for ETSU 55
BIBLIOGRAPHY........ 57
APPENDICES 58
Appendix A: Graphs and Tables from Bench Test 58
Appendix B: Graphs and Tables From Modified Test........ 76
Appendix C: Graphs and Tables From Final Test 78
Appendix D: Kyocrea KD135GX-LPU........ 80
Appendix E: Building Schematics, Wiring Schematics, and Directions 82
VITA 93

LIST OF ACRONYMS

Standard Test Conditions	(STC)
Nominal Operating Cell Temperature Conditions	(NOCT)
Voltage open circuit	(Voc)
Maximum Power Point	(Pmp)
Maximum Power Voltage	(Vmp)
Maximum Power Current	(Amp)
American Wire Gauge	(AWG)
Photovoltaic	(PV)
Strengths, Weaknesses, Opportunities, Threats	(SWOT)
Original Equipment Manufacturer	(OEM)
National Electrical Code	(NEC)
Direct Current	(DC)
Alternating Current	(AC)

LIST OF TABLES

Table Page

1: Maximum USB Power Demands...17

2: Solar Panel Production Numbers...18

3: Maximum Solar Power Output...19

4: Approximate Cost of Final Design and Design A 39

5: Modified Test Data 49

6: Final Test Data 53

LIST OF FIGURES

Figure Page

1: Peak Solar Hours in a Day 15

2: Map of potential solar power across the U.S. 16

3: Kyocrea KD135GX-LPU....21

4: Kimdrox DC-DC Power Converter 22

5: PortaPow USB Power Monitor....23

6: Tenma 72-2080 DC Power Supply....24

7: Fluke 87V Multi-meter 25

8: Current Concrete Picnic Tables at ETSU 26

9: Model of Design A....27

10: Model of Design B....28

11: Model of Design C....29

12: Model of Design D 30

13: Sufficient Charging Power Light Circuit....39

14: Initial Test Average Charging Current Over the Input Voltage Range 42

15: Charging Current Data Points form the OEM Charger 43

16: Charging Voltage Data Points form the OEM Charger....43

17: Charging Current Data Points form the Computer USB port....44

18: Charging Voltage Data Points form the Computer USB port....44

19: The Modified Test Average Charging Current Over the Time of Day....47

20: The Final Test Average Charging Current Over the Time of Day 52

CHAPTER 1

INTRODUCTION

The premise of this thesis came from East Tennessee State University's (ETSU) Green Program. The members of the Green Program are tasked with exploring and implementing new ways to make the ETSU campus more sustainable. In addition, their mission is to help educate the students of ETSU about sustainable applications. One of the next ventures the Green Program would like to explore is the topic of this thesis. The solar powered picnic table will be able to provide power to a student's hand held devices while they are enjoying the beautiful surroundings of the campus. Getting students outdoors and around sustainable technology is the primary goal. When a student's phone or other hand held device needs to be charged, the student has to be by a wall outlet to be able to charge it, most of which are located inside. However, if there was another option for students to be outside and charge their phones, many students would make use of the technology. Picnic tables and other similar structures have been popping up around the country at universities and businesses. Members of the Green Program are excited by the idea and want to follow the trend. The design for the picnic table suggested in this thesis will be able to charge multiple small electronic devices such as phones and tablets through USB ports that will be installed on the table. The goal is to get the students close to the solar panel and spark interest in them with a more tangible idea of what the solar panel can do. The table will be operational during the daylight hours. The solar panel will be most effective around lunch time as the sun is approaching its peak intensity. In addition, the tables should see their most use during the mid-day hours. The solar panel is dependent upon clear weather conditions. As the weather delivers appropriate circumstances, the table will provide free and clean energy to students during the middle of the day.

CHAPTER 2

BACKGROUND

East Tennessee State University actively searches for new ways to be green and involve their students in the process. One of the ways they do this is through the green fee. The fee is collected with the students' registration and is used to produce new ways to help the university to become greener and educate the students about the schools endeavors. One of the primary forms of sustainability the university pursues is alternative power. Examples include the solar wall on the Center for Physical Activity's roof, solar panels with a battery bank to supply lights and fans at the recycling center, and wind turbines to help power instruments on the schools radio tower.

Dr. Paul Sims is working on a new grant to build an alternative power production learning area. It will have examples of some of the most popular methods being used throughout the world. The new learning area will include a compressed air power car, electrolysis for hydrogen powered car, a hydrogen power car, and a solar array with battery bank. In addition, a weather station will be added to the area so data may be collected. The data will be able to help correlate weather patterns to the alternative power generation methods. Other colleges and universities around the country have a mix of these options but ETSU will be unique in having all of them in one location. A solar picnic table will help round out the university's sustainability practices. The table will be a great learning tool to draw the students close to the technology while assisting them in charging their phones and other small electric devices.

Similar Products on the Market

Currently there are a few companies who offer solar powered picnic tables or other like products. The most popular company is EnerFusion Inc. and their solar panel picnic table is called Solar-Dok. The Solar-Dok design implements a canopy over the table and is priced around $9,000. The solar panels are located on the topside of the canopy. Under the tabletop, a battery bank is provided to store any unused power that was produced. The table offers power through normal GFCI outlets and USB power outlets. The Solar-Dok also has lights under the canopy above the table that automatically come on at dusk to provide illumination when the light of the day is on its way out (EnerFusion Inc., 2012).

The following is a list EnerFusion has provided,, listing the colleges and universities who have their products as a part of their sustainability portfolio (EnerFusion Inc., 2012).

1. Austin Peay State University
2. APSU
3. Boise State University
4. Broward College
5. Emory University
6. Oxford College of Emory University
7. Florida Atlantic University
8. Florida A & M University
9. George Mason University
10. Hillborough Community College
11. Hope College
12. Illinois State University
13. Lehman College
14. Maryville College
15. Missouri State University
16. University of Missouri
17. Mt. Hood Community College
18. Pellissippi State Community College
19. University of Florida
20. Pikes Peak Community College
21. Queens College
22. Southern Illinois University
23. Southwest Tennessee Community College
24. Temple University
25. Tennessee State University
26. Tennessee Tech University
27. Texas A & M University
28. University of Central Florida
29. University of California Los Angeles
30. University of Colorado
31. University of Rochester
32. University of South Florida
33. University of Wisconsin
34. Vanderbilt University
35. Texas A & M University
36. Jacksonville University
37. Broward College

Another picnic table product that universities and businesses have implemented is called the ConnecTable. With a slightly different design from the Solar-Dok, the majority of the features are the same. It implements a canopy as the location of the solar panels and has a battery bank to provide storage for any of the unused energy produced (ConnecTable, 2014).

Objective

The objective of this thesis was to create a simple solar powered picnic table that can provide charging power for small electronic devices through USB charging ports located around the table. In order to achieve the design, research was completed to find the best option for ETSU to peak the interests of their students. Once the final design was chosen, bench testing of the equipment was completed to insure the calculations transfer into real world applications. After the bench testing was finalized and enough data has been collected for a proof of concept, a test prototype was built and tested for safety and functionality. The National Electrical Codes (NEC) were followed to insure the safety of the system. In addition, a multi-meter was used to collect real data from the charging ports to insure proper functionality. The data was then compared to a standard wall outlet and computer USB charge. Once the prototype was tested the final testing began.

After the final testing, the data collected was sufficient in detail to provide a best fit design and recommendations to ETSU.

Literary Review

The main technology surrounding this thesis is Photovoltaic (PV) solar power. To get a better understanding of the topics discussed and the theory behind my design the following is a review of current literary work on the subject of PV solar power. The topics discussed under this section will include current applications using solar power, a strength, weakness, opportunities, and threats (SWOT) analysis of solar power, and realistic power generation numbers for solar power.

Japan is a perfect example of current solar power applications. Japan is known for being a world leader in solar PV production. They were the first country to cumulatively install one gigawatt of PV power in 2004. Japan did this through three main ways: aggressive government policies, PV research and development, and having a large export culture which allowed them to produce the PV technology at low manufacturing costs (Robert Foster, 2009).

It made sense for the Japanese people to consider using the PV technology in their homes to offset energy costs because Japan has one of the highest residential energy costs per kilowatt hour. This was only heightened when the Japanese government offered incentives and rebates to install PV systems (Robert Foster, 2009). As for the United States, the technology is not quite efficient or cheap enough to justify a massive energy production overhaul. As of today, the technology leans more towards the support role or for providing power to locations that it would be difficult to get power to easily. An example of the support role would be using the solar panel to power the water heater for a house with any unused energy being fed back into the power grid.

Because energy in the United States is relatively cheap, approximately 10 cents per kilowatt hour, it is hard to justify the payback periods for PV systems. The U.S. government helps offset the costs of PV systems by providing incentives to help the cost be more manageable; however, it is still very expensive when compared to other generation methods.

A good way to look at the PV technology is through the lens of a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats.) The strengths of solar power are significant. One major factor is the energy produced is completely free and sustainable. In addition, there is technology that can help forecast the location and intensity of the sun which gives important information that helps boost generation methods. The down fall to the forecasting comes with weather predictions. It can be challenging to foresee storms and other weather patterns very accurately. Another strength is the amount of solar radiation hitting the earth at one time. Haugan in Sustainable Program Management states if humanity could harness "the amount of sunlight that hits the earth in one hour it would be more than 6,000 times the amount of power that is consumed by humans in a year." If we figure out how to harness a very small fraction of the sun's power it will provide for all of mankind's needs. Another substantial problem with this theory is mankind does not yet have the means to store that much energy. Storage method would have to increase along with the PV solar technology for this to be feasible (Haugan, 2013).

In terms of sustainability solar power does not provide pollution while operating like many other power production processes do. Once the system is in place there is very little maintenance and upkeep for the PV system. Solar power is ideal for locations that would be difficult to provide power because once the panels and system are installed they do not require continued transport of fuel or power to the location. General maintenance may be required to maintain the system (Haugan, 2013).

Even though solar power has many strengths, it also has several weaknesses. One of the largest deficits to solar generation is the inefficiency of the technology. Some of the most efficient solar panels on the market today only have ~22% efficiency. The inefficiency of the panel would almost be acceptable if there were no other losses in the system; however, there is a ripple of continued inefficiencies that follow. Solar panels produce Direct Current (DC) power whereas homes and other buildings need Alternating Current (AC) power. The conversion from DC to AC further reduces the efficiency by 5-10%. Furthermore, the final reduction comes from where the system is physically located in the world. As figure 2 shows if the system is in the U.S. maximum possible kilowatts per square meter is reduced down to 25% of its potential, or 250 watts (Yogi Goswami, 2001). For example, the one kilowatt per square meter potential could easily be reduced to .036 kilowatts per square meter even with good weather conditions. Another major weakness to solar power is time without direct sunlight like at night or unclear weather conditions. The lack of direct light will greatly diminish the potential of the solar panels. Also as the graph shows below there may be ambient sunlight but solar panels need good direct light which is only for around six hours each day depending on the location of the panel.

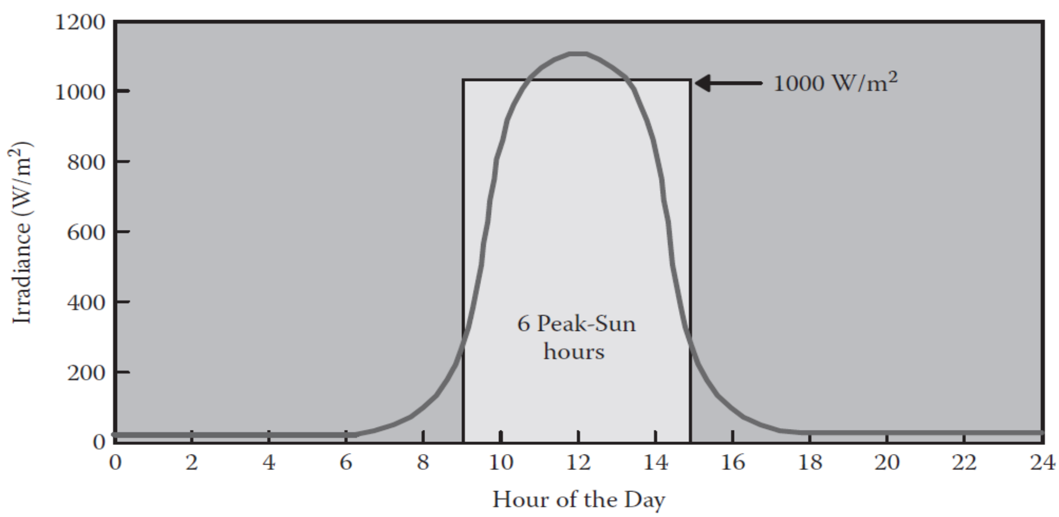


Figure 1: Peak Solar Hours in a Day (Robert Foster, 2009).

There are great opportunities for advancement of solar technologies. Compared to other generation methods like fossil fuels and hydroelectric power, solar technology has had much less money and research focused on it. If the efficiency of the panels could be improved then solar power could easily replace other generation methods.

As previously stated, at the equator, under the best conditions, sunlight can provide one kilowatt of energy per square meter. If the energy is extrapolated out to the size of an acre, the number is increased to more than 4 megawatts of energy. This is truly a staggering number but unfortunately only a fraction of this potential can be converted to energy with current technologies. Even with some of the downfalls, solar energy should not be overlooked as it can still produce a fair amount of energy and should be strongly considered for appropriate applications. The solar panel used in this thesis under proper conditions is ~13% efficient. This number does not directly correlate to energy production as the sun is only available during daylight hours and provides different potential depending on where you are in the world. The figure below shows a graphical representation of the average daily energy potential in watts per square meter for solar power in the US.

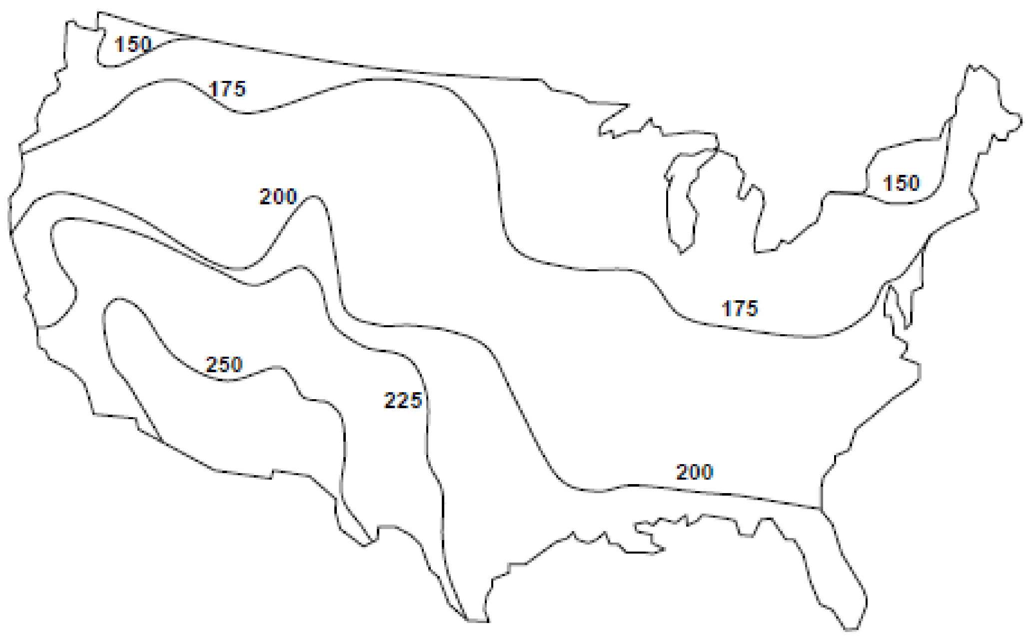


Figure 2: Map of potential solar power across the U.S. (Yogi Goswami,2001).

According to Figure 2, East Tennessee is located in between the 200 and 175 marks. This allows for assumption of the potential for this area is ~185 watts per square meter. Calculations of 13% of 185 watts per square meter per day equals to approximately 24.5 watts per square meter. Table 1 gives a simple calculation of the maximum power usage that the table could see.

Table 1: Maximum USB Power Demands.

$E_{(kWh)} = P_{(W)} \times t_{(hr)} / 1000$			
USB max Power Demands			
1 usb port	P = E x I	5	W
	E =	5	V
	I =	1	A
8 usb ports	P =	40	W
	E = (P x t)/1000	0.24	kWh
	P =	40	W
	t =	6	hr

Tables 2 and 3 give a general estimate of what the Kyocrea PV panel could do.

Table 2: Solar Panel Production Numbers

PV Solar Panel					
Kyocera		600VDC Max System Voltage			
KD135GX-LPU		15A fuse		MC4 connectors	
STC = 1000W/M^2 irradiance @ 25°C, AM 1.5 spectrum					
Under Standard Test Conditions (STC)					
Pmp	135	W			
Vmp	17.7	V			
Imp	7.63	A			
Theortical Pmp	185	W			
Voc	22.1	V			
Isc	8.37	A			
Ptolerance	+ or - 5	%			
NOCT = 800 W/M^2 irrandiance @ 20°C, AM 1.5 spectrum					
Nominal Operating Call Temperature Conditions (NOCT)					
Tnoct	45	°C			
Pmax	97	W			
Vmp	16	V			
Imp	6.1	A			
Voc	20.2	V			
Isc	6.78	A			
PTC	122.2	W			
Temperture Coefficients					
Pmax	-0.45	%/°C			
Vmp	-0.52	%/°C			
Imp	0.0066	%/°C			
Voc	-0.36	%/°C			
Isc	0.06	%/°C			
Operating Temp	-40 to +90	°C			

Table 3: Maximum Solar Power Output (Photovoltaic Software, 2014).

The global formula to estimate the electricity generated in output of a photovoltaic system is :	
One of the PV panels will produce this in one normal day	
E = A * r * H * PR	
0.481931	**E = Energy (kWh)**
1	**A = Total solar panel Area (m^2)**
0.134731	**r = solar panel yield (%)**
4.9	**H = Annual average solar radiation on tilted panels (shadings not included)**
0.73	**PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)**
73%	= Pmp/T Pmp or PR

If the calculations of the PV solar panel under typical weather conditions for this area are taken into consideration, the panels should be able to produce the amount of kilowatt hours the system would need in one day. These numbers are based off normal operating test conditions which may differ from the actual power generated. The solar power calculations from the data tables above provide the proof of concept for this project. Physical data will be collected later to see if these calculations are correct and apply to the application of this thesis.

CHAPTER 3

SCOPE

The scope of this thesis was to peak the interests of the ETSU students and challenge their idea of what a solar panel can do. This was done by developing the best design of the table through research on the following categories: Current projects or products of similar ideas and designs, Safety, and testing of the product. The goal was to create a simple and reliable design ETSU can use and re-use for years to come. A Kyocrea KD135GX-LPU PV solar panel was used as the power generation method for the project. The structure of the table was designed and researched in four possible configurations. The testing of the solar panel took place in Morristown Tennessee and will compare the actual generation data to the theoretical numbers.

Equipment

The following is a brief description of the testing equipment used for the project and will need to be used in the future testing in order to help replicate the findings.

Kyocrea PV Solar Panel

The solar panel used was a Kyocrea KD135GX-LPU. This type of panel is one of the highest overall rated products for sale among all solar panels. The specific solar panel being tested was repurposed from one of the buildings on ETSU's campus. There was an array of three Kyocrea solar panels that previously powered a battery bank which in turn provided power to lights and fans in one of the recycling builds. The system was in working order but the university decided to build on the land where the recycling building was located. With the panels no longer serving a purpose, Dr. Sims allowed me to repurpose them for this testing and build. If the recycling center is rebuilt then there is a possibility that a new array and system will be installed. The solar panel under standard test conditions (STC) can produce a maximum power point of (Pmp) of 135 Watts, a maximum power voltage (Vmp) of 17.7 Volts, and a maximum power current of 7.63 Amperes (Kyocera, 2013). These numbers are impressive but are not plausible in normal operating conditions. A reduction of at least 25% was expected in testing.

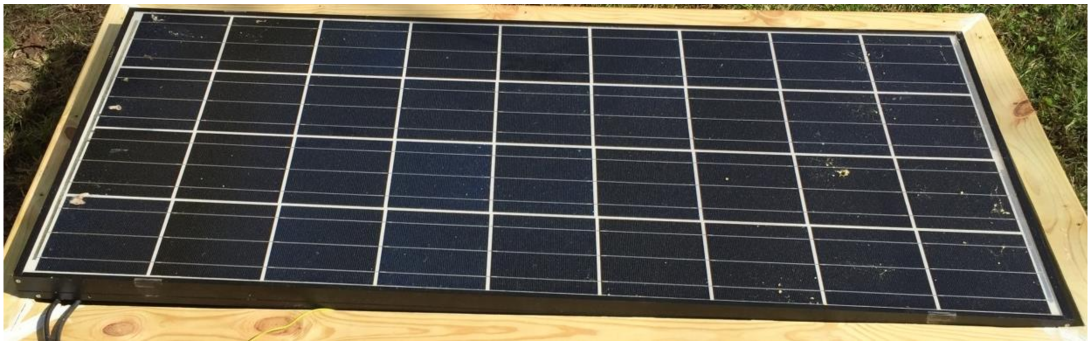


Figure 3: Kyocrea KD135GX-LPU

Kimdrox Dual Power Adapter

This power adapter is a combination of a boost and buck DC to DC converter. The power from the solar panel was fed through a circuit breaker then to the Kimdrox converters. Each converter has two female USB connectors that will be used to charge the students small electronics. The converter can consitantly handle an input voltage of 8-22 Volts. This input will be converted to a constant DC output of 5 Volts. The output current will vary depending on the device hooked up to the charger. Each converter can have a maximum output current of 3 Amperes. These converters will do well for the project because they are protected from reverse polarity, over currents, over temperatures, and short circuits. They are also closed off with glue craft which provides the circuit to be waterproof, moister proof, and earthquake proof. These features are critical for the conditions of this project.

Figure 4: Kimdrox DC-DC Power Converter

<u>PortaPow USB Power Monitor</u>

PortaPow is the multi-meter used to measure the outputs from the USB ports of the table. The multi-meter displays the voltage, current, and power to any USB that the meter is connected to. It can measure current ranging from 0 to 2.5 amperes, voltage from 3 to 7 volts, and power from 0 to 17.5 watts. The meter is accurate to .01 amperes, .01 volts and .01 watts. To accurately measure the data, the multi-meter was first connected to USB output of the DC to DC converter. After connected, the hand held device’s USB cord was connected to the side port on the multi-meter. This was necessary to get the amperage which can only be measured in line with the circuit.

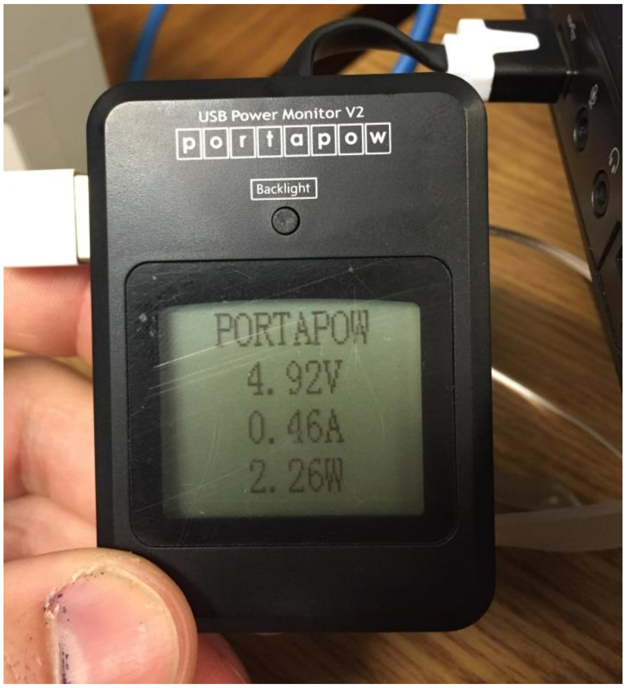


Figure 5: PortaPow USB Power Monitor

Tenma DC Power Supply

The Tenma 72-2080 is a DC power supply that can provide 0-30 volts DC at approximately 3 amps (Tenma, 2000). The unit was used to test the DC-DC converters insuring they are functioning properly before attaching them to the solar panel circuit. The converters were be soldered spiced together with a 4 wire 16 awg cable. Once the converters were wired together they were tested with the PortaPow power monitor and Tenma power supply. The power supply was set at 15 different voltage outputs to see if the converters could keep the proper voltage output as the input voltage changed. The input voltage range will mimic the output range of the solar panel. Because the solar panel will not be able to provide the same amount of energy all throughout the day, it will be more or less depending on the position of the sun.

Figure 6: Tenma 72-2080 DC Power Supply

<u>Fluke 87V Multi-meter</u>

The multi-meter used in the testing and measuring of data was a Fluke 87V multi-meter. This brand multi-meter is known to be very reliable and accurate and regularly used in industrial applications. It has a DC accuracy of .05% and can measure up to 1000 VAC or DC. The Fluke87V can measure up to 10A or 20A for 10 seconds without harm to the meter (Fluke, 2005). The Fluke meter was only used to measure the DC currents and voltages but it provided a very accurate reading of the data. This multi-meter was be used in conjunction with the PortaPow monitor. The Fluke meter measured the direct output of the solar panel before it went through the system.

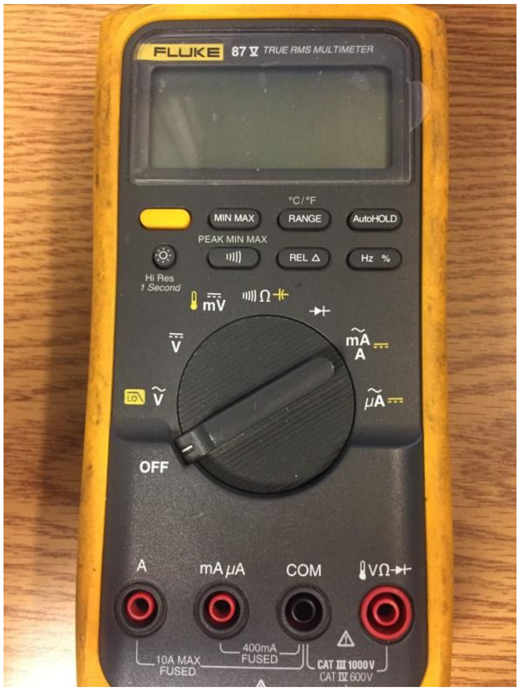


Figure 7: Fluke 87V Multi-meter

Designs

Since there are many ways to build a picnic table only four designs were evaluated. The majority of other designs on the market use a canopy above the table to provide an area for the solar panels. Since the canopy design is very popular it was one of the options of the design with second option of mounting the solar panel on the tabletop. Both of these options were evaluated and one a design was chosen. The final choice was to decide whether to build all new tables or reuse the universities current concrete tables. There are advantages and disadvantages associated to each design which are covered in this section.

Table Types

Design A reuses the current stone tables and add a roof for shading. The roof is where the solar panel will be mounted. In addition to the roof, this design will also include a modular table top frame built around the existing table. The top provides a place for the charging ports and a place to hide all of the wiring and components needed for the project. This allowed the system to be safer and makes it harder for someone to steal or vandalize the equipment.

Figure 8: Current Concrete Picnic Tables at ETSU

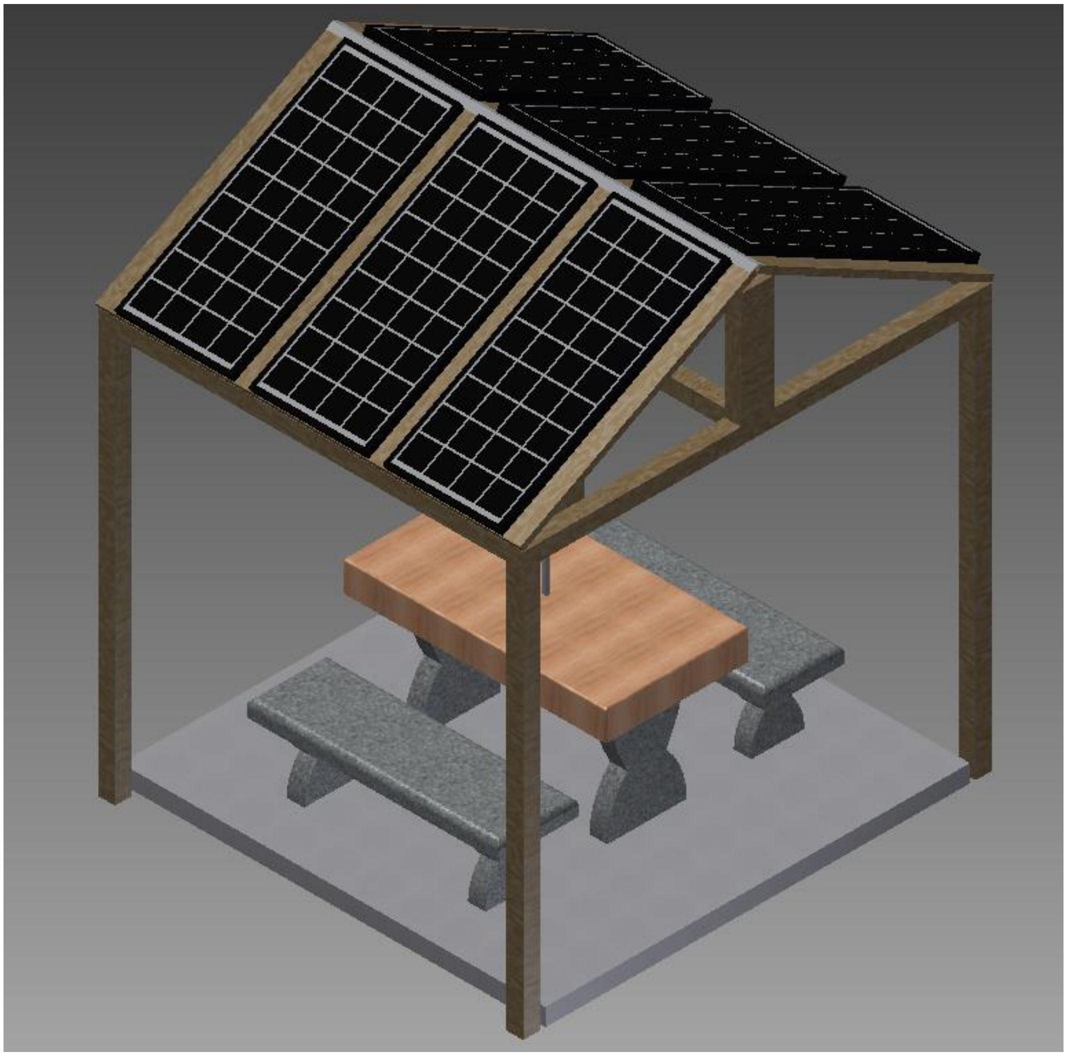


Figure 9: Model of Design A

Design B is similar to design A but, it does not use a roof or canopy but rather locate the solar panel on the modular tabletop frame. Like design A, design B allows for the university to reuse their current tables. Design B is more simplistic than design A because the roof structure would not have to be engineered or built. It would only require adding the solar panel to the table top frame that was already planning on being built.

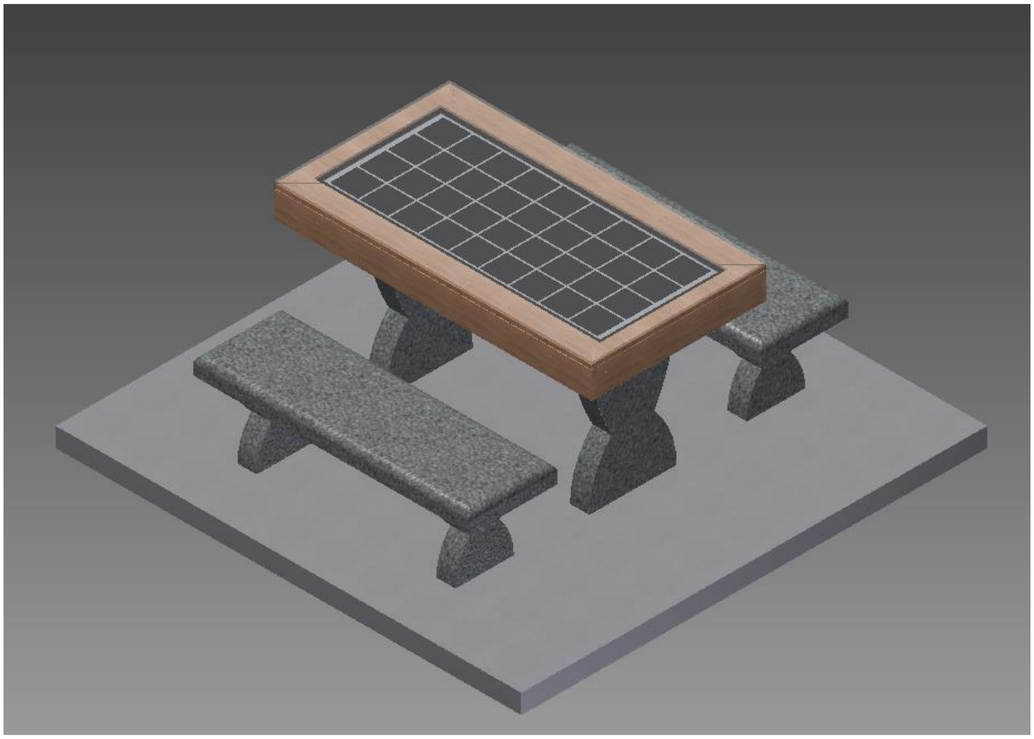


Figure 10: Model of Design B

Design C is a brand new picnic table with a roof for shading. This design would allow the school to update the old tables and have the tables be more customizable. Like design A the solar panel is located on the top on the roof and a tabletop frame would need to be built so that there is a place to hide the charging ports, wiring, and components needed for the project.

Figure 11: Model of Design C

Design D is a new table without a roof and will have the solar panel mounted on the table top. This allows the university to update some of their tables and customize them like design C. One major appeal to this option is that it allows the university to present a completely new product rather than fixing up what they currently have. The attention brought with the new tables would help promote the table as well.

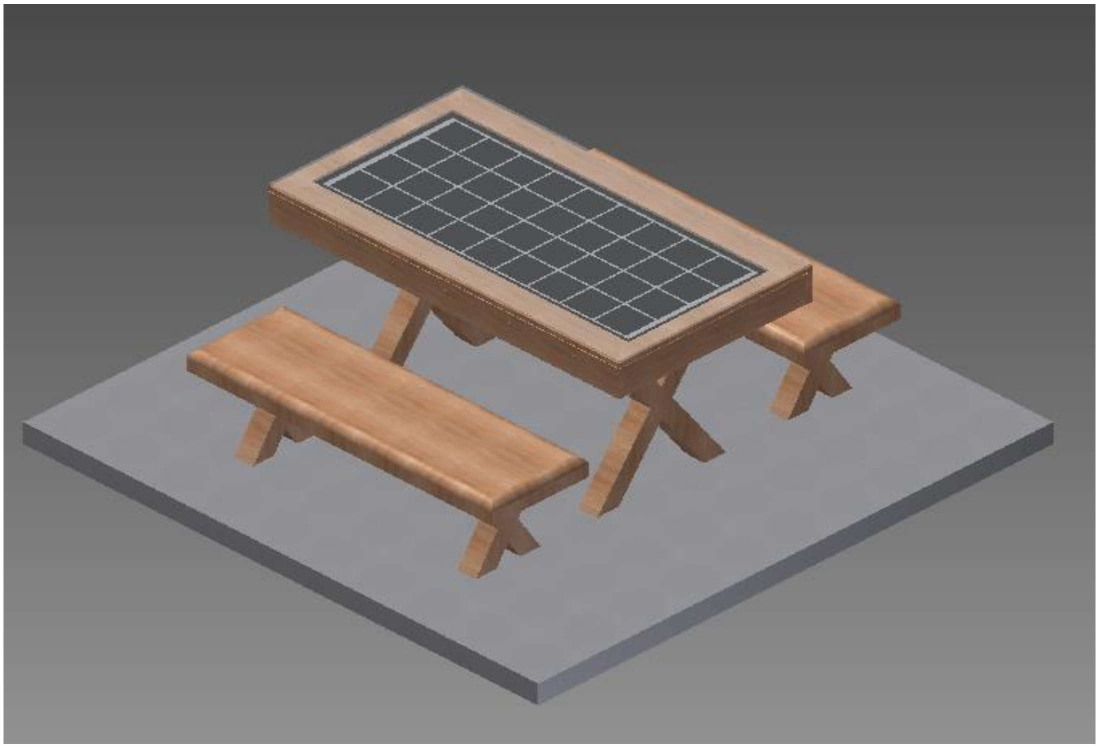


Figure 12: Model of Design D

Solar Panel Locations

The majority of companies produce their product with the solar panel located on a canopy over the table. The canopy allows the solar panel to receive the most light possible. It also places the panel out of physical reach so that it is not in the way of the students using the table. A major disadvantage of this location is that the panel can easily be out of sight so it could go unnoticed by the students at the table. The students could easily think that the power is coming from a nearby building and miss one of the major goals of the system.

The other option for the location of the solar panel is to have it located on the top of the table. This makes it very difficult for the students to miss. It also gets them close to the technology so that they may be intrigued to learn more. A disadvantage of this option is that the panel could make the surface of the table too hot to use. Another disadvantage is that anything set on the top of the table will reduce the amount of energy that the panel can produce.

System Design Options

One design option from leading companies is the 120Vac GFIC outlets. These power larger electronics like laptops, battery banks to store unused energy produced by the solar panels, and lights of fans for the table when needed (Kyocera, 2013). Options of this capacity would be nice to have but the direction of this project is to create a simplistic design and the addition of these options would make the table too complex (Kyocera, 2013).

Safety of the Design

The safety of the design is a crucial piece of this project. When electricity is a part of the system there has to be strict safety measures in place so users may safely interact with the system. The National Electrical Code (NEC) has specific regulations and code guidelines that electrical devices and systems need to follow in order to dissipate the risks associated with electrical systems.

Article 110 of the code has many parts dealing with the general requirements of electrical installations. One section included in the article pertains to this thesis is section 110.14, Electrical connections. Wires and cables in the circuit design are soldered spliced and this section states how splices should be created to be in line with code standards. The solder splices should be joined together in a way that they are secure without solder. Once this is achieved then the splice was soldered. After the splice was soldered, the connection needed to be insulated. The code states the connection will need to be covered with an insulation material that is equivalent to the conductor. Rated heat shrink was added to the soldered connections to insulate according to the standard (NEC, 2014).

The next section of the article pertaining to my design is 110.28, Guarding of Live Parts. The code references electrical equipment operating at 50 volts or more must be guarded against accidental contact. The system will not get to the 50 volts mark but measures were taken to isolate the electrical components to keep the system and students safe. A box was built around all of the components to protect anyone from reaching the internal electronics. A warning sign was added to the location of potential danger from voltage and or current (NEC, 2014).

Article 240 of the code pertains to the over current protection of the parts of the system. The DC to DC converters used to provide the power to the USBs have preinstalled over current protection, but the code will be applied to the whole system so the system is safe to itself and the users. A circuit breaker that is rated for the current load being used in the system will be implemented to protect the system. If the circuit breaker detects the current through the breaker is higher than what the breaker is rated for, it will mechanically break the connection to protect the system (NEC, 2014).

Article 250 of the code pertains to the requirements for properly grounding electronics. The code states, electrical systems need to be grounded in a way that protects them from voltages imposed by outside forces such as lightning, line surges, and unintentional contact with higher voltage lines. The code also states, any electrical equipment that is normally noncurrent-carrying but is a conductive materials that encloses electrical conductors or equipment need to be grounded, bonded, and have an effective ground-fault current path. Since the solar panels have a three wire DC system, the third wire will need to be grounded. The grounding wire cannot be smaller than the neutral conductor or the largest conductor. Also it should not be smaller than 8

AWG copper or 6 AWG aluminum. A grounding rod was driven into the ground directly under the table with the bare copper wire connected to it. This will provide a strong earth ground for the system so that the lightening and surge potential of system can be avoided. The grounding rod was at least 8 feet long and driven into the ground to where no more than a foot is above the surface. The rod may be made out of steel or copper; however, if the rod is steel, it needs to be galvanized or coated with some material to prevent corrosion and must be at least 3/4 of an inch in diameter. If the rod is copper or steel coated in zinc, the rod needs to be at least 5/8 of an inch in diameter (NEC, 2014).

Article 300 of the code covers the general requirements for wiring and materials in installations. Under section 300.4 the code references how wires and connectors will need to be protected against physical damage. All of the wiring for this project are located between the table and the solar panel. This kept them away from the students to protect the wires from potential harm. Since all of the fasteners for the project are secured there will be no need for tubing or shrouding around the cables to protect them. Zip ties and cable ties were used to attach the cable to the wooden enclosure. This helped insure the cable stays out of harm's way. Under section 300.6, the enclosure will need to be water tight to protect the cables and electronics from corrosion. The boards for the enclosure are treated, stained, and sealed so that the electronics will be protected (NEC, 2014).

Article 690 discusses solar photovoltaic (PV) systems. It describes all the main configurations of general solar panel systems. Under section 690.4 the code requires the equipment used in the system to be listed for the PV system. The design for this thesis uses four DC-DC converters. Each converter has two regulated USB charging outputs. Section 60.5 says the ground mounted PV panels that have no more than two source circuits with their entire DC source and output circuits, isolated from buildings, are not required to have ground fault protection. The PV system for this thesis does not have ground fault protection due to this code. Under section 690.8 the code states that the maximum circuit current needs to be calculated. Since the DC to DC converters have the lowest current tolerance the maximum current for the circuit breaker will be rated to them. Under section 690.9 the code states the system will need to have an over current protection with either a fuse or a circuit breaker that can carry 125% of the maximum circuit current. The maximum continuous output current form the converters is 3 amperes. A 4 ampere circuit breaker was added to the circuit as to protect the circuit from over currents. Under section 690.51 the code states the module needs to be marked with identification of: open circuit voltage, operating voltage, maximum permissible system voltage, operating current, short circuit current and maximum power. This will be located in the enclosure near the system disconnect so anyone doing maintenance on the system has knowledge of what the system can produce (NEC, 2014).

Advantages and Tradeoffs

There are advantages and tradeoffs for each of the designs. The designs' differences can be broken down into two main categories. The first is whether to build all new tables or to reuse the current tables at the university and the second is whether to use the table top for the solar panel or to build a canopy to house the panels.

In terms of the first category, if the final design is chosen to build all new tables the university faces three main advantages. When building all new tables the university is able to update or fix broken down tables. This is important as the university grows to keep things nice and working properly. A second advantage of building all new tables is it allows the university to customize the tables. Once the design is complete, the physical dimensions and properties of the design could be changed rather easily depending on the wants and needs of ETSU. The tables could be made bigger or taller without majorly affecting the function of the electronics. A third advantage of building new tables is the table can be relocated rather easily and/or ETSU can add more options to get students to enjoy the beautiful campus. A disadvantage of building new tables is it is not as sustainable as reusing their current tables found without any damages. The university is trying to convey good sustainability practices and replacing tables still in acceptable condition, could potentially convey the wrong message. Another important disadvantage to consider is since the tables will have electronics they will have to be grounded. This will be challenging with the concrete pads that some of the tables are located on.

If the design for reusing the current tables is chosen, there are some significant advantages. As mentioned above, the major advantage to reusing the old table is that it conveys the message of sustainable practices. The university demonstrates it is committed to doing the work to be sustainable. It could be more simplistic for the university to purchase a finished product from a reliable company, but they chose to encourage their students to get involved and demonstrate their skills. This empowerment is a major part of the university's mission. A second advantage to reusing the current tables is the cost. Reusing the tables will be able to cut the cost of the product because the new tables will not have to bought or built.

In terms of the second category, if the design was chosen to position the solar panel on a canopy above the table, the university faces three main advantages. First it keeps the solar panel out of the reach of the students. Second, if the solar panel was on top of the canopy there is potential for more than one panel in the system which would provide more power to the table. The roof could also be slanted with the panel which is helpful as an angled roof is a great advantage to get the most sunlight for the system. A panel mounted on the table top will produce less than it would if it were angled. A few disadvantages to mounting the solar panels on a canopy would be the time and money to produce a well-functioning canopy. The canopy would need to be angled precisely for the most direct sun light and it would have to survive the elements of wind, rain and snow. All of these factors would need to be researched and tested. To keep from deviating away from the electrical side of this project, the angled canopy was not favored for the purpose of this thesis. In addition, if the panel is located on top of the canopy, it could easily go unnoticed, defeating the purpose of trying to peak the interests of the students.

Choosing to place the solar panel on the table top has some great advantages. The largest advantage is the panel cannot go unnoticed, peaking the interests of the students. If the students are not aware of the solar panel then it would be hard for them to be interested in it. This is also important because it brings the students closer to the technology so they can observe it and challenge what they believe it can do. Another advantage of placing the panel on the top of the table is that it will again cost less and keep the focus on the goal of the project rather than the build of a structure. Cost is always a driving factor and if the system is more simplistic, it will be easier to maintain. A third advantage is that it will be easier to protect all of the components from the elements if they are in one location rather than being spread out. The final benefit is that the tabletop method can be contained to the size of the table. Since the system is moveable, it can be easily transported and moved to other parts of the campus. One potential down fall to this design would be if the table top gets too hot for use. Since the solar panel is black it will heat up very quickly especially on hot summer days. A design feature that will be included is an air barrier between the solar panel and the clear surface of the table. This will allow air flow through the system which will help regulate the temperature of the table top to a reasonable temperature. An added benefit to the clear surface providing the air barrier, as direct contact with the solar panel could damage it. The medium used would have to be very clear as to not block the sun since some of the direct light may already be blocked by the student's items already on top of the table. The best option for the clear medium is Plexiglas Solar. This special type of Plexiglas offers 92% visible light transmission (Evonik Industries, 2013). This is very important because even if the medium is very clear but blocks the light to the solar panel then the solar panel would not function properly. Another added benefit to this type of Plexiglas is that it is very resistant to abrasion and impact. With the addition of this material of the solar panel some of the light will be blocked, which will affect the overall performance of the system. However, if the Plexiglas Solar is used only 8% of the light should be blocked. This material was not used during testing because it was not feasible to purchase at the time of testing. Further testing is needed to insure that the Plexiglas Solar does not block too much of the light to the solar panel.

Final Design

The idea for the table is to have it as simple as possible. Simplicity provides repeatability and reliability, which will give the university the longest life of the table while being cost effective. Since the table is simple, it does not have all of the same features as other products on the market but will be able to provide similar energy production. After careful consideration to the final design of table, the solar panel was mounted to the tabletop and the design chose to reuse the current concrete tables. This was for three main reasons:

The main reason for was to be different from most other designs. The majority of the designs on the market typically have a canopy that provides a space for the panels to get the most light. The other rationale for being different is to get the panel closer to the students. This was an important factor to peak the student's interests. The panels could easily go unnoticed if they are out of sight on top of the canopy; the students could misconstrue that power is coming from a standard outdoor outlet rather than the solar panel.

The second design feature included in the final design was the panel setup in direct power generation without a battery bank. The rationale for not having a battery bank was to make the table as self-sustainable as possible. Battery banks need monitoring to insure the batteries will not be damaged over time. They also require more electronics that could fail which would require more maintenance.

The third design feature of the table is to reuse the current picnic tables throughout campus. This was crucial to reduce the price of the table. In addition, it allows the university to be sustainable in recycling picnic tables rather than buying all new tables.

An additional feature that could be added to the design would be a LED light on the table. This LED light would be there to indicate whether the table is able to produce enough power to charge. This is important because it is hard to tell if there is enough sunlight getting to the table. If too much has been set on top of the table then the light would go out warning the users to take some of the items off of the tabletop. This could be accomplished through many different ways on of the easiest ways would be through a simple circuit using a zener diode, resistors, and a LED. A wire from the positive voltage of the solar panel output would be connected to a variable resistor then to a fixed resistor followed by a zener diode then lastly the LED. The resistors act as a current control so that the LED will not burn out from too much current. Also the variable resistor is there to adjust circuit to the minimum voltage output from the solar panel to can still provide satisfactory charge. This would allow for the LED to be on when the solar panel is producing voltage above the minimum charging output.

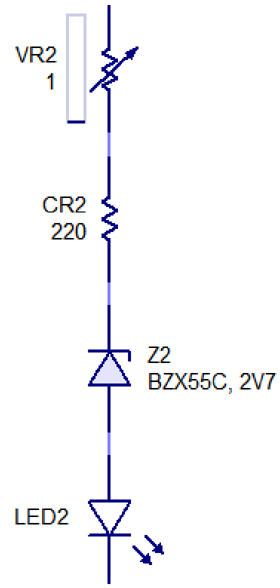


Figure 13: Sufficient Charging Power Light Circuit. (Zaid Pirwani, 2011).

Bill of Materials

Table 4:Approximate Cost of Final Design and Design A

Approximate Cost for the Final Design			Approximate Cost for Design A	
Solar Panel	$400.00		Solar Panel	$400.00
Cables, Wire, and Grounding Rod	$25.00		Cables, Wire, and Grounding Rod	$25.00
DC-DC Converters	$45.00		DC-DC Converters	$45.00
Circuit Breaker	$40.00		Circuit Breaker	$40.00
Lumber	$50.00		Lumber	$50.00
Screws	$10.00		Canopy/Roof	$300.00
Paint or Stain	$20.00		roof mounting for solar panel	$100.00
Waterproof Seal	$20.00		Screws	$25.00
Plexiglass Solar	$240.00		Paint or Stain	$20.00
16 hours of Labor at $50 an Hour	$800.00		Waterproof Seal	$20.00
Approximate Total	$1,650.00		Plexiglass Solar	$240.00
			40 hours of Labor at $50 an Hour	$2,000.00
			Approximate Total	$3,265.00

CHAPTER 4

PROCEDURE

Implementation

The implementation of the solar panel table was done in three stages. The first stage is the research stage and bench testing. In discovering others' findings, it allows me to learn from their designs and improve on them. The bench testing provides a proof of concept for the project. In the second stage, initial tests were performed on the electronics in conjunction with the solar panel. This was to confirm the chosen design will provide enough power for the student's electronics. The final stage tested the design in conditions similar to everyday use of the table. Portions of the solar panel were blocked mimicking items being placed on top of the table. After the table was tested and proven to be working, the final design will be completed and given to ETSU with recommendations on how to build and use the system.

Initial Test Plan

The initial test for the thesis was a proof of concept bench test. The test used the bench power supply with the DC-DC converters. The power supply was set at increments within the range of the solar panel output and voltage the converters can handle. The converters will reliably convert the input voltage to the proper output voltage if the input range is in within 8-22 volts. The solar panels will produce 22.1 volts under perfect test conditions and will normally produce 20.2 volts under normal operating conditions. Bench testing voltages from 6-20 volts will be tested as it is the normal range of the solar panel output. The following equipment and procedure was used in the initial bench test.

Equipment

- Tenma 72-2080 DC power supply
- PortaPow multi-meter
- Phoenix Contact terminals and Jumper wire
- iPhone 6 with ~50% battery life
- Apple lighting USB cord
- Kimdrox DC-DC converter

Testing Procedure

1. Turn on power supply and adjust the output voltage to 6 volts.
2. Turn off the power supply to connect the circuit.
3. Connect the system circuit using the phoenix terminals.
    a. Double check all of the connections.
4. Turn on the power supply.
5. Connect the PortaPow to one of the USB outputs of the DC-DC converters.
6. Record the no load voltage for the specific power supply voltage.
7. Connect the iPhone 6 with the USB cable to the PortaPow.
8. Record the charging voltage and current.
    a. This measurement was taken 6 times per-minute or every 10 seconds, for 5 minutes which yields 30 data points.
9. Repeat the first eight steps for each input voltage. Input voltages will begin at 6 volts and will be tested up to 20 volts in one volt increments.
10. After all 15 voltages are recorded, the results will be analyzed.

Initial Test Findings

The initial bench test reveals the following data:

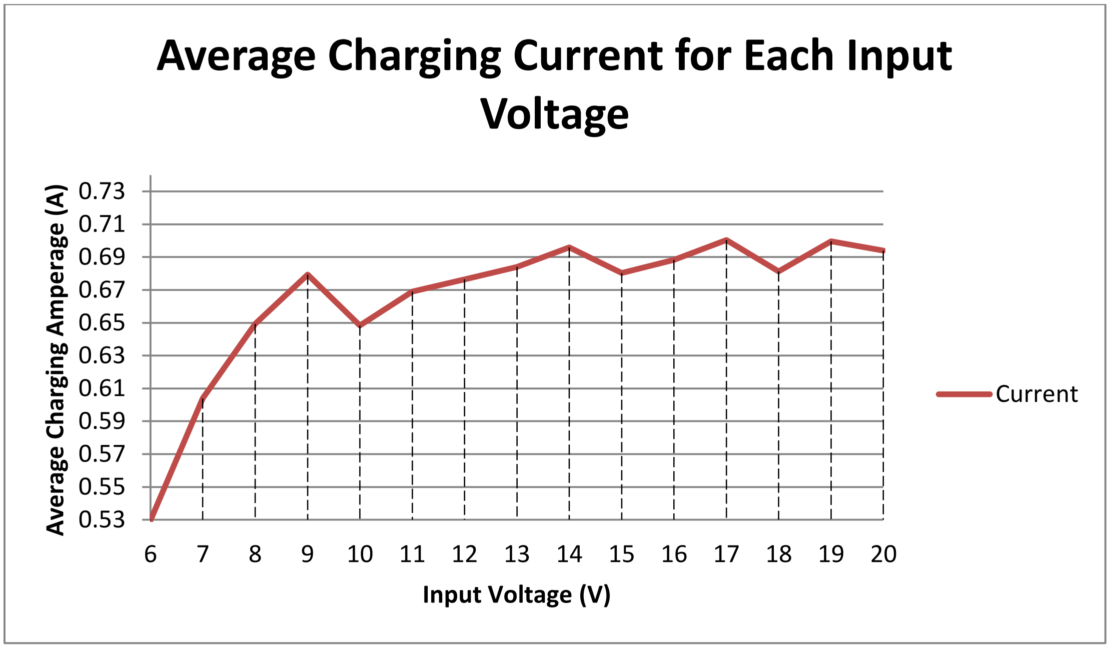


Figure 14: Initial Test Average Charging Current Over the Input Voltage Range

The typical USB power produces approximately .5 amps of charging power. The bench test appeared to be promising as it was able to produce more than the average amperage at a steady voltage. Even at voltages below the recommended input for the DC-DC converters, the converters were able to boost the outputs to an acceptable voltage and current. As the input voltage increases so does the charging current. The higher charging current range allows for a faster charge.

The testing procedure was repeated two more times to provide baselines for comparative data. The first test was performed with a computer as the charging power source and the second testing with the OEM factory charger. Figure 14 shows the findings of those two tests:

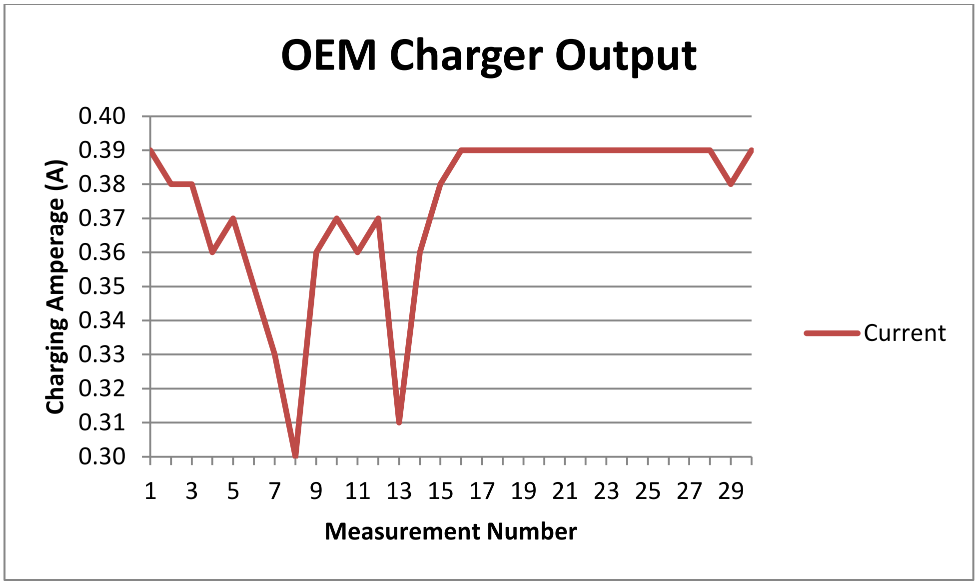


Figure 15: Charging Current Data Points form the OEM Charger

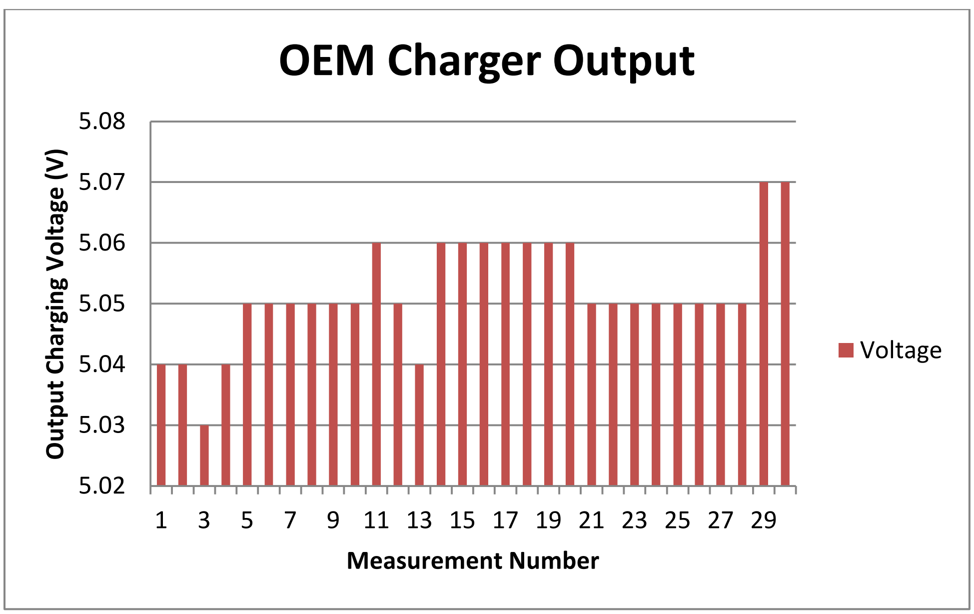


Figure 16: Charging Voltage Data Points form the OEM Charger

Surprisingly, the OEM wall charger was very sporadic as compared to the converters and charged at much lower amperage. The charger's specifications states it will charge at 5 volts and

1 amp. From the test results, the voltage measured as close enough but the amperage was less than half of what the charger claims to charge at.

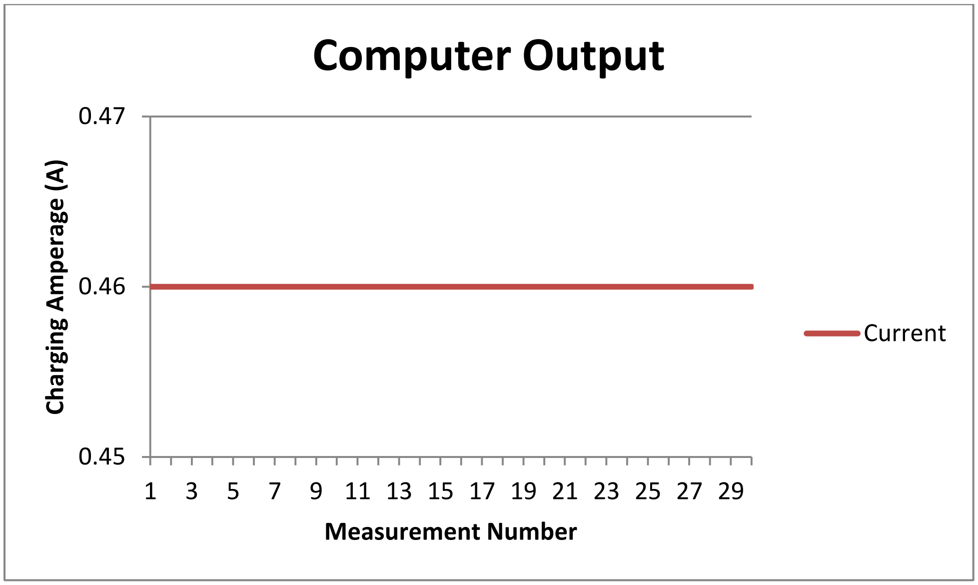


Figure 17: Charging Current Data Points form the Computer USB port

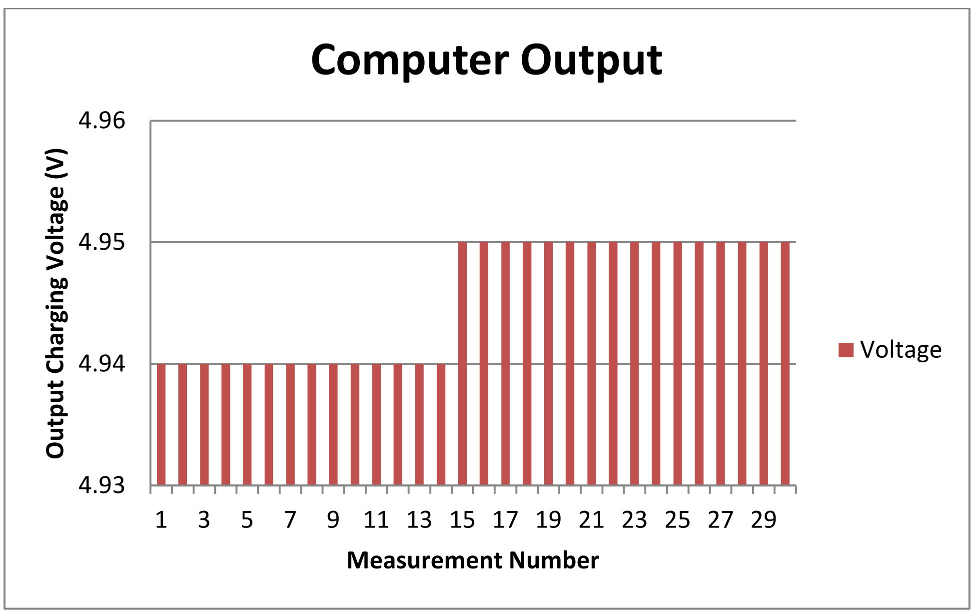


Figure 18: Charging Voltage Data Points form the Computer USB port

The computer output was consistent throughout testing and regulated so well it did not change the amperage throughout the test. The only change in voltage was by a very small amount, .01 volts. The average USB port will provide 5 volts at 500 milliamps. This test showed both numbers a little low but not low enough to consider it abnormal.

With this data the input voltage for the converters needs to be at least 8 volts to be able to handle the amperage and charging needs for a proper charge. The voltages below 8 volts seemed to be too sporadic for a consistent charge.

Modified Test Plan

With the baseline established by the bench testing, there was enough information and a proof of concept to be able to ramp the experiment up to full scale. The original testing procedure was a good starting point but it was modified to accommodate for other factors in the full scale testing.

Equipment

- PortaPow multi-meter
- Phoenix Contact terminals and Jumper wire
- Seimens 4 amp Circuit Breaker
- iPhone 6 with ~50% battery life
- Apple lighting USB cord
- Kimdrox DC-DC converter
- Kyocrea KD135GX-LPU PV solar panel
- Fluke 87V multi-meter

Testing Procedure

1. Position the table in a sunny area.
2. Make sure the circuit breaker is off.
3. Connect the system circuit using the phoenix terminals and circuit breaker.
    a. Double check all of the connections.
4. Turn on the circuit breaker.
5. Connect the PortaPow to one of the USB outputs of the DC-DC converters.
6. Record
    a. The no load voltage for the specific power supply voltage
    b. Time of the first reading and temperature
    c. The no load output voltage from the solar panel, using the Fluke multi-meter.
    d. Number of devices connected to the system for the test.
7. Connect the iPhone 6 with the USB cable to the PortaPow.
8. Record
    a. The PortaPow charging voltage and amperage
    b. The output of the solar panels with load, using the Fluke multi-meter.
9. This measurement will be taken 6 times per-minute or every 10 seconds, for 5 minutes yielding 30 data points.
10. Repeat the first nine steps at two additional times during the following hours: 8-noon, noon-4, and 4-7pm.
11. After all time frames are recorded, analyze the results.

Modified Test Findings

The data recorded using the modified testing procedure is the following:

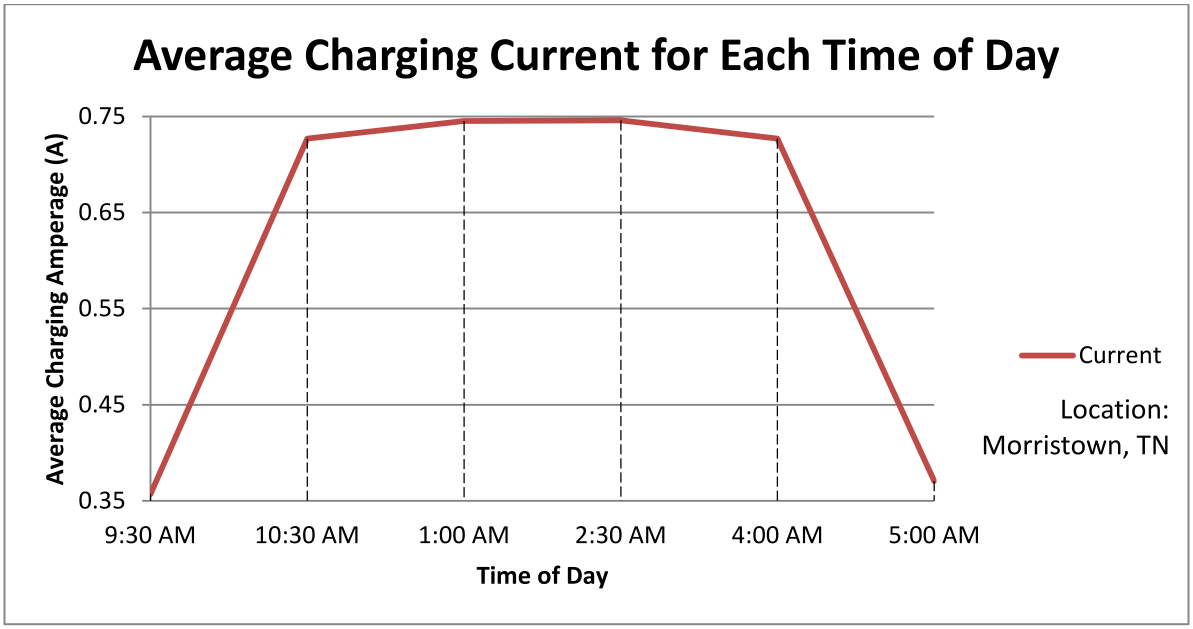


Figure 19: The Modified Test Average Charging Current Over the Time of Day

In this round of testing, similar results to what can be expected were found (shown in Figure 1). Measurements were attempted at 8:00 am and 5:30pm with little success. The solar panel was able to provide around 6-7 volts but the intensity from the sun was not present to provide the power or amperage needed for charging. To mitigate this issue, two options are feasible. The first is to add a battery bank to store unused power for when the solar panel is not able to provide the power in demand. The other option is to get a more efficient solar panel. There are panels on the market that provide around 21% efficiency verses the 13% of the model tested. Higher efficiency comes with a higher price tag as well. It is unlikely many students will need the picnic table early in the morning or too late in the evening. As long as the students are using the table within the mid-morning to mid-afternoon hours, the table should be able to provide the power needs of the user. If seeking to charge outside the desirable time frame, as the current design will most likely not provide enough power to charge the devices.

Table 5:Modified Test Data

real life test												
Number of devices	1		1		1		1		1		1	
Time frame	8-noon				noon-4pm				4-7pm			
Time of reading	9:30am		10:30am		1pm		2:30pm		4:00pm		5:00pm	
Location	Morristown, Tennessee											
Solar Voltage no load	7.55 (V)		18.42 (V)		20.97 (V)		20.93 (V)		18.63 (V)		7.65 (V)	
Ouput No Load voltage	5.12 (V)		5.13 (V)		5.10 (V)		5.10 (V)		5.15 (V)		5.14 (V)	
Temperature	53° F		55° F		73° F		75° F		74° F		70° F	
Solar Voltage with load	5.58 (V)		15.67 (V)		20.28 (V)		20.27 (V)		16.71 (V)		5.7 (V)	
Output	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
	4.67 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.39 (A)
	4.67 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.39 (A)
	4.68 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.74 (A)	4.55 (V)	0.38 (A)
	4.68 (V)	0.35 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.37 (A)
	4.67 (V)	0.35 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.55 (V)	0.37 (A)
	4.69 (V)	0.35 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.70 (A)	4.55 (V)	0.36 (A)
	4.67 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.73 (A)	4.55 (V)	0.38 (A)
	4.66 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.73 (A)	4.55 (V)	0.39 (A)
	4.66 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.55 (V)	0.38 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.71 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.55 (V)	0.38 (A)
	4.65 (V)	0.35 (A)	4.98 (V)	0.72 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.38 (A)
	4.67 (V)	0.34 (A)	4.97 (V)	0.72 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.71 (A)	4.55 (V)	0.37 (A)
	4.67 (V)	0.36 (A)	4.96 (V)	0.72 (A)	4.95 (V)	0.76 (A)	4.96 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.37 (A)
	4.68 (V)	0.36 (A)	4.97 (V)	0.71 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.69 (V)	0.35 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.38 (A)
	4.68 (V)	0.34 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.38 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.54 (V)	0.38 (A)
	4.63 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.72 (A)	4.97 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.54 (V)	0.37 (A)
	4.63 (V)	0.37 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.53 (V)	0.36 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.76 (A)	4.96 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.53 (V)	0.36 (A)
	4.62 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.54 (V)	0.36 (A)
	4.62 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.37 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
	4.64 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.61 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.71 (A)	4.54 (V)	0.37 (A)
	4.61 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.96 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.37 (A)
	4.70 (V)	0.36 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.38 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.71 (A)	4.54 (V)	0.36 (A)
	4.61 (V)	0.38 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
Averages	4.65 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.37 (A)

Final Test Plan

The final test plan was similar to the modified test plan. The procedure was the same; however, items were placed on top of the solar panel partially blocking some of the direct sun light. The test provided data for the circumstances most like when the students will be using the table, giving more realistic statistics. For the final test, approximately 40% of the solar panel will be blocked with common items students might set on top of the table. These items will be a book, a book bag, and a small gym bag. These items will replicate possible operating conditions of the table. The following equipment and test procedure was used as a final test.

Equipment

- PortaPow multi-meter
- Phoenix Contact terminals and Jumper wire
- Seimens 4 amp Circuit Breaker
- iPhone 6 with ~50% battery life
- Apple lighting USB cord
- Kimdrox DC-DC converter
- Kyocrea KD135GX-LPU PV solar panel
- Fluke 87V multi-meter
- Items to block light
    - A book, book bag, and small gym bag.

Testing Procedure

1. Position the table in a sunny area.
2. Make sure the circuit breaker is off.
3. Connect the system circuit using the phoenix terminals and circuit breaker.
    a. Double check all of the connections.
4. Block ~40% of the panel from the sun by placing the items on top.
5. Turn on the circuit breaker.
6. Connect the PortaPow to one of the USB outputs of the DC-DC converters.
7. Record
    a. The no load voltage for the specific power supply voltage.
    b. Time of the first reading and temperature
    c. The no load output voltage from the solar panel, using the Fluke multi-meter.
    d. Number of devices connected to the system for the test.
8. Connect the iPhone 6 with the USB cable to the PortaPow.
9. Record
    a. The PortaPow charging voltage and amperage
    b. The output of the solar panels with load, using the Fluke multi-meter.
10. This measurement will be taken 6 times per-minute or every 10 seconds, for 5 minutes yielding 30 data points.
11. Repeat the first nine steps at two additional times during the following hours: 8-noon, noon-4, and 4-7pm.
12. After all time frames are recorded, analyze the results.

CHAPTER 5

RESULTS

Below are the results from the final test:

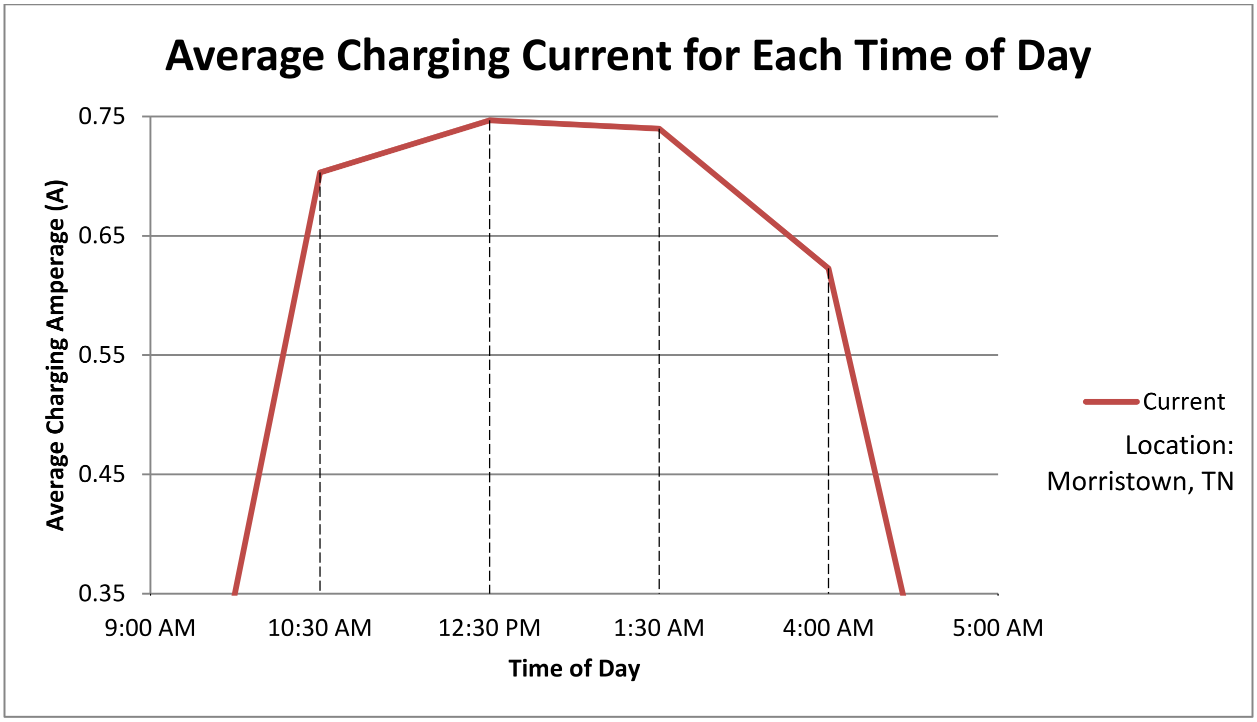


Figure 20: The Final Test Average Charging Current Over the Time of Day

Table 6: Final Test Data

real life test												
Number of devices	1		1		1		1		1		1	
Percent Block	~40%		~40%		~40%		~40%		~40%		~40%	
Time Frame	8-noon				noon-4pm				4-7pm			
Time of reading	9:00am		10:30am		12:30pm		1:30pm		4:00pm		5:00pm	
Solar Voltage no load	8.45 (V)		15.45 (V)		16.25 (V)		15.98 (V)		14.26 (V)		7.56 (V)	
Output No Load voltage	5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)	
Temperature	56° F		65° F		73° F		73° F		69° F		67° F	
Location	Morristown, Tennessee											
Solar Voltage with load	6.12 (V)		7.98 (V)		8.99 (V)		8.23 (V)		7.23 (V)		5.76 (V)	
Output	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
	4.80 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.66 (A)	4.79 (V)	0.00 (A)
	4.79 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.65 (A)	4.80 (V)	0.00 (A)
	4.78 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.64 (A)	4.56 (V)	0.00 (A)
	4.78 (V)	0.00 (A)	4.93 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.65 (A)	4.75 (V)	0.00 (A)
	4.79 (V)	0.00 (A)	4.93 (V)	0.72 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.65 (A)	4.65 (V)	0.00 (A)
	4.80 (V)	0.00 (A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.69 (A)	4.79 (V)	0.00 (A)
	(V)	(A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.64 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.64 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.70 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.71 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.71 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.76 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.95 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.68 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.68 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.71 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.72 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.72 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
Averages	4.79 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	4.72 (V)	0.00 (A)

Analysis of Final Results

The initial results from the final testing were discouraging at first glance, as the power generation output was affected at times. The major hindrance of this design is that the sun light can easily be blocked by normal use of the table. However, even with approximately 40% of the panel blocked the system is still able to provide sufficient voltage and current charging needs during the mid-section of the day. The table would only be operational when it is approximately 40% blocked from the hours of 10:30am to 4:00pm. However the addition of a battery bank, will increase the use of the table during the morning and evening hours. The costs and maintenance to battery bank system will be considerable factors to be added to the system. The other option mentioned in the final design feature section, would be to exchange the solar panel for a more efficient model that might be able to provide the more power. There are panels on the market today that offer over 20% efficiency verses the 13% of the current panel. The extra efficiency could be enough to provide the needs without having to go to a battery bank. However the more efficient the panel the more expensive it will be. The more efficient panel would be better than a battery bank in terms of maintenance but might still not provide the extended power needs that a battery bank would.

CHAPTER 6

CONCLUSIONS

The final design of the solar powered picnic table should be able to provide the power needs of students during the peak hours of the day, from approximately 10:00 am to 4:00 pm. The test results support this finding even with the panel being partially blocked from direct sunlight on a clear day. In addition, if the university has needs greater than what was done in this thesis, the design could easily be modified to support a longer time frame for more power. To extend the usable time frame, the system can either be grid tied or have a battery bank added to the system. Both options would allow the system to provide power during the non-peak sunlight hours. Also if a more efficient solar panel was used it could offset some of the challenges faced by the current design. If ETSU would like to pursue building more solar powered picnic tables, the schematics and directions are included in appendix E.

Recommendations for ETSU

ETSU should build several of the solar panel tables. The tables can be installed and tested for a semester followed by a brief survey to receive feedback from students to determine if the tables are meeting the students' needs. Further tests should be done with multiple devices charging at the same time to see if charging is impacted. According to the calculations there should be enough power generated to charge on all 8 ports (Table 1). Another recommendation would be to add the sufficient charging power LED to the circuit. This could be accomplished with a small zeiner diode and a LED bulb or with a more complicated system. The addition of this circuit should not noticeably affect the overall performance of the system but further testing would be needed to insure this. The final recommendation is to test the system with the solar Plexiglas to insure that the system is still able to provide the power needs.

BIBLIOGRAPHY

ConnecTable. (2014) *Products, FAQs, Resources.* Retrieved September 1, 2015, from EnerFusion Inc.: http://www.theconnectable.com/

EnerFusion Inc. (2012) *Portfolio, Products, SolarDok.* Retrieved September 1, 2015, from EnerFusion Inc.: http://www.enerfusioninc.com/index.html

Evonik Industries. (2013, April) *PLEXIGLAS for Solar Applications.* Retrieved September 1, 2015, from Evonik Industries.: http://www.plexiglas.net/product/plexiglas/Documents/Marktsegmente/511-4-Solar-Applications-en.pdf

Fluke. (2005, April). *Fluke 83V and 87V Digital Multimeters.* Retrieved September 1, 2015, from Fluke: http://media.fluke.com/documents/2161164_6116_ENG_B_W.PDF

Giovanni Petrone, G. S. (2011). *Solar Power Conversion.* CRC Presss, 1-19.

Haugan, G. T. (2013). *Sustainable Program Management.* Auerbach Publications, 235-248.

Kyocera. (2013, July 1). *High Efficiency Multi-crystal Photovoltaic Module.* Retrieved September 1, 2015, from Kyocera: http://www.kyocerasolar.com/assets/001/5126.pdf

Monteiro, C. (2012). *Electric Power Systems: Advanced Forecasting Techniques and Optimal Generation Scheduling.* CRC Press, 1-26.

National Electrical Code. (2014). *National Electrical Code.* Retrieved September 1, 2015, from The National Fire Protection Association: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70

Photovoltaic Software. (2014) *How to calculate the annual solar energy output of a photovoltaic system.* Retried September 1, 2015 from Photovoltaic Software: http://photovoltaic-software.com/PV-solar-energy-calculation.php

Robert Foster, M. G. (2009). *Solar Energy: Renewable Energy and the Environment.* CRC Press, 153-229.

Tenma. (2000, October 10). *Tenma Triple Output Power Supply.* Retrieved September 1, 2015, from Farnell: http://www.farnell.com/datasheets/6357.pdf

Tsakalakos, L. (2010). *Nanotechnology for Photovoltaics.* CRC Press, 1-48.

Yogi Goswami, J. F. (2001). *Distributed Generation: The Power Paradigm for the New Millennium.* CRC Press, 173-201.

Zaid Pirwani. (2011, January 5) *Voltage Indicator.* Retrieved October 30, 2015, from http://zaidpirwani.com/267/voltage-indicator/

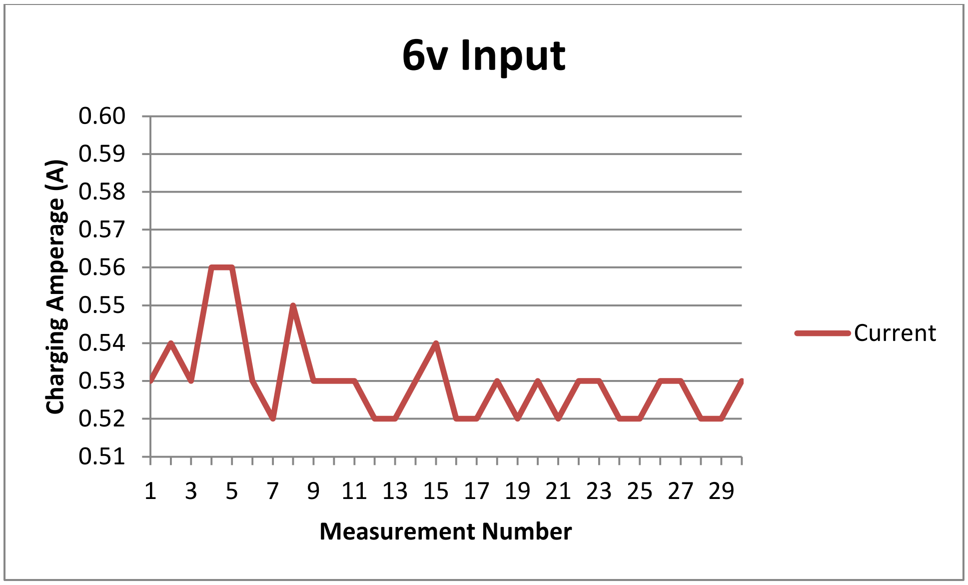
APPENDICES

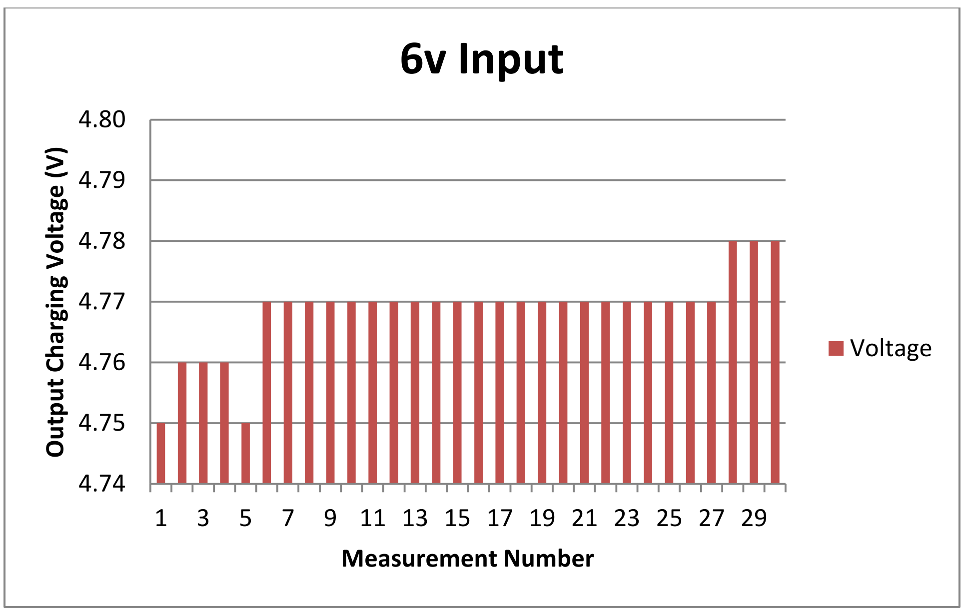
Appendix A: Graphs and Tables from Bench Test

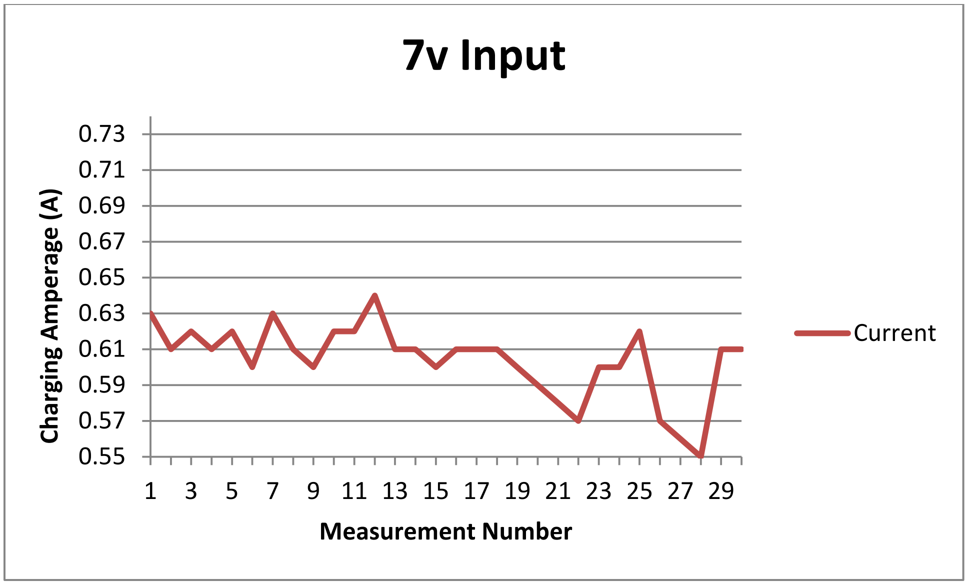
Bench Testing	at room temp									
Input voltage	6V		7V		8V		9V		10V	
No Load voltage	5.10 (V)		5.10 (V)		5.14 (V)		5.14 (V)		5.14 (V)	
Output	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
	4.75 (V)	0.53 (A)	4.96 (V)	0.63 (A)	5.03 (V)	0.63 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.68 (A)
	4.76 (V)	0.54 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.61 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.65 (A)
	4.76 (V)	0.53 (A)	4.97 (V)	0.62 (A)	5.03 (V)	0.62 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.65 (A)
	4.76 (V)	0.56 (A)	4.97 (V)	0.61 (A)	5.04 (V)	0.61 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.66 (A)
	4.75 (V)	0.56 (A)	4.97 (V)	0.62 (A)	5.03 (V)	0.65 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.72 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.66 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.65 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.63 (A)	5.03 (V)	0.70 (A)	5.02 (V)	0.70 (A)	5.03 (V)	0.63 (A)
	4.77 (V)	0.55 (A)	4.97 (V)	0.61 (A)	5.04 (V)	0.67 (A)	5.02 (V)	0.70 (A)	5.03 (V)	0.62 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.66 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.63 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.62 (A)	5.03 (V)	0.62 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.62 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.62 (A)	5.04 (V)	0.62 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.63 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.64 (A)	5.03 (V)	0.64 (A)	5.02 (V)	0.72 (A)	5.02 (V)	0.64 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.61 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.63 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.65 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.62 (A)
	4.77 (V)	0.54 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.67 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.62 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.68 (A)	5.03 (V)	0.67 (A)	5.03 (V)	0.66 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.61 (A)	5.04 (V)	0.64 (A)	5.03 (V)	0.67 (A)	5.03 (V)	0.66 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.66 (A)	5.03 (V)	0.67 (A)	5.03 (V)	0.65 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.60 (A)	5.04 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.03 (V)	0.62 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.59 (A)	5.04 (V)	0.67 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.63 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.58 (A)	5.04 (V)	0.66 (A)	5.02 (V)	0.66 (A)	5.04 (V)	0.66 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.57 (A)	5.03 (V)	0.65 (A)	5.03 (V)	0.67 (A)	5.04 (V)	0.65 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.66 (A)	5.03 (V)	0.66 (A)	5.04 (V)	0.64 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.65 (A)	5.03 (V)	0.67 (A)	5.03 (V)	0.70 (A)
	4.77 (V)	0.52 (A)	4.97 (V)	0.62 (A)	5.04 (V)	0.69 (A)	5.03 (V)	0.67 (A)	5.03 (V)	0.65 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.57 (A)	5.03 (V)	0.64 (A)	5.03 (V)	0.68 (A)	5.03 (V)	0.67 (A)
	4.77 (V)	0.53 (A)	4.97 (V)	0.56 (A)	5.03 (V)	0.64 (A)	5.03 (V)	0.70 (A)	5.03 (V)	0.65 (A)
	4.78 (V)	0.52 (A)	4.97 (V)	0.55 (A)	5.03 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.03 (V)	0.66 (A)
	4.78 (V)	0.52 (A)	4.97 (V)	0.61 (A)	5.03 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.03 (V)	0.65 (A)
	4.78 (V)	0.53 (A)	4.97 (V)	0.61 (A)	5.04 (V)	0.64 (A)	5.02 (V)	0.67 (A)	5.03 (V)	0.65 (A)
Averages	4.77 (V)	0.53 (A)	4.97 (V)	0.60 (A)	5.03 (V)	0.65 (A)	5.02 (V)	0.68 (A)	5.03 (V)	0.65 (A)

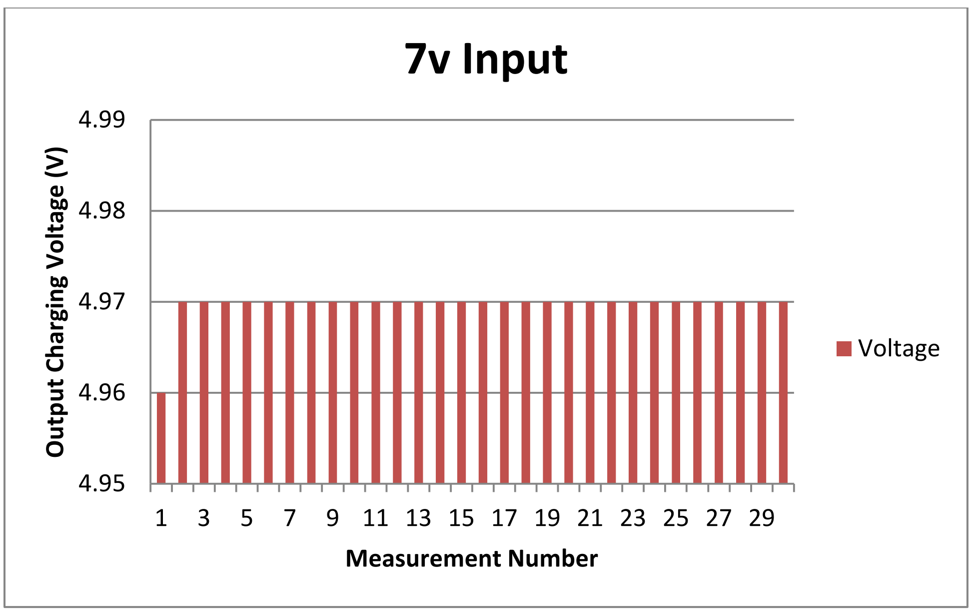
16V		17V		18V		19V		20V	
	5.14 (V)		5.14 (V)		5.14 (V)		5.14 (V)		5.15 (V)
Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.71 (A)	5.00 (V)	0.70 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.00 (V)	0.70 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.70 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.00 (V)	0.69 (A)
5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.74 (A)	5.01 (V)	0.70 (A)
5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.72 (A)	5.01 (V)	0.71 (A)
5.01 (V)	0.71 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.73 (A)	5.01 (V)	0.70 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.01 (V)	0.70 (A)	5.01 (V)	0.71 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.71 (A)
5.02 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.69 (A)	5.01 (V)	0.67 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.01 (V)	0.73 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.69 (A)	5.00 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.01 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)	5.02 (V)	0.69 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)
5.01 (V)	0.72 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.01 (V)	0.71 (A)	5.01 (V)	0.71 (A)	5.02 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)
5.03 (V)	0.62 (A)	5.01 (V)	0.73 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.73 (A)
5.03 (V)	0.62 (A)	5.01 (V)	0.72 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)
5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.68 (A)
5.01 (V)	0.68 (A)	5.01 (V)	0.71 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.67 (A)
5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)	5.00 (V)	0.69 (A)
5.01 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.68 (A)
5.01 (V)	0.71 (A)	5.01 (V)	0.71 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.68 (A)
5.01 (V)	0.70 (A)	5.01 (V)	0.73 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.69 (A)	5.01 (V)	0.69 (A)
5.01 (V)	0.72 (A)	5.01 (V)	0.72 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.70 (A)
5.01 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.69 (A)

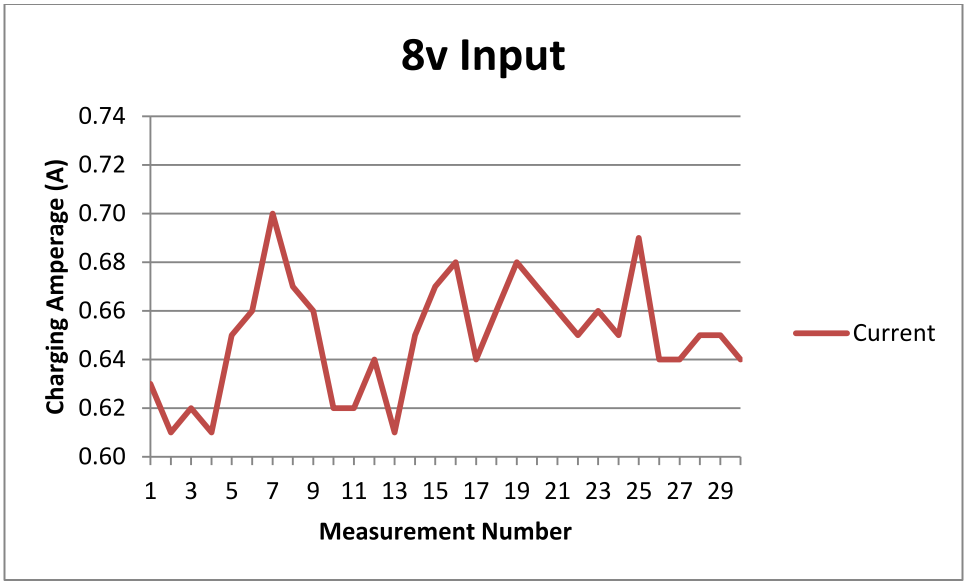
11V		12V		13V		14V		15V	
	5.14 (V)		5.14 (V)		5.14 (V)		5.14 (V)		5.14 (V)
Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
5.01 (V)	0.74 (A)	5.02 (V)	0.69 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.70 (A)	5.01 (V)	0.71 (A)
5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.69 (A)	5.01 (V)	0.71 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.72 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.72 (A)	5.01 (V)	0.70 (A)
5.02 (V)	0.72 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.72 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.69 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.69 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.72 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.70 (A)	5.01 (V)	0.68 (A)
5.03 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)
5.03 (V)	0.67 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.70 (A)	5.01 (V)	0.69 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.72 (A)	5.01 (V)	0.68 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.73 (A)	5.02 (V)	0.70 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.69 (A)
5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.69 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.69 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.74 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.71 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.66 (A)
5.03 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.67 (A)
5.03 (V)	0.70 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.65 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.67 (A)	5.01 (V)	0.72 (A)	5.02 (V)	0.65 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.66 (A)	5.01 (V)	0.70 (A)	5.02 (V)	0.65 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.65 (A)	5.02 (V)	0.66 (A)	5.01 (V)	0.69 (A)	5.02 (V)	0.68 (A)
5.02 (V)	0.66 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.72 (A)	5.01 (V)	0.68 (A)	5.02 (V)	0.70 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.01 (V)	0.69 (A)	5.02 (V)	0.69 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.65 (A)
5.02 (V)	0.65 (A)	5.02 (V)	0.67 (A)	5.02 (V)	0.66 (A)	5.02 (V)	0.69 (A)	5.02 (V)	0.65 (A)
5.03 (V)	0.65 (A)	5.02 (V)	0.73 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.66 (A)
5.02 (V)	0.67 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.68 (A)	5.02 (V)	0.70 (A)	5.02 (V)	0.68 (A)

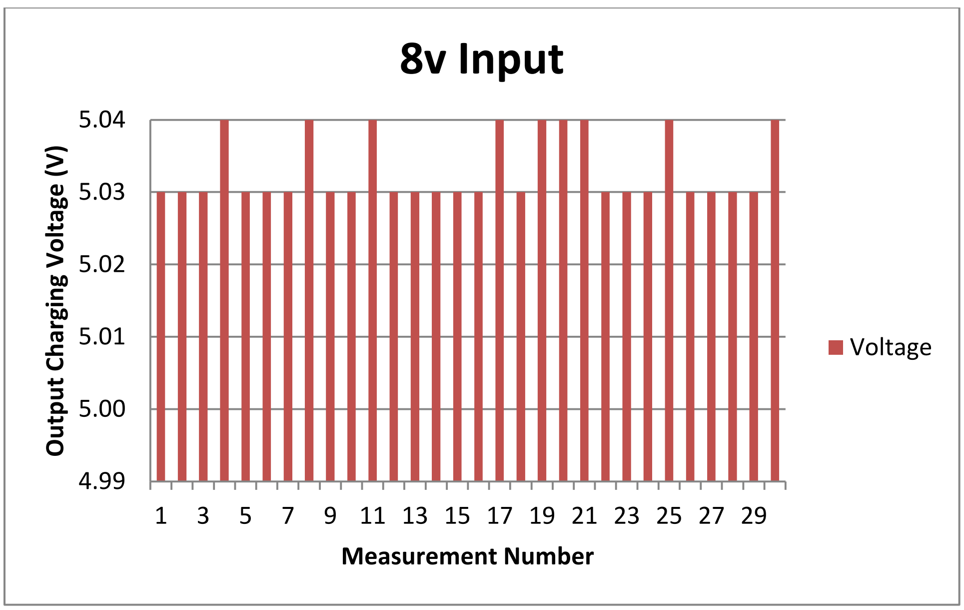

6v Input
Charging Amperage (A)
0.60
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

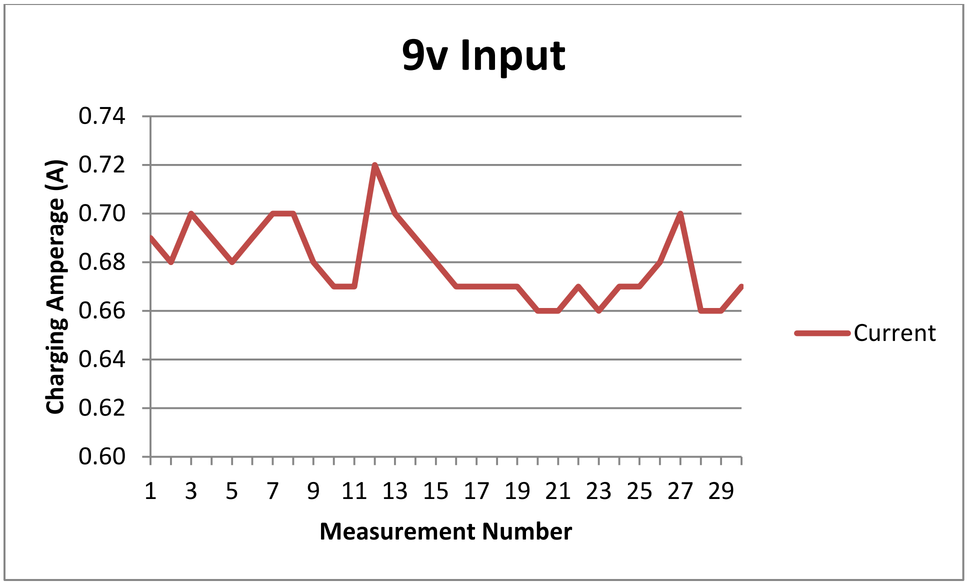

6v Input
Output Charging Voltage (V)
4.80
4.79
4.78
4.77
4.76
4.75
4.74
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

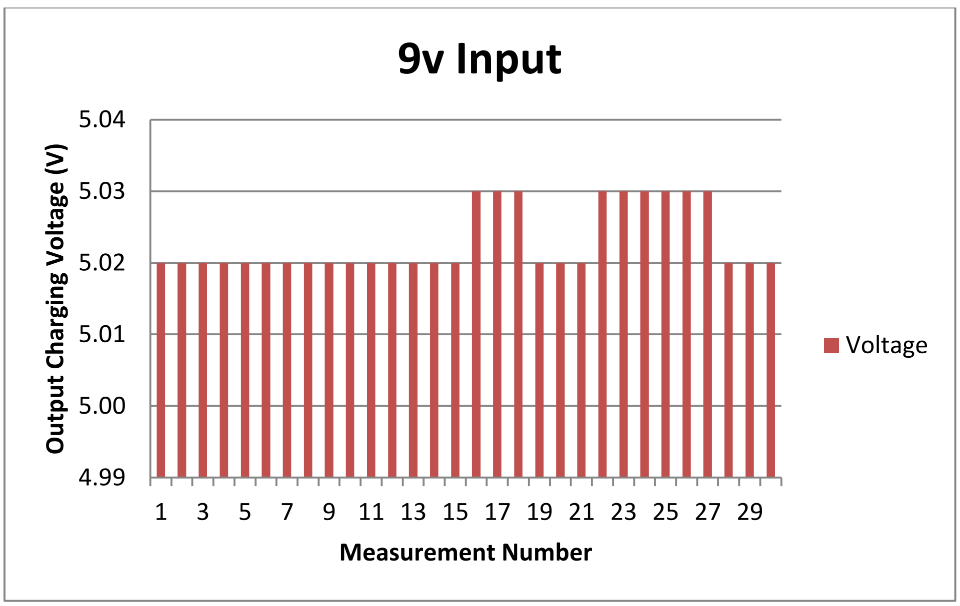

7v Input
Charging Amperage (A)
0.73
0.71
0.69
0.67
0.65
0.63
0.61
0.59
0.57
0.55
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

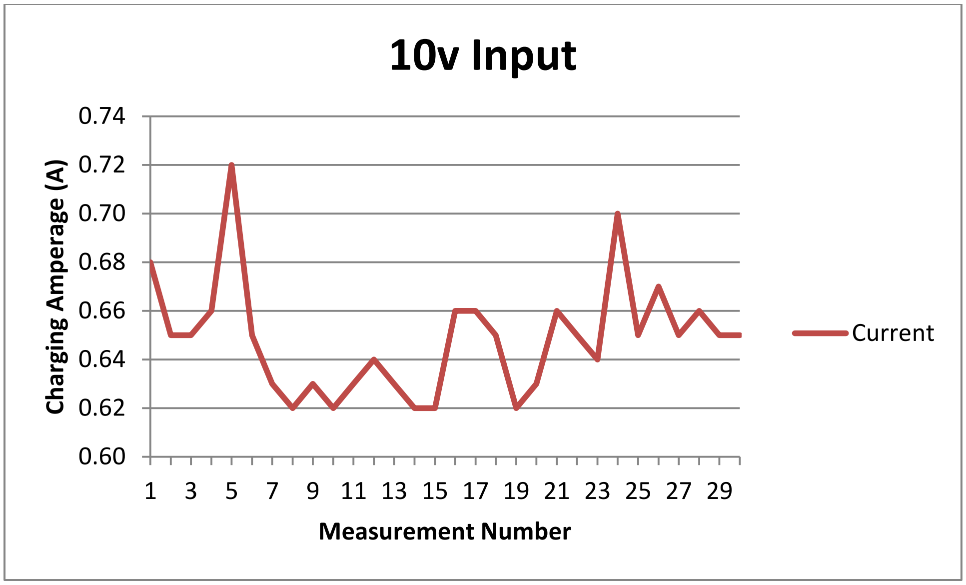

7v Input
Output Charging Voltage (V)
4.99
4.98
4.97
4.96
4.95
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

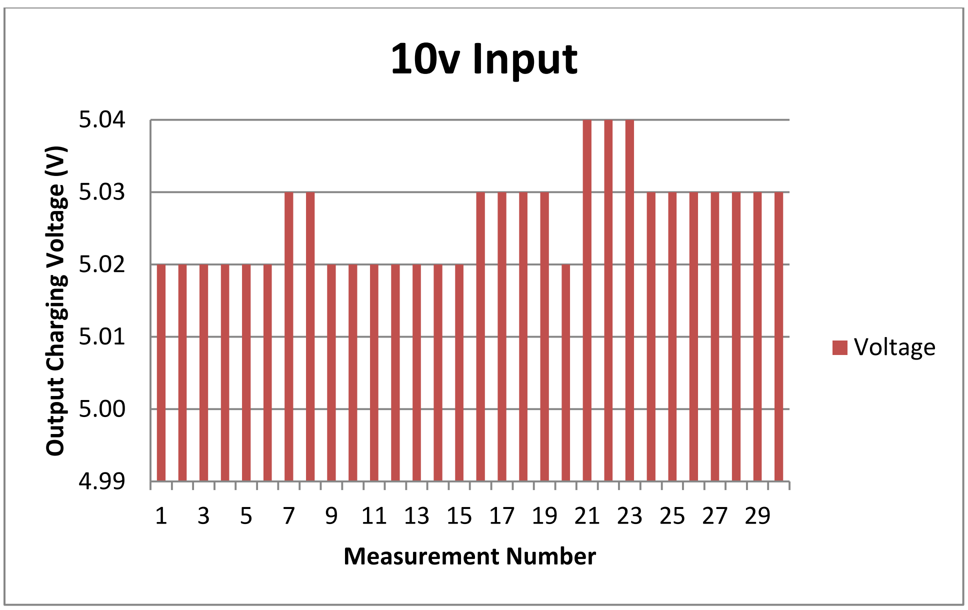

8v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

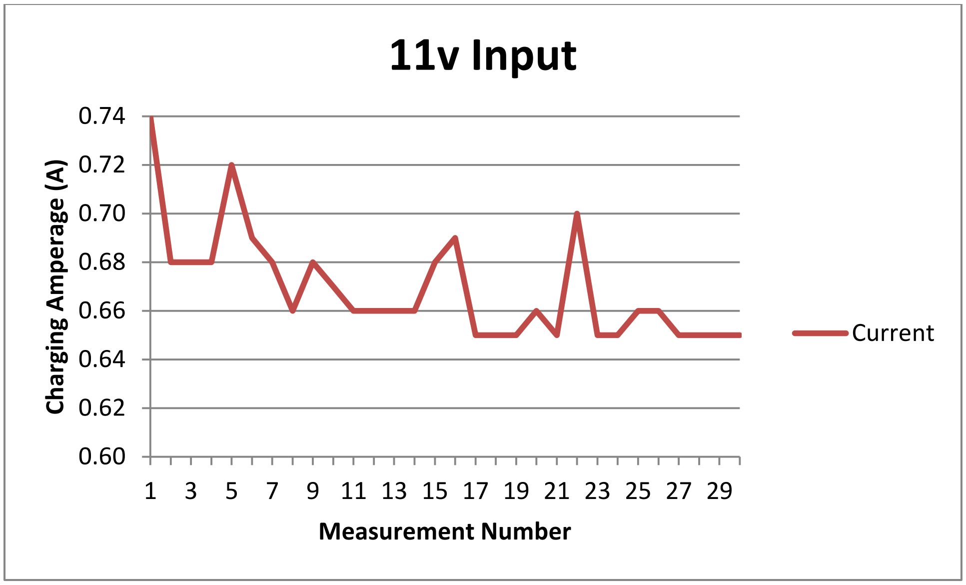

8v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

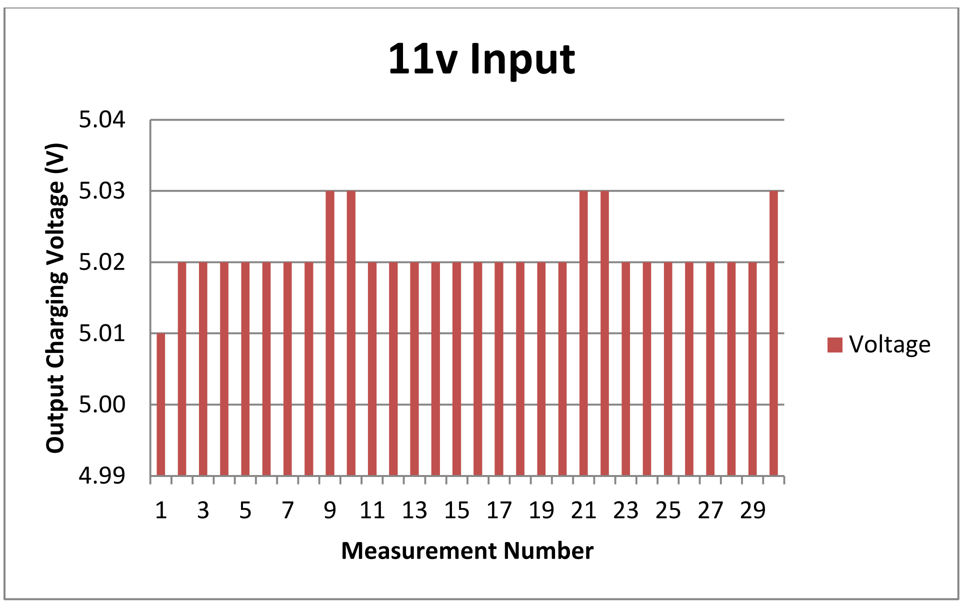

9v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

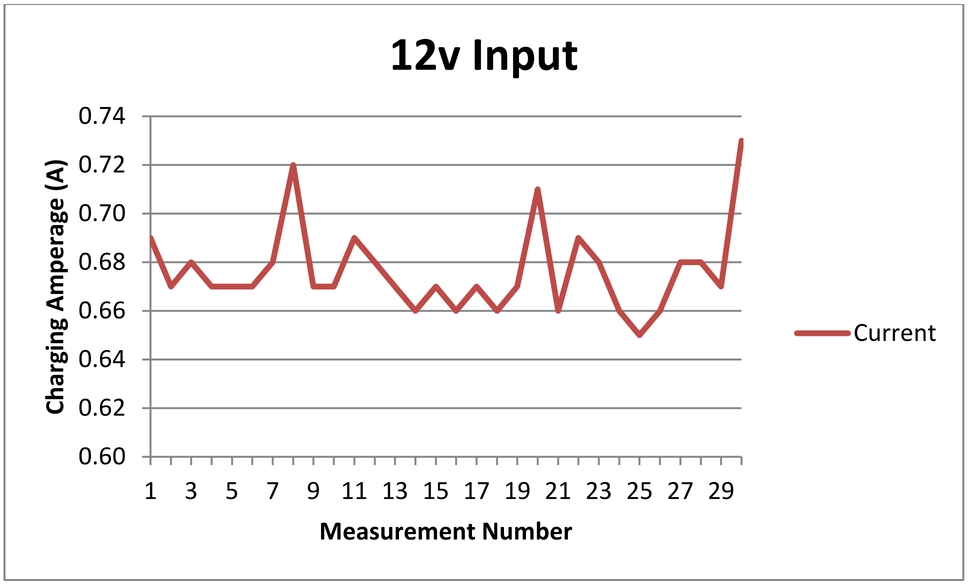

9v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

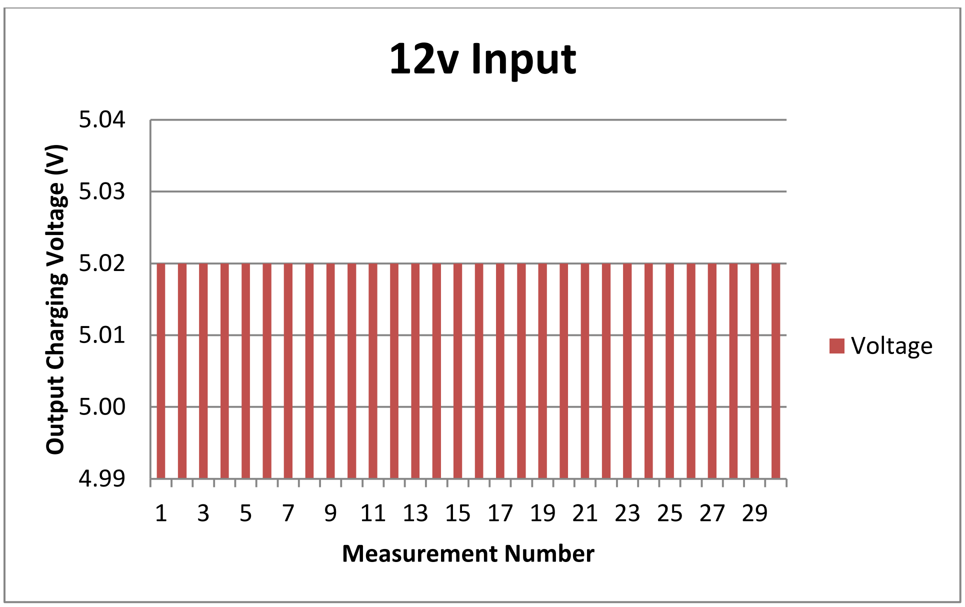

10v Input
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
Charging Amperage (A)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

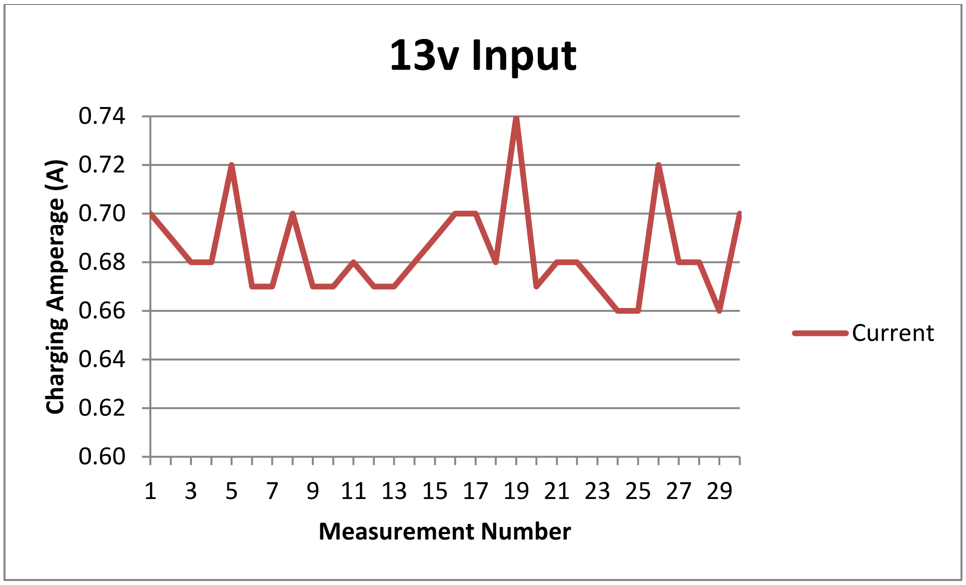

10v Input
5.04
5.03
5.02
5.01
5.00
4.99
Output Charging Voltage (V)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

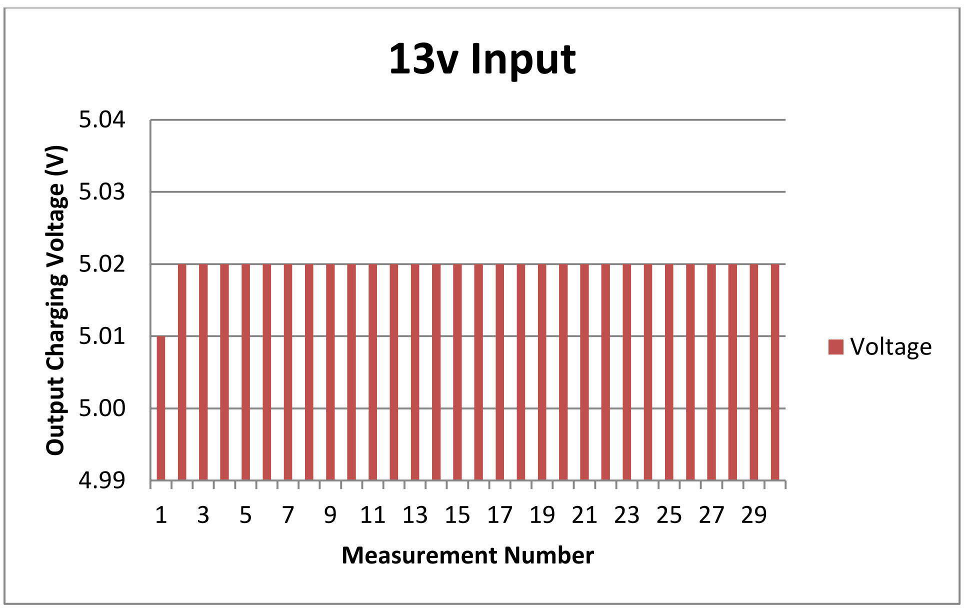

11v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

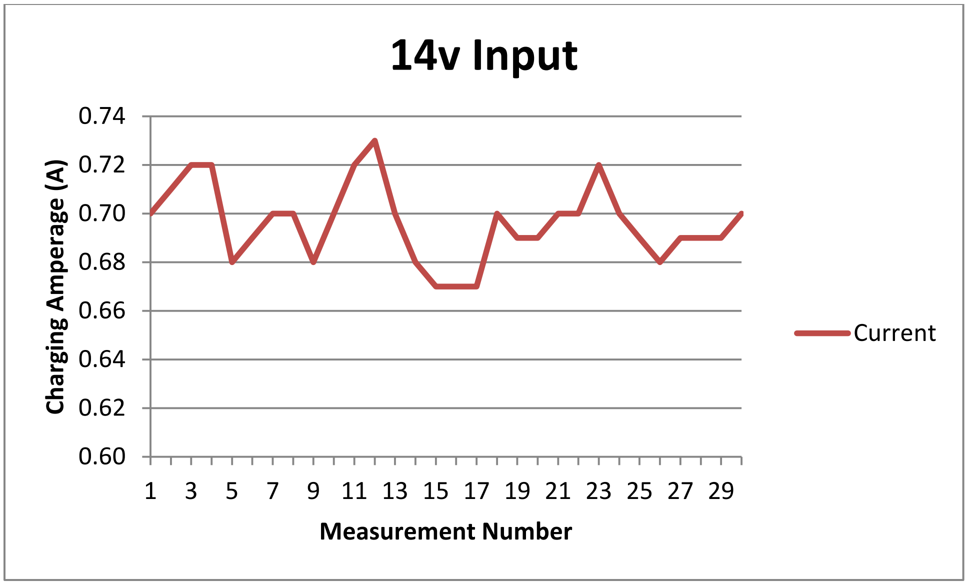

11v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

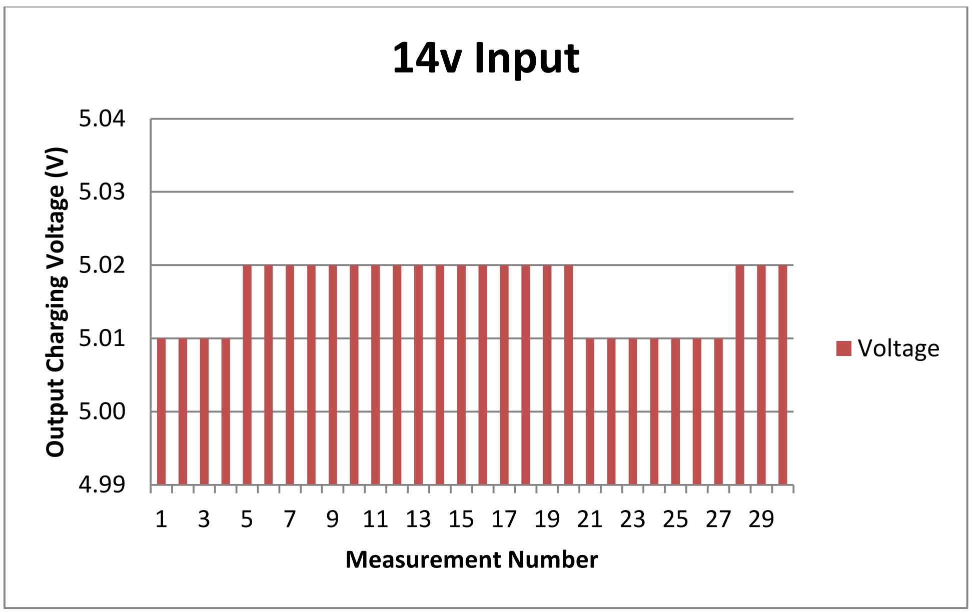

12v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

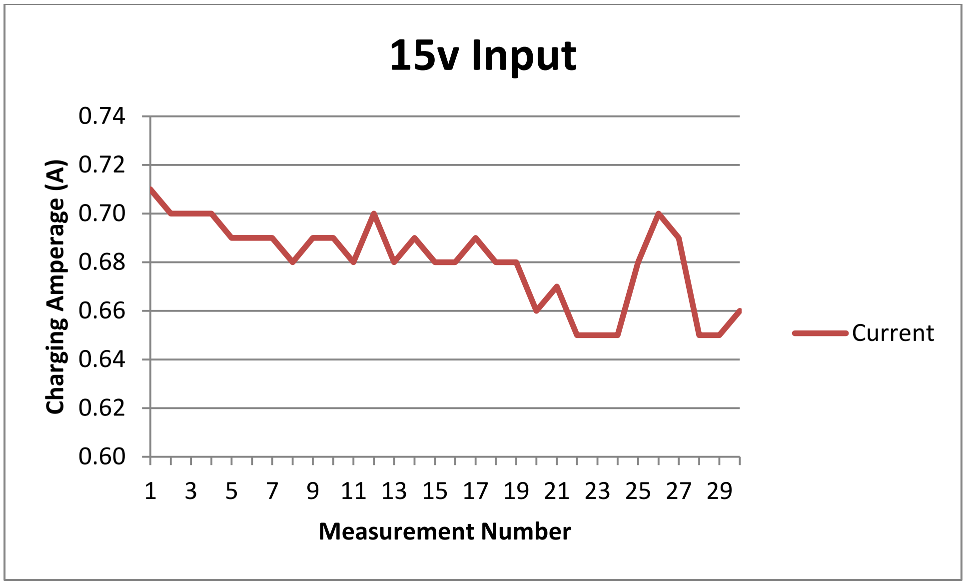

12v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

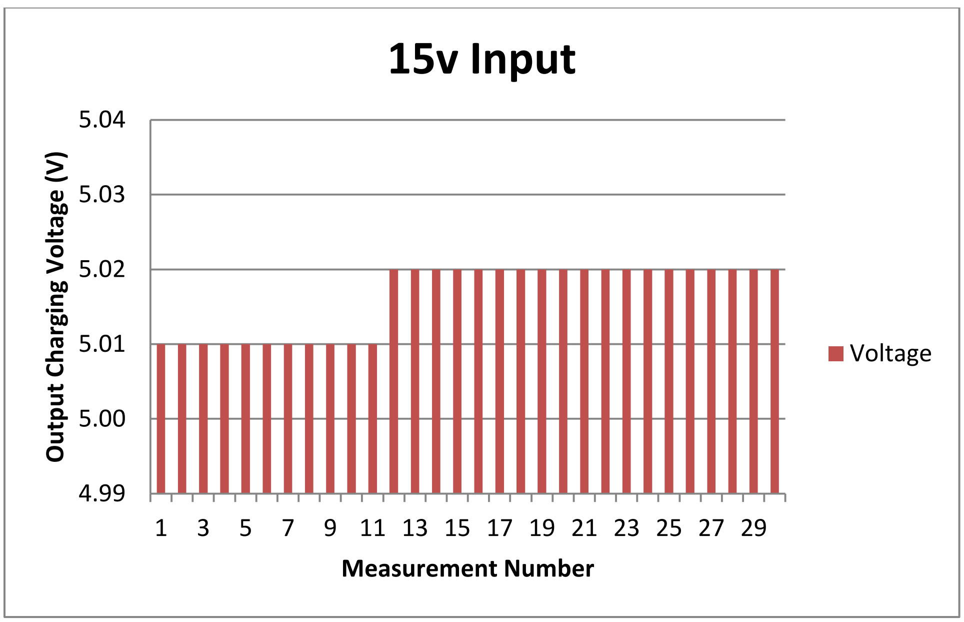

13v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

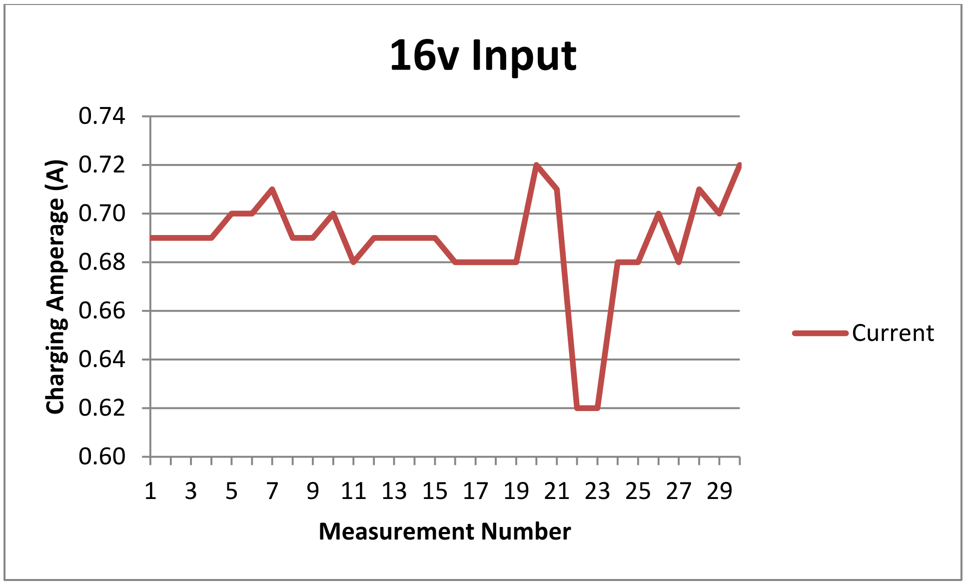

13v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

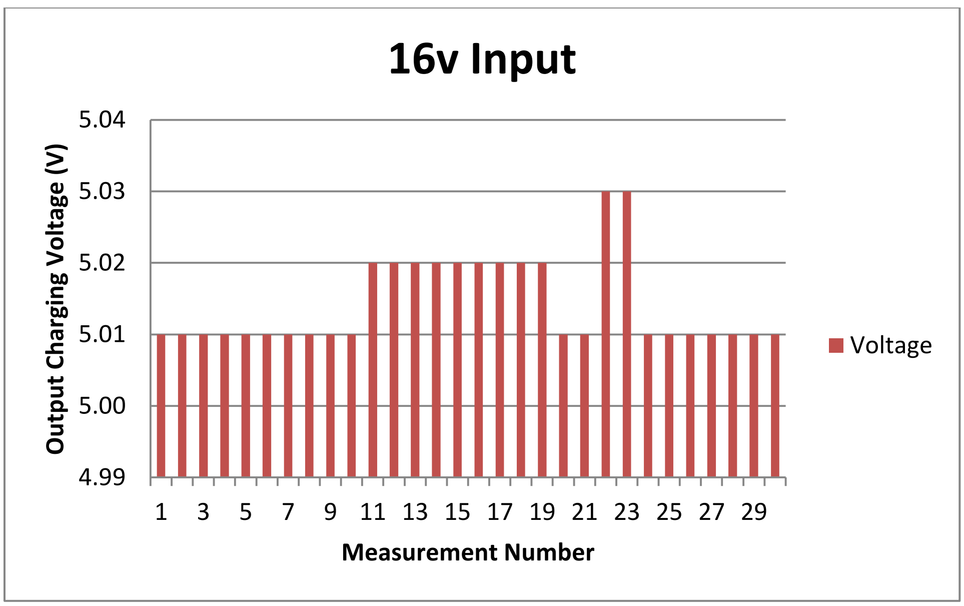

14v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

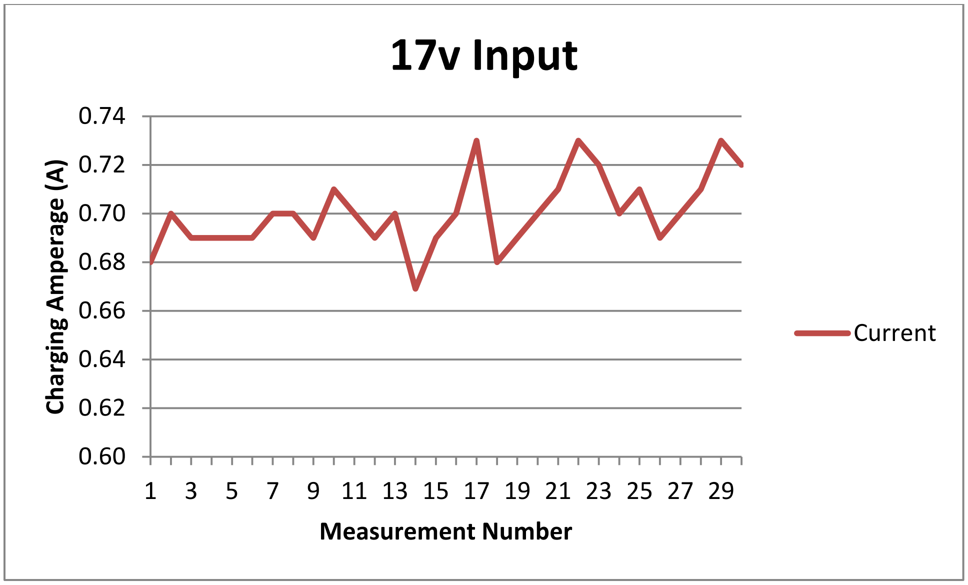

14v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

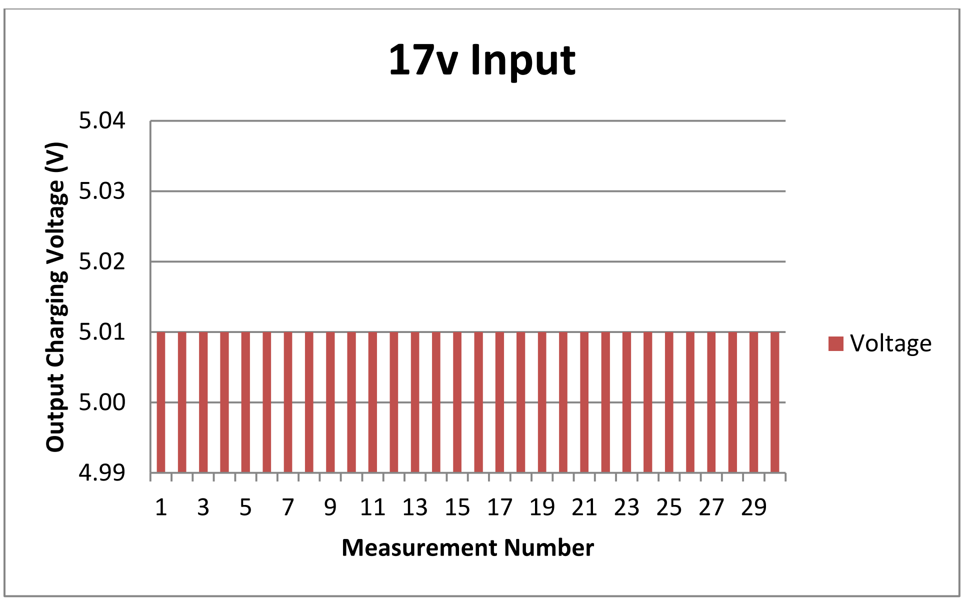

15v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

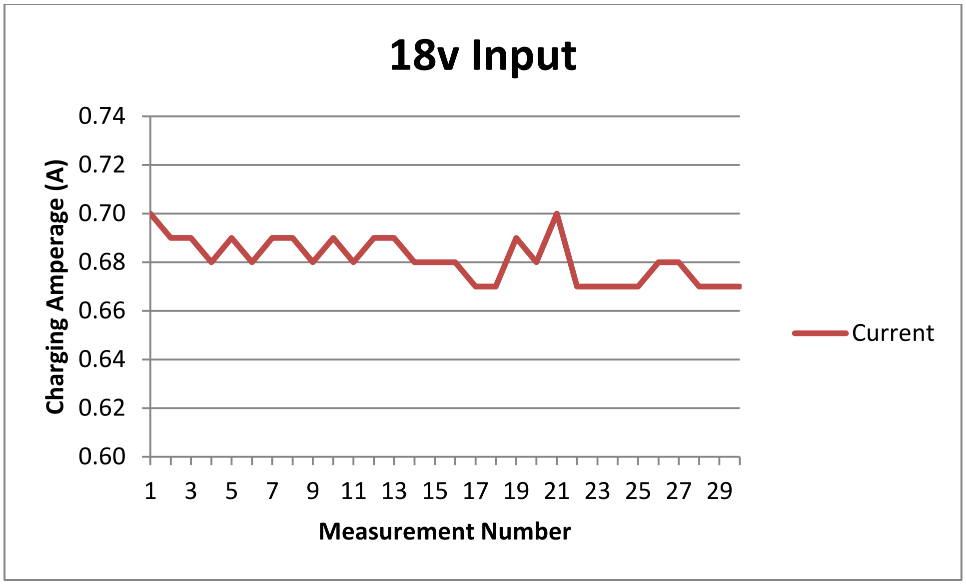

15v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

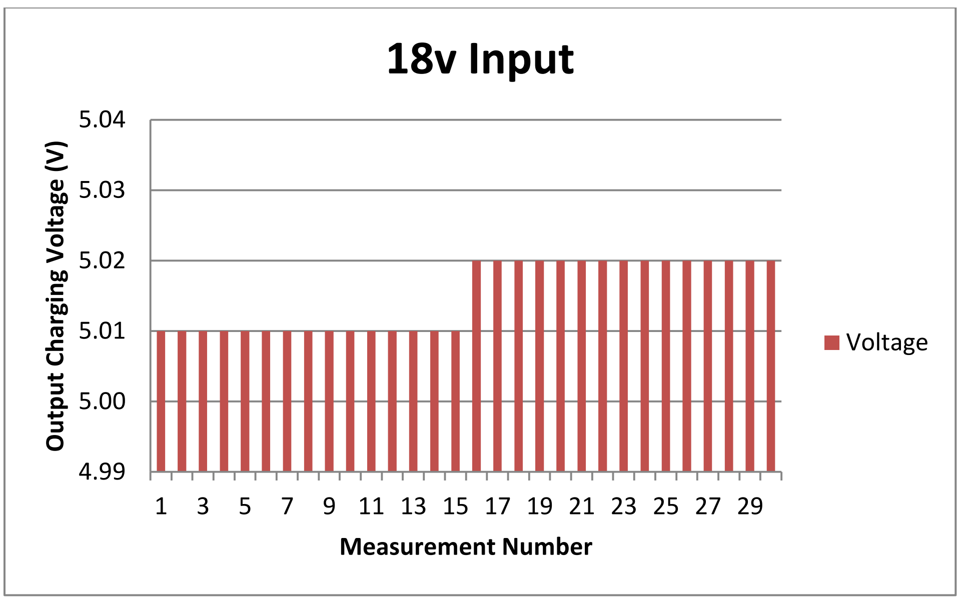

16v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

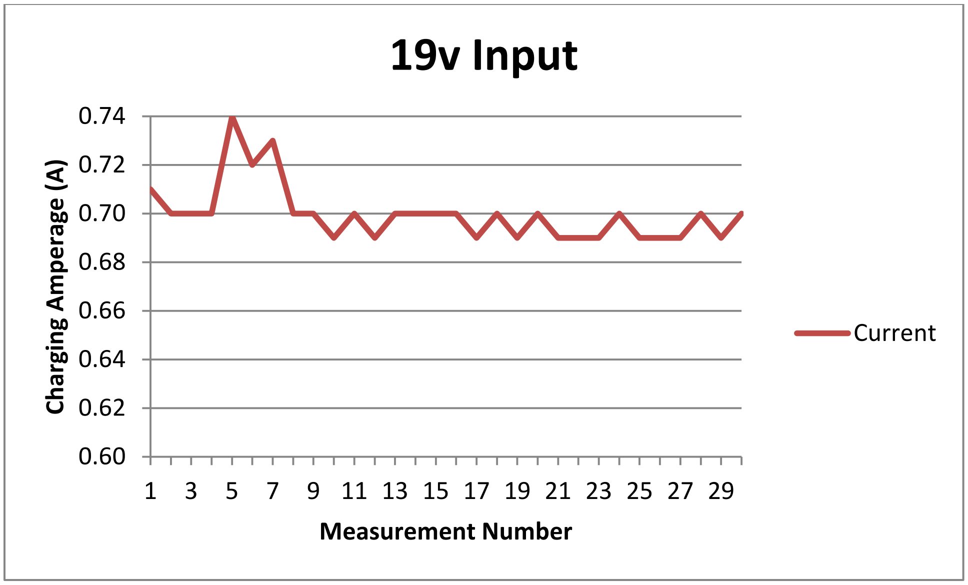

16v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

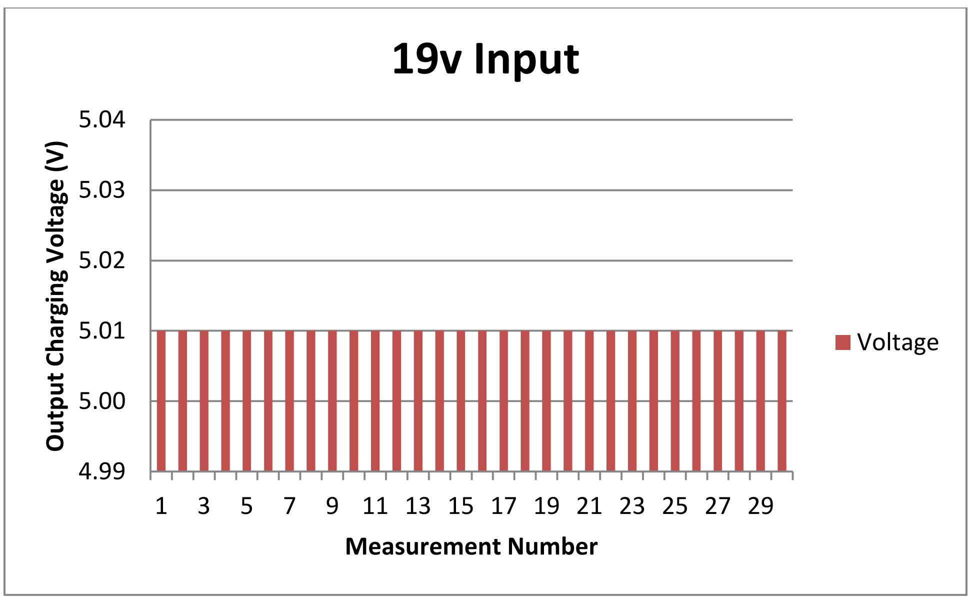

17v Input
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
Charging Amperage (A)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

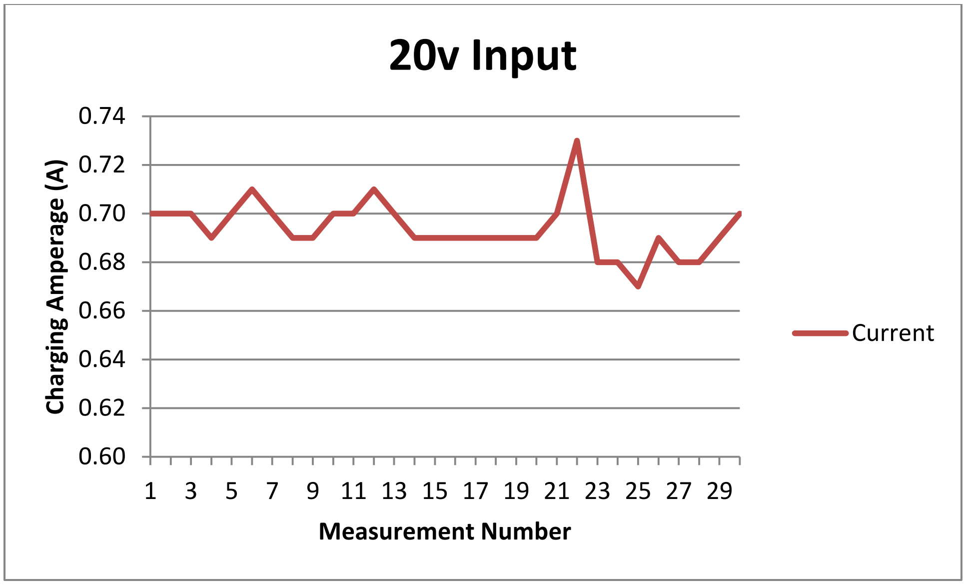

17v Input
5.04
5.03
5.02
5.01
5.00
4.99
Output Charging Voltage (V)
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

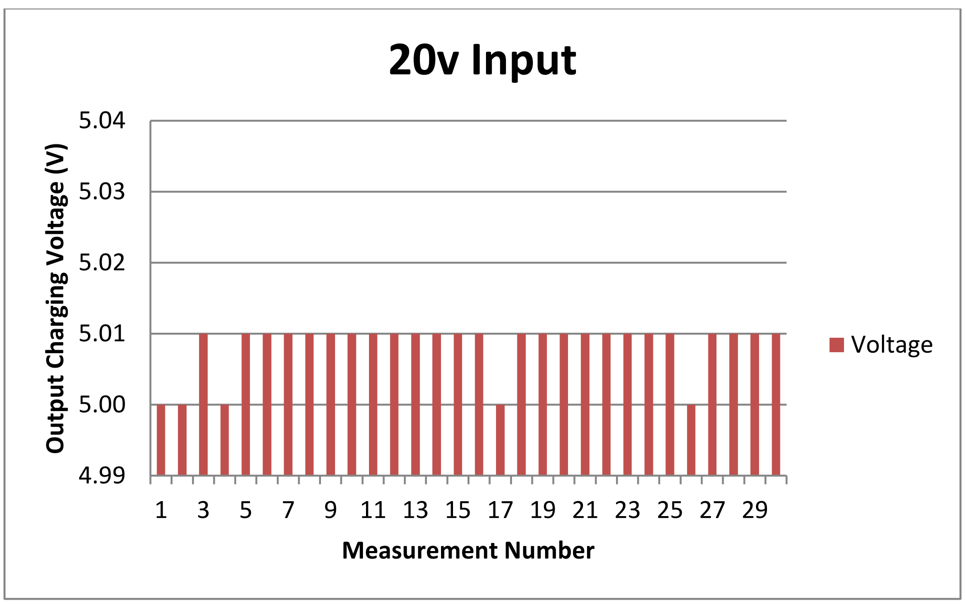

18v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current


18v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage


19v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current

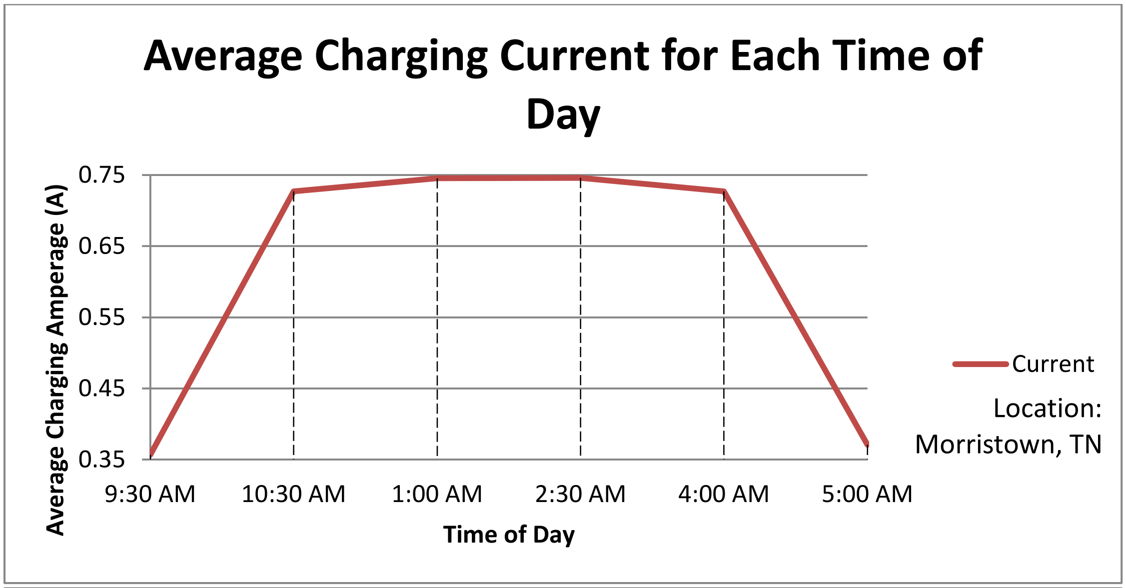

19v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

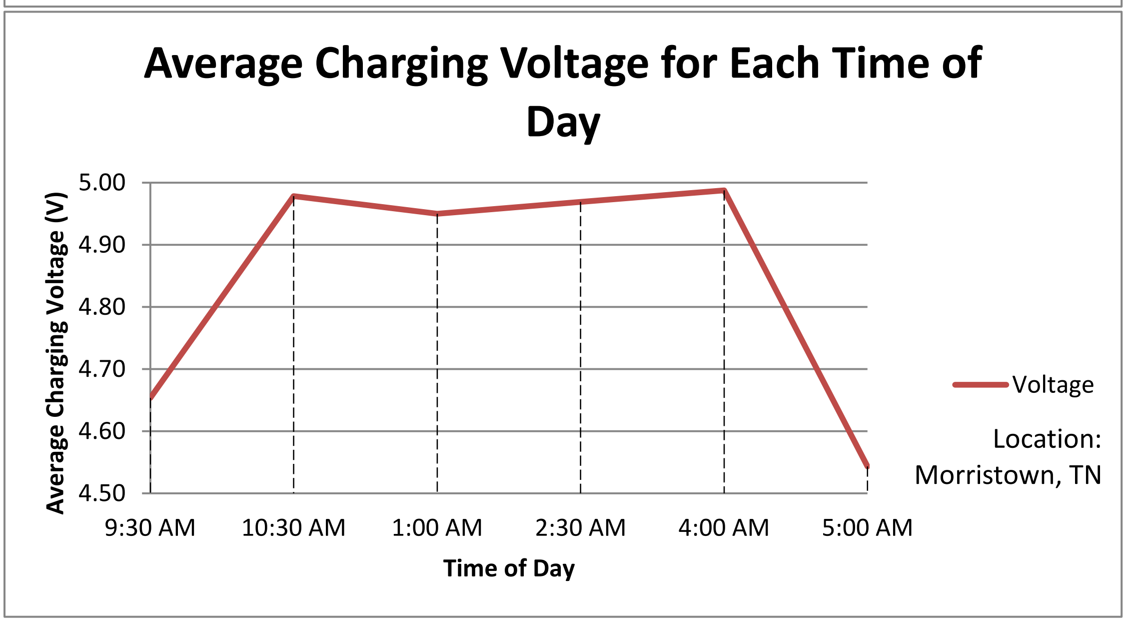

20v Input
Charging Amperage (A)
0.74
0.72
0.70
0.68
0.66
0.64
0.62
0.60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Current


20v Input
Output Charging Voltage (V)
5.04
5.03
5.02
5.01
5.00
4.99
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Measurement Number
Voltage

Appendix B: Graphs and Tables From Modified Test

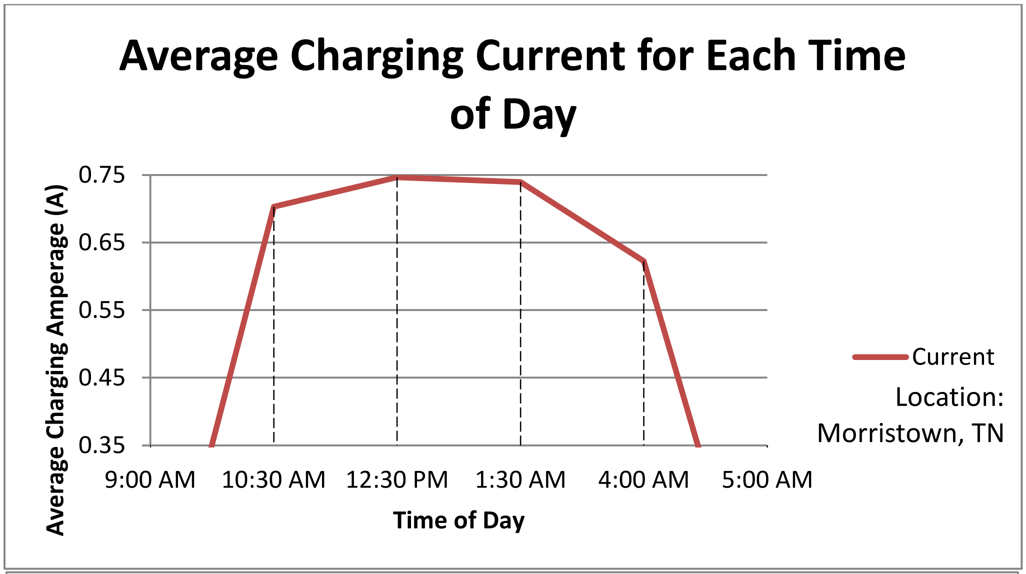
real life test												
Number of devices	1		1		1		1		1		1	
Time frame	8-noon				noon-4pm				4-7pm			
Time of reading	9:30am		10:30am		1pm		2:30pm		4:00pm		5:00pm	
Location	Morristown, Tennessee											
Solar Voltage no load	7.55 (V)		18.42 (V)		20.97 (V)		20.93 (V)		18.63 (V)		7.65 (V)	
Ouput No Load voltage	5.12 (V)		5.13 (V)		5.10 (V)		5.10 (V)		5.15 (V)		5.14 (V)	
Temperature	53° F		55° F		73° F		75° F		74° F		70° F	
Solar Voltage with load	5.58 (V)		15.67 (V)		20.28 (V)		20.27 (V)		16.71 (V)		5.7 (V)	
Output	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
	4.67 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.39 (A)
	4.67 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.39 (A)
	4.68 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.74 (A)	4.55 (V)	0.38 (A)
	4.68 (V)	0.35 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.37 (A)
	4.67 (V)	0.35 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.55 (V)	0.37 (A)
	4.69 (V)	0.35 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.70 (A)	4.55 (V)	0.36 (A)
	4.67 (V)	0.34 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.73 (A)	4.55 (V)	0.38 (A)
	4.66 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.73 (A)	4.55 (V)	0.39 (A)
	4.66 (V)	0.35 (A)	4.98 (V)	0.70 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.55 (V)	0.38 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.71 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.55 (V)	0.38 (A)
	4.65 (V)	0.35 (A)	4.98 (V)	0.72 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.75 (A)	4.55 (V)	0.38 (A)
	4.67 (V)	0.34 (A)	4.97 (V)	0.72 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.71 (A)	4.55 (V)	0.37 (A)
	4.67 (V)	0.36 (A)	4.96 (V)	0.72 (A)	4.95 (V)	0.76 (A)	4.96 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.37 (A)
	4.68 (V)	0.36 (A)	4.97 (V)	0.71 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.69 (V)	0.35 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.38 (A)
	4.68 (V)	0.34 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.38 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.54 (V)	0.38 (A)
	4.63 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.72 (A)	4.97 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.54 (V)	0.37 (A)
	4.63 (V)	0.37 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.53 (V)	0.36 (A)
	4.65 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.76 (A)	4.96 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.53 (V)	0.36 (A)
	4.62 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.98 (V)	0.75 (A)	4.54 (V)	0.36 (A)
	4.62 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.37 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
	4.64 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.61 (V)	0.37 (A)	4.98 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.71 (A)	4.54 (V)	0.37 (A)
	4.61 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.96 (V)	0.76 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.37 (A)
	4.70 (V)	0.36 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.70 (A)	4.54 (V)	0.36 (A)
	4.63 (V)	0.38 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.71 (A)	4.54 (V)	0.36 (A)
	4.61 (V)	0.38 (A)	4.98 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.97 (V)	0.74 (A)	4.99 (V)	0.72 (A)	4.54 (V)	0.36 (A)
Averages	4.65 (V)	0.36 (A)	4.98 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.97 (V)	0.75 (A)	4.99 (V)	0.73 (A)	4.54 (V)	0.37 (A)

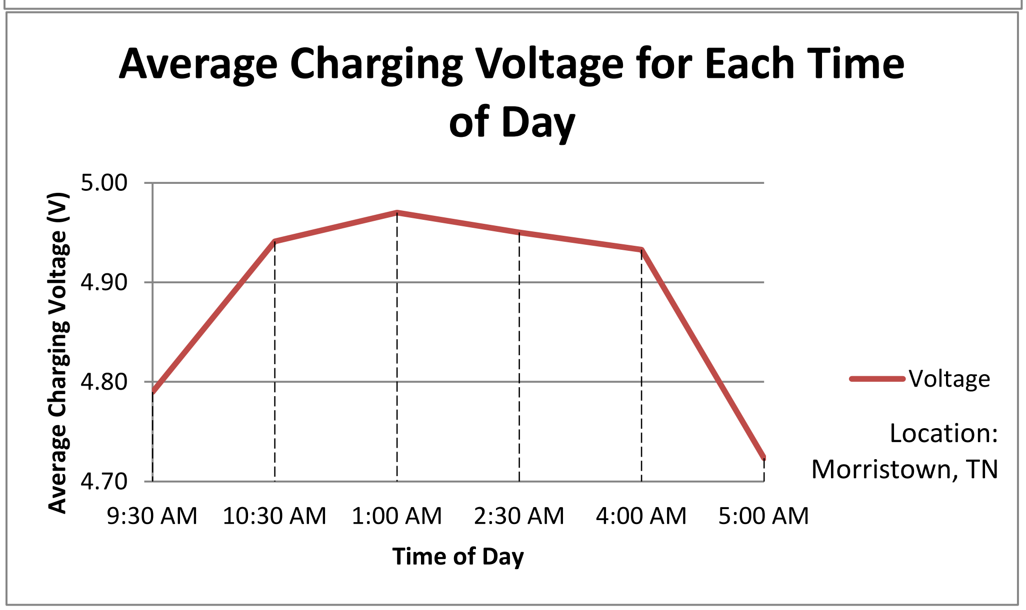

Average Charging Current for Each Time of Day
0.75
0.65
0.55
0.45
0.35
Average Charging Amperage (A)
9:30 AM
10:30 AM
1:00 AM
2:30 AM
4:00 AM
5:00 AM
Time of Day
Current
Location:
Morristown, TN


Average Charging Voltage for Each Time of Day
5.00
4.90
4.80
4.70
4.60
4.50
Average Charging Voltage (V)
9:30 AM
10:30 AM
1:00 AM
2:30 AM
4:00 AM
5:00 AM
Time of Day
Voltage
Location:
Morristown, TN

Appendix C: Graphs and Tables From Final Test

real life test												
Number of devices	1		1		1		1		1		1	
Percent Block	~40%		~40%		~40%		~40%		~40%		~40%	
Time Frame	8-noon				noon-4pm				4-7pm			
Time of reading	9:00am		10:30am		12:30pm		1:30pm		4:00pm		5:00pm	
Solar Voltage no load	8.45 (V)		15.45 (V)		16.25 (V)		15.98 (V)		14.26 (V)		7.56 (V)	
Output No Load voltage	5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)		5.10 (V)	
Temperature	56° F		65° F		73° F		73° F		69° F		67° F	
Location	Morristown, Tennessee											
Solar Voltage with load	6.12 (V)		7.98 (V)		8.99 (V)		8.23 (V)		7.23 (V)		5.76 (V)	
Output	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current	Voltage	Current
	4.80 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.66 (A)	4.79 (V)	0.00 (A)
	4.79 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.65 (A)	4.80 (V)	0.00 (A)
	4.78 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.94 (V)	0.64 (A)	4.56 (V)	0.00 (A)
	4.78 (V)	0.00 (A)	4.93 (V)	0.74 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.65 (A)	4.75 (V)	0.00 (A)
	4.79 (V)	0.00 (A)	4.93 (V)	0.72 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.65 (A)	4.65 (V)	0.00 (A)
	4.80 (V)	0.00 (A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.69 (A)	4.79 (V)	0.00 (A)
	(V)	(A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.64 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.64 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.70 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.71 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.93 (V)	0.71 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.76 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.95 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.73 (A)	4.95 (V)	0.75 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.74 (A)	4.94 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.71 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.69 (A)	4.97 (V)	0.73 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.94 (V)	0.68 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.68 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.69 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.70 (A)	4.97 (V)	0.76 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.71 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.73 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.72 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.76 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.72 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.75 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
	(V)	(A)	4.95 (V)	0.73 (A)	4.97 (V)	0.74 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.60 (A)	(V)	(A)
Averages	4.79 (V)	0.00 (A)	4.94 (V)	0.70 (A)	4.97 (V)	0.75 (A)	4.95 (V)	0.74 (A)	4.93 (V)	0.62 (A)	4.72 (V)	0.00 (A)


Average Charging Current for Each Time of Day
0.75
0.65
0.55
0.45
0.35
Average Charging Amperage (A)
9:00 AM
10:30 AM
12:30 PM
1:30 AM
4:00 AM
5:00 AM
Time of Day
Current
Location:
Morristown, TN


Average Charging Voltage for Each Time of Day
5.00
4.90
4.80
4.70
Average Charging Voltage (V)
9:30 AM
10:30 AM
1:00 AM
2:30 AM
4:00 AM
5:00 AM
Time of Day
Voltage
Location:
Morristown, TN

Appendix D: Kyocrea KD135GX-LPU

HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

KYOCERA

KD 135 P Series

KD135GX-LPU KD140GX-LPU

CUTTING EDGE TECHNOLOGY

As a pioneer with over 35 years in the solar energy industry, Kyocera demonstrates leadership in the development of solar energy products. Kyocera's *Kaizen* Philosophy, commitment to continuous improvement, is shown by repeatedly achieving world record cell efficiencies.

QUALITY BUILT IN

- UV stabilized, aesthetically pleasing black anodized frame
- Supported by major mounting structure manufacturers
- Easily accessible grounding points on all four corners for fast installation
- Proven junction box technology with 12 AWG PV wire to work with transformerless inverters
- Quality locking MC4 plug-in connectors to provide safe and quick connections

RELIABLE

- Proven superior field performance
- Tight power tolerance
- Only module manufacturer to pass rigorous long-term testing performed by TÜV Rheinland

QUALIFICATIONS AND CERTIFICATIONS

UL Listing
QIGU.E173074

NEC 2008 Compliant, UL 1703, ISO 9001, and ISO 14001
UL1703 Certified and Registered, UL Fire Safety Class C, CEC, FSEC
Certified IEC61215 Ed 2 IEC61730 by JET

SOLAR by KYOCERA

ELECTRICAL SPECIFICATIONS

Standard Test Conditions (STC) *STC = 1000 W/m² irradiance, 25°C module temperature, AM 1.5 spectrum**			
	KD135GX-LPU	KD140GX-LPU	
P_{mp}	135	140	W
V_{mp}	17.7	17.7	V
I_{mp}	7.63	7.91	A
V_{oc}	22.1	22.1	V
I_{sc}	8.37	8.68	A
$P_{tolerance}$	+5/-5	+5/-5	%
Nominal Operating Cell Temperature Conditions (NOCT) *NOCT = 800 W/m² irradiance, 20°C ambient temperature, AM 1.5 spectrum**			
T_{NOCT}	45	45	°C
P_{max}	97	101	W
V_{mp}	16.0	16.0	V
I_{mp}	6.10	6.33	A
V_{oc}	20.2	20.2	V
I_{sc}	6.78	7.03	A
PTC	122.2	Pending	W
Temperature Coefficients			
P_{max}	-0.45	-0.45	%/°C
V_{mp}	-0.52	-0.52	%/°C
I_{mp}	0.0066	0.0066	%/°C
V_{oc}	-0.36	-0.36	%/°C
I_{sc}	0.060	0.060	%/°C
Operating Temp	-40 to +90	-40 to +90	°C
System Design			
Series Fuse Rating			15 A
Maximum DC System Voltage (UL)			600 V
Hailstone Impact			1in (25mm) @ 51mph (23m/s)

* Subject to simulator measurement uncertainty of +/- 3%.
KYOCERA reserves the right to modify these specifications without notice.

NEC 2008 COMPLIANT
UL 1703 LISTED
CERTIFIED IEC61215 ED2 IEC61730 BY JET

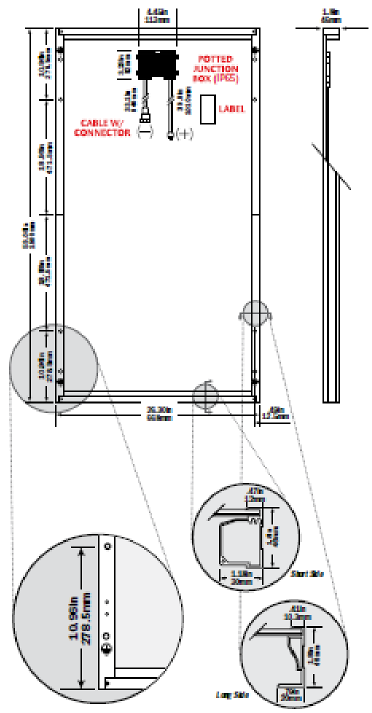
WARNING: Read the instruction manual in its entirety prior to handling, installing & operating Kyocera Solar modules.

MODULE CHARACTERISTICS

Dimensions: *length/width/height*	59.06in/26.30in/1.8in (1500mm/668mm/46mm)
Weight:	27.6lbs (12.5kg)

PACKAGING SPECIFICATIONS

Modules per pallet:	20
Pallets per 53' container:	54
Pallet box dimensions: *length/width/height*	63.19in/27.56in/49.02in (1605mm/700mm/1245mm)
Pallet box weight:	632.8lbs (287kg)



Expanded View of Grounding Holes

Frame Cross Section Diagrams

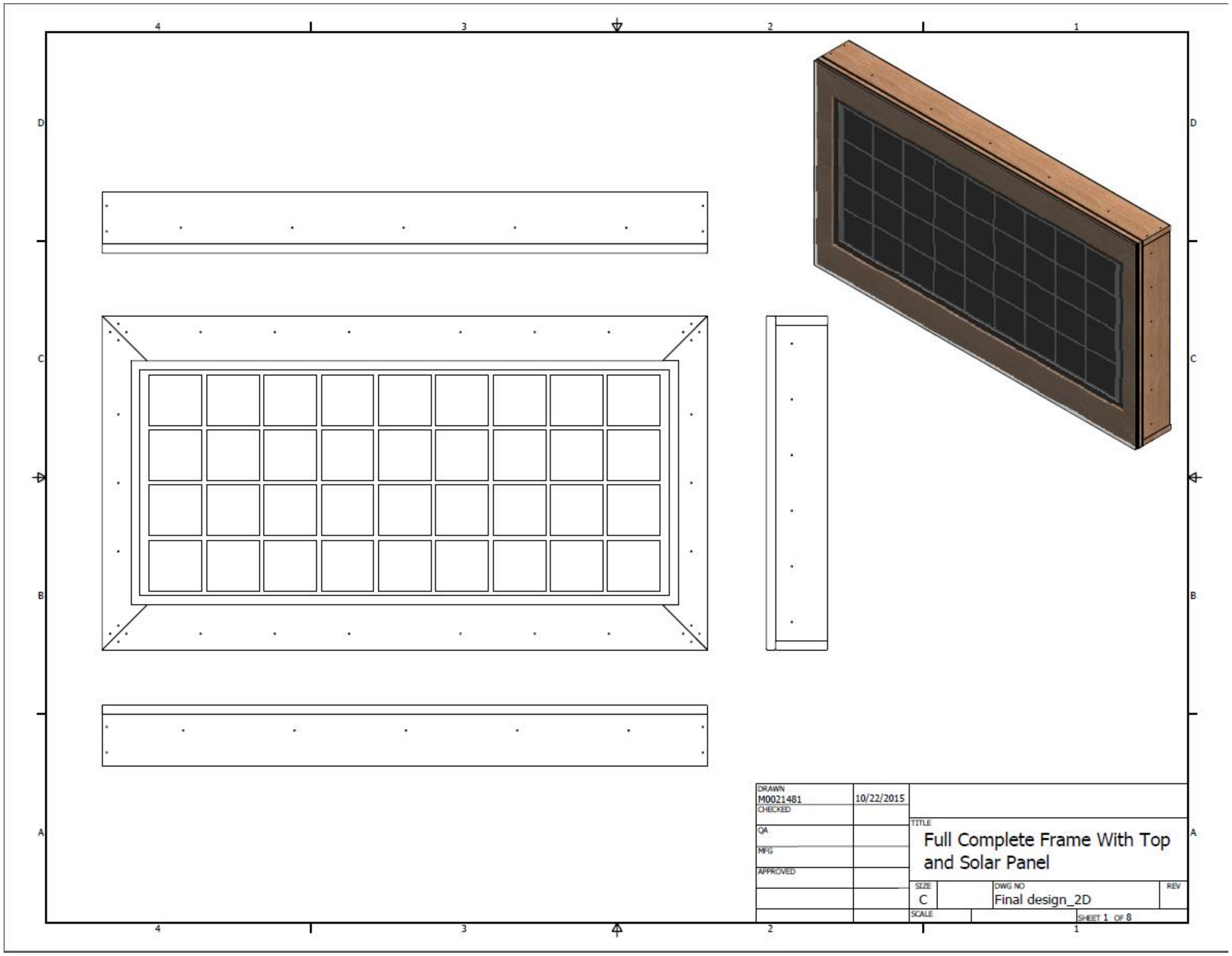
Legend
MOUNTING HOLES .35in (9mm) | DRAINAGE HOLES | GROUND SYMBOL .35in (9mm)

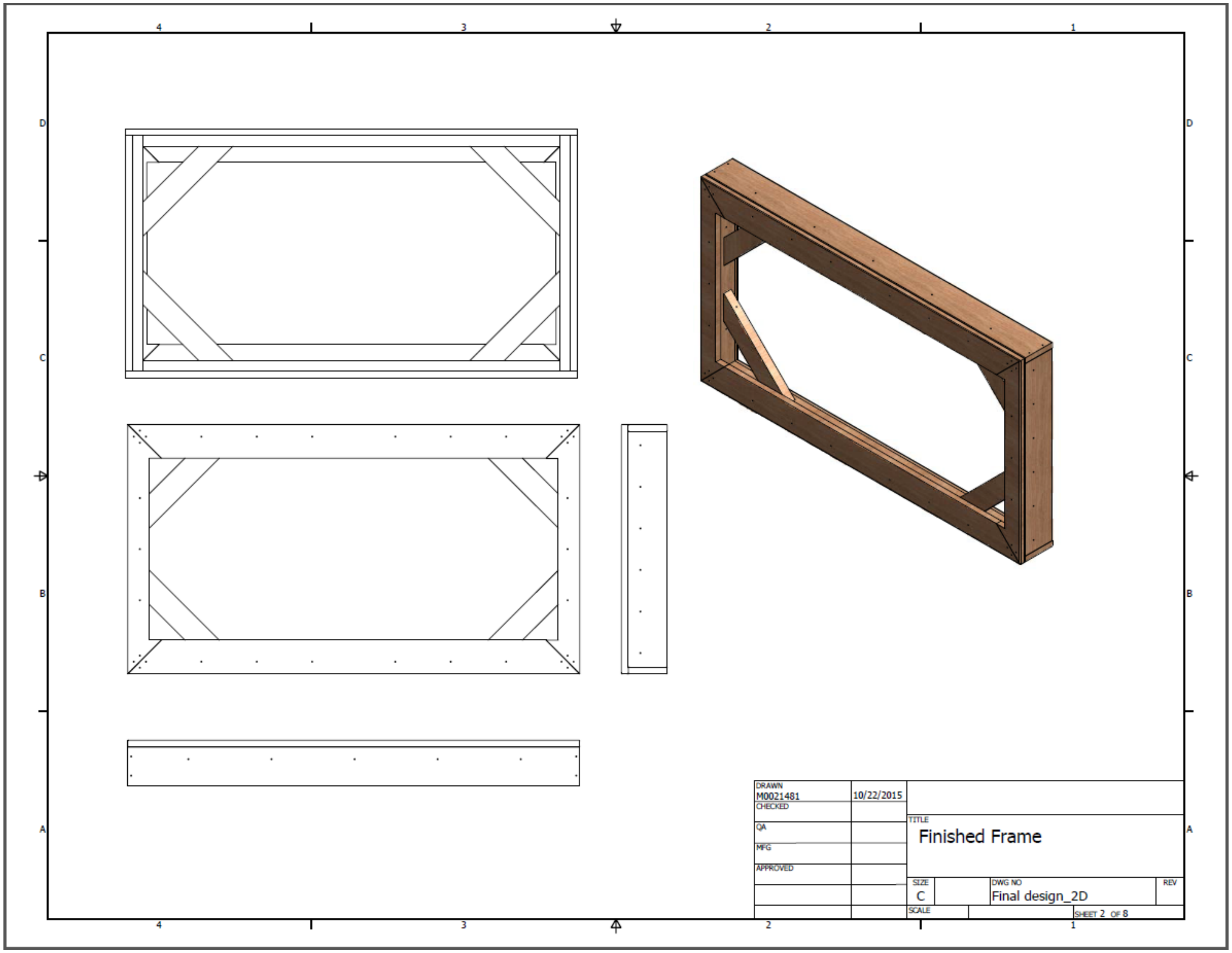
010713

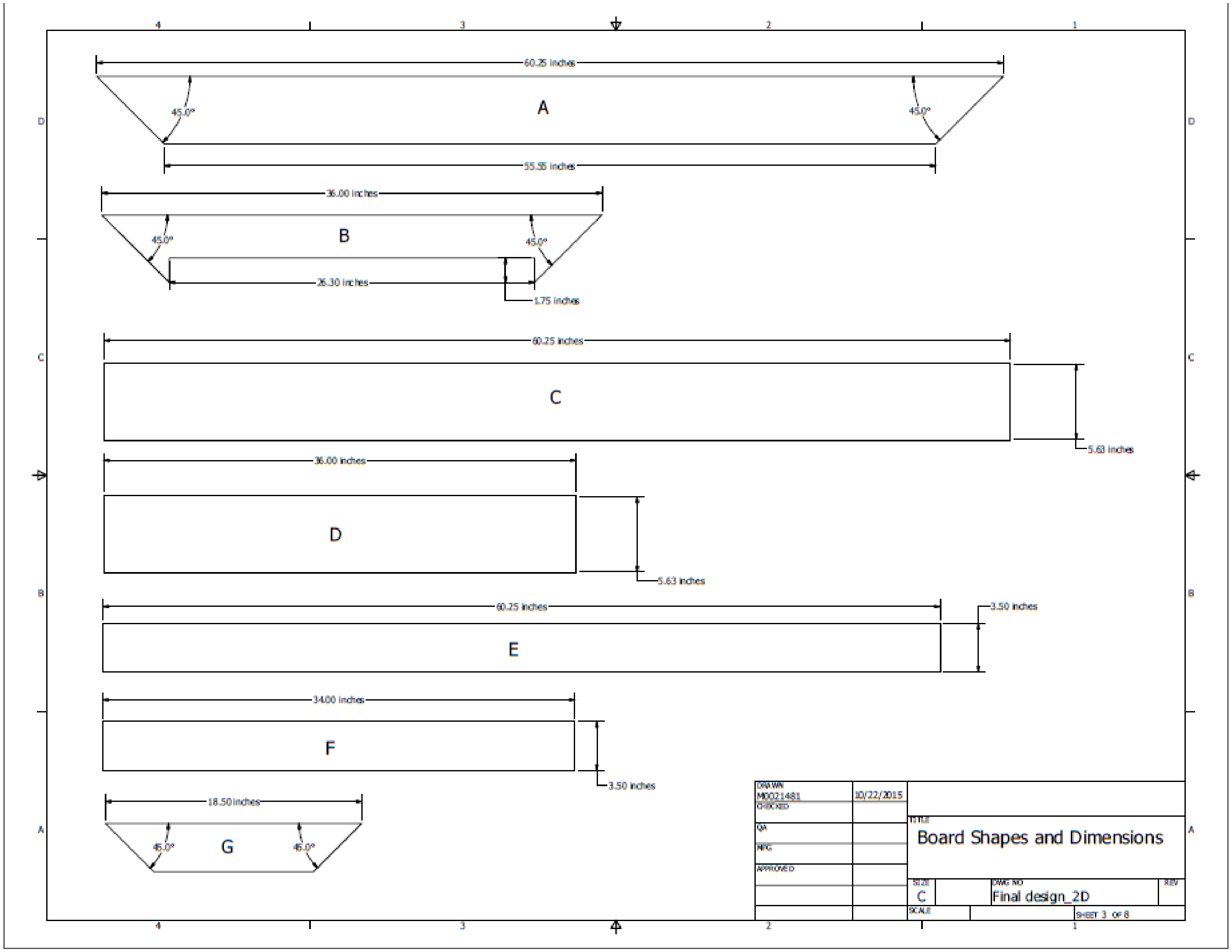
OUR VALUED PARTNER

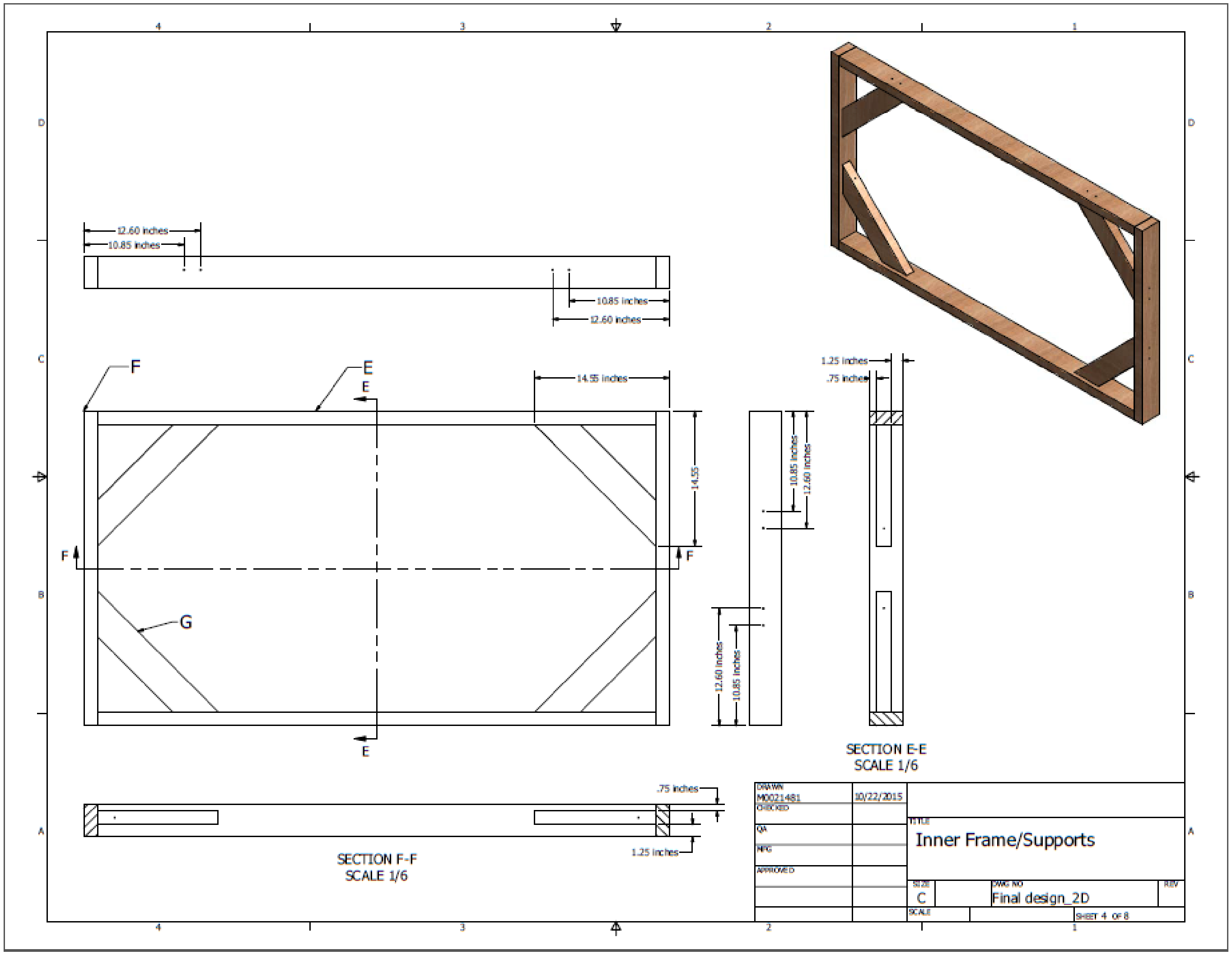
KYOCERA Solar, Inc. 800-223-9580 800-523-2329 fax www.kyocerasolar.com

Appendix E: Building Schematics, Wiring Schematics, and Directions

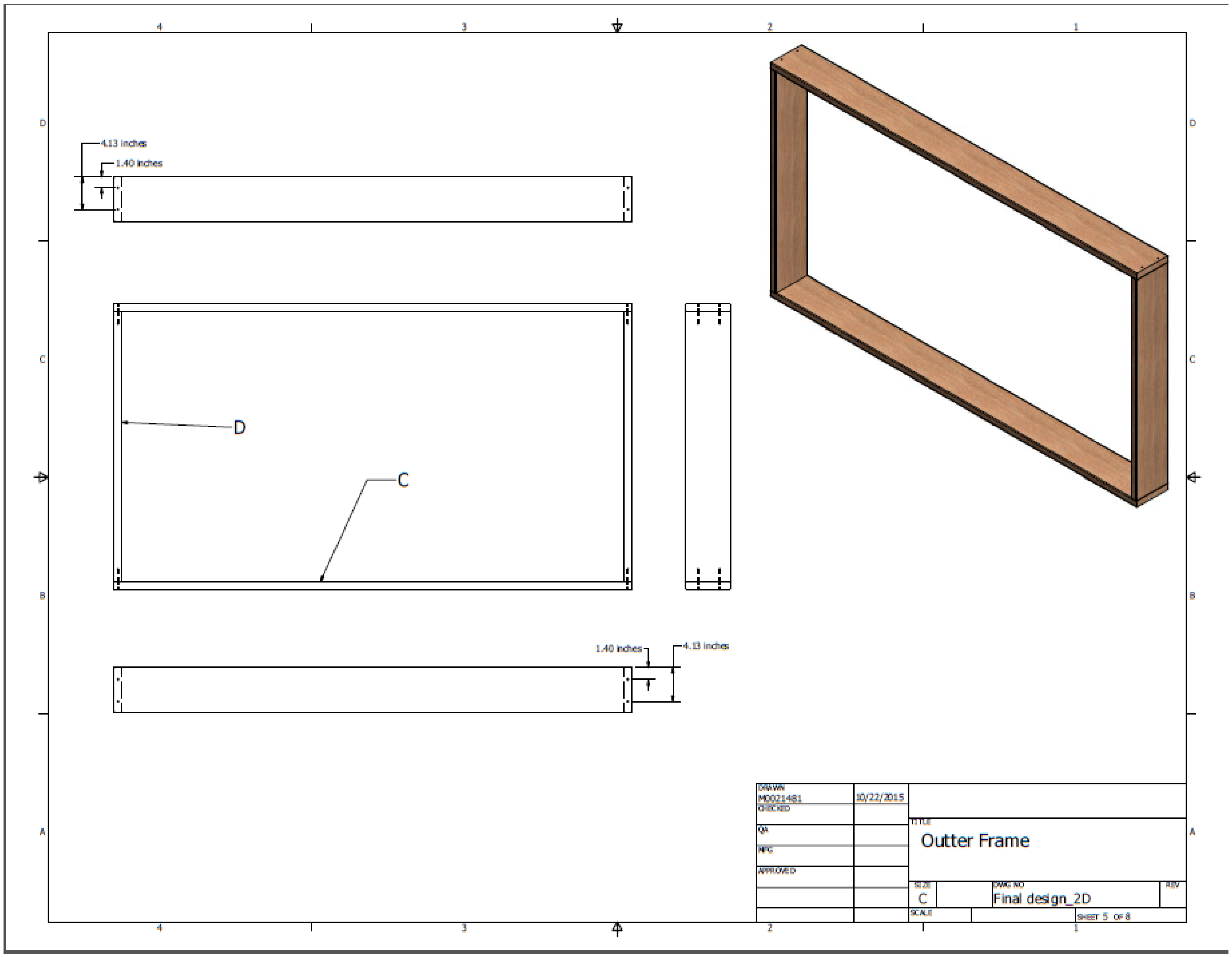


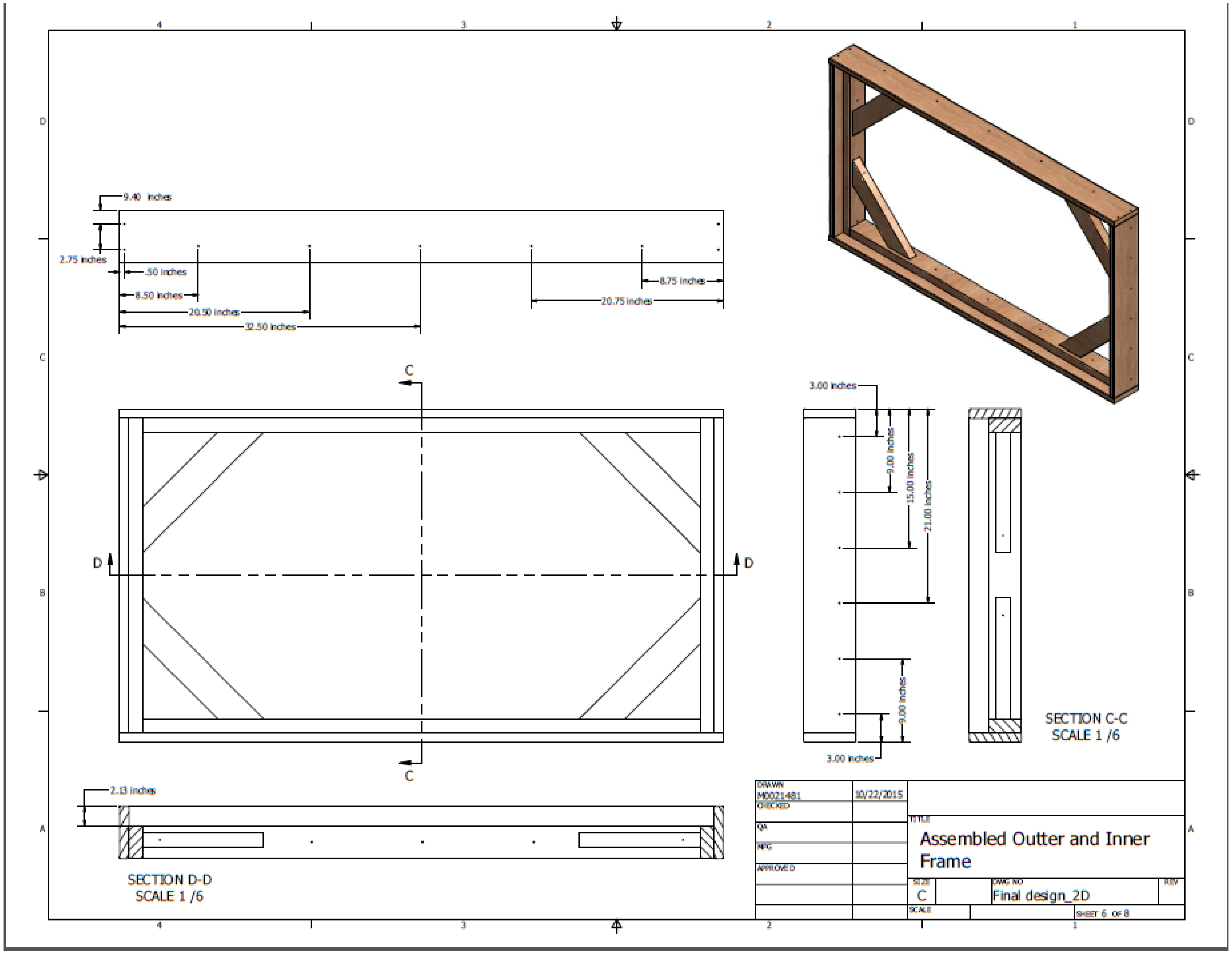

DRAWN
M0021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Finished Frame
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 2 OF 8

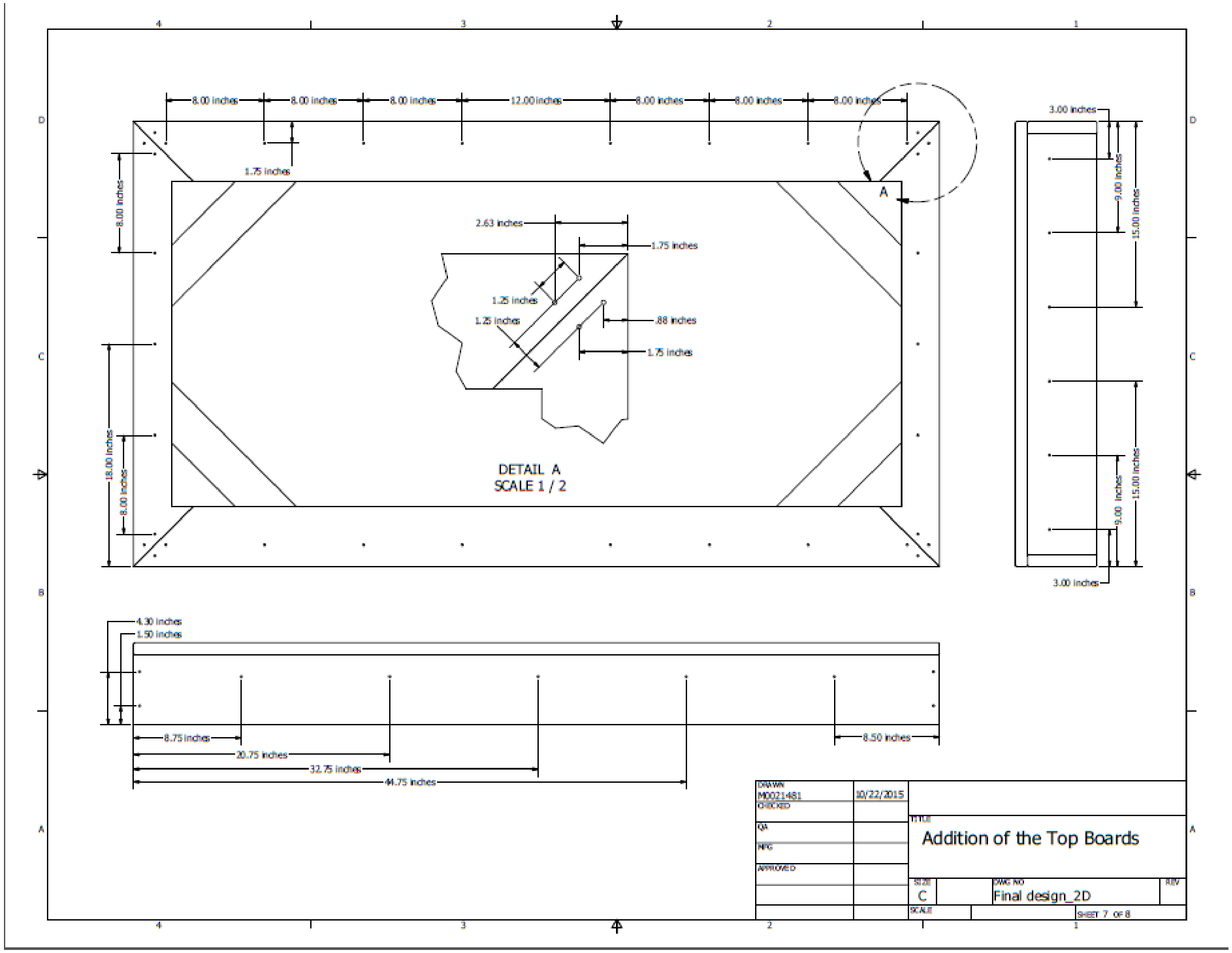

60.25 inches
A
45.0°
45.0°
55.55 inches
36.00 inches
B
45.0°
45.0°
26.30 inches
1.75 inches
60.25 inches
C
5.63 inches
36.00 inches
D
5.63 inches
60.25 inches
3.50 inches
E
34.00 inches
F
3.50 inches
18.50 inches
G
45.0°
45.0°
DRAWN
M00021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Board Shapes and Dimensions
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 3 OF 8



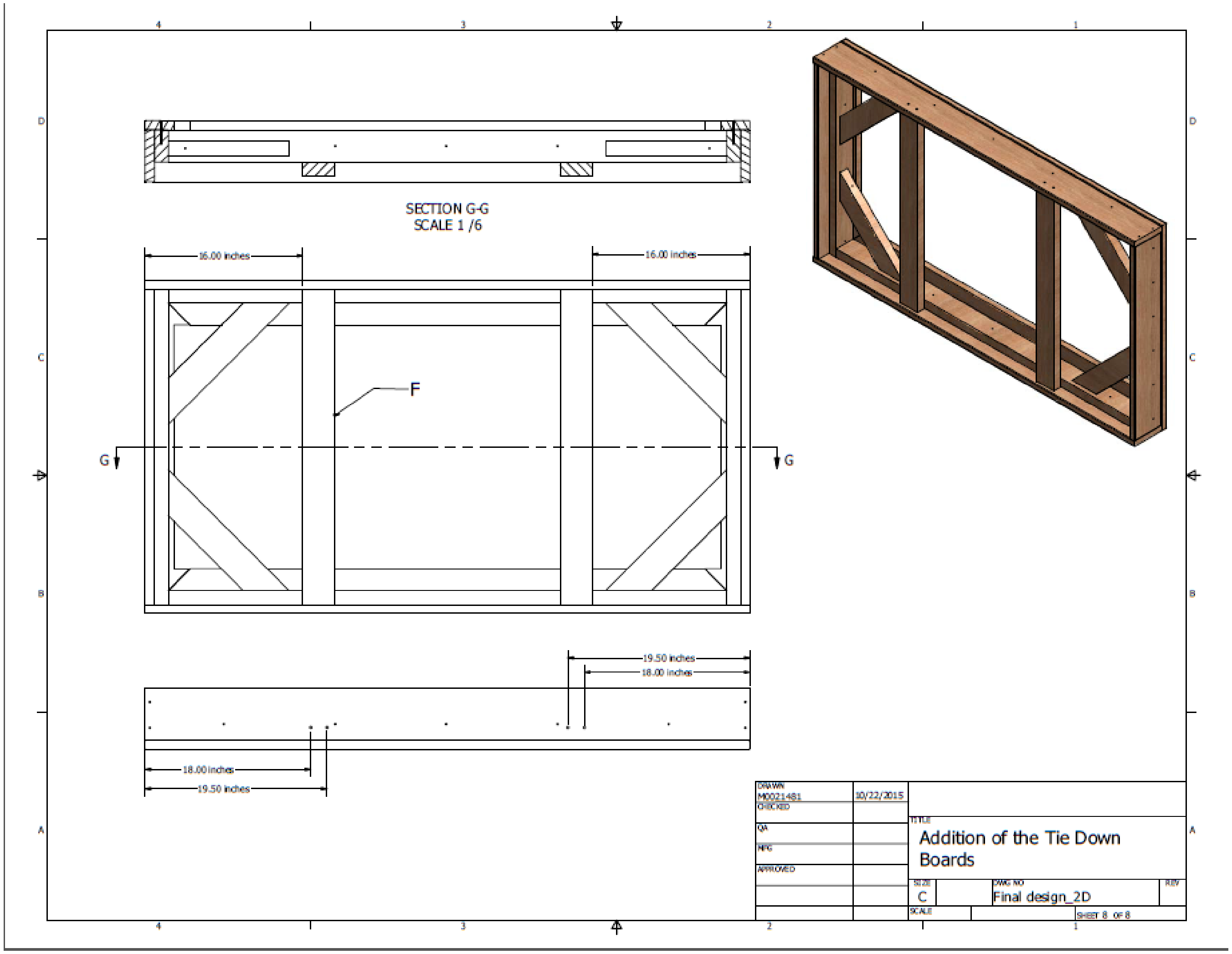
12.60 inches
10.85 inches
10.85 inches
12.60 inches
F
E
E
14.55 inches
14.55
F
F
G
E
10.85 inches
12.60 inches
12.60 inches
10.85 inches
1.25 inches
.75 inches
SECTION E-E
SCALE 1/6
.75 inches
1.25 inches
SECTION F-F
SCALE 1/6
DRAWN
M0021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Inner Frame/Supports
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 4 OF 8


4.13 inches
1.40 inches
D
C
1.40 inches
4.13 inches
DRAWN
M0021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Outter Frame
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 5 OF 8

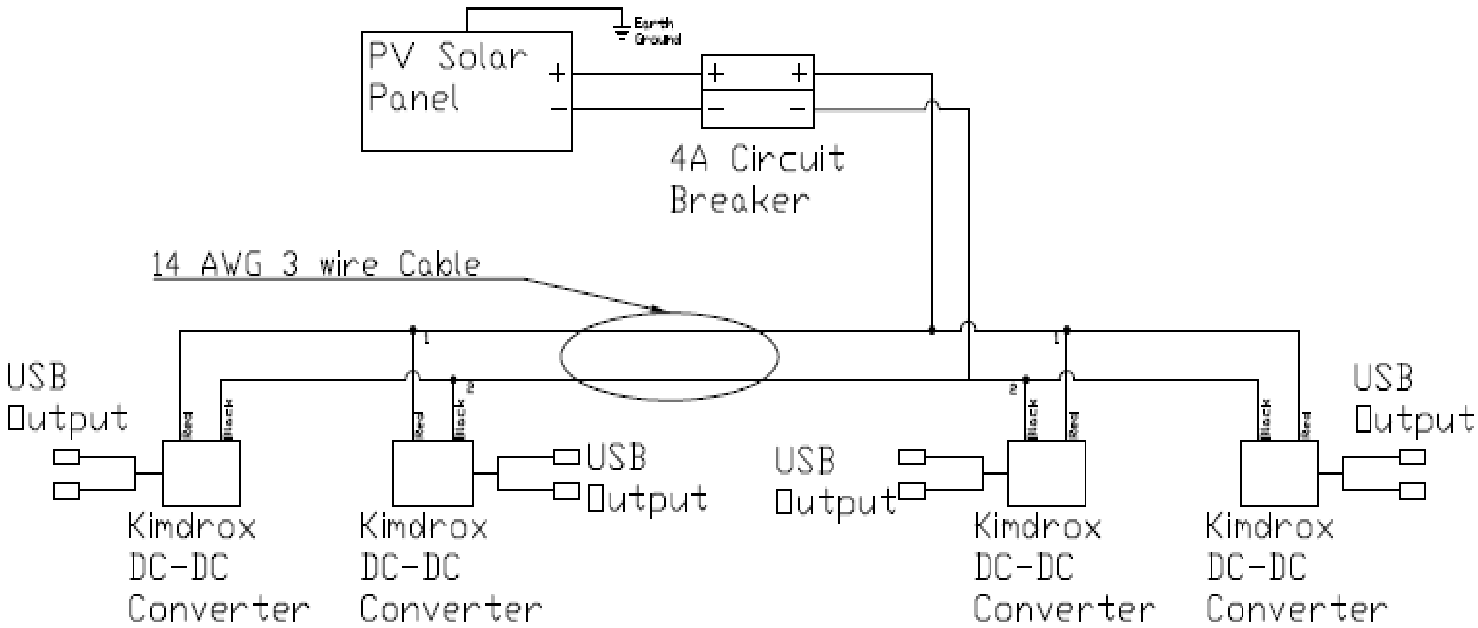

9.40 inches
2.75 inches
.50 inches
8.50 inches
20.50 inches
32.50 inches
8.75 inches
20.75 inches
3.00 inches
9.00 inches
15.00 inches
21.00 inches
9.00 inches
3.00 inches
SECTION C-C
SCALE 1 /6
2.13 inches
SECTION D-D
SCALE 1 /6
DRAWN
M0021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Assembled Outter and Inner Frame
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 6 OF 8



8.00 inches
12.00 inches
1.75 inches
2.63 inches
1.25 inches
.88 inches
DETAIL A
SCALE 1 / 2
3.00 inches
9.00 inches
15.00 inches
18.00 inches
4.30 inches
1.50 inches
8.75 inches
20.75 inches
32.75 inches
44.75 inches
8.50 inches
DRAWN
M0021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Addition of the Top Boards
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 7 OF 8


SECTION G-G
SCALE 1 /6
16.00 inches
16.00 inches
F
G
G
19.50 inches
18.00 inches
18.00 inches
19.50 inches
DRAWN
M00021481
10/22/2015
CHECKED
QA
MFG
APPROVED
TITLE
Addition of the Tie Down Boards
SIZE
C
DWG NO
Final design_2D
REV
SCALE
SHEET 8 OF 8

Circuit Diagram



Building Directions

1. Buy wood or other similar building material. The material used for this thesis was treated decking boards and treated studs.
2. Cut decking boards and studs to the dimensions shown in the schematics.
3. Assemble the inner frame using boards E, F, and G.
    a. The schematics show the recommended placement of screws.
        i. The screws used in the building of my frame are galvanized 2 in decking screws with a star bit.
    b. The star bit helps discourage unauthorized dismantling of the frame.
4. Be sure to square the frame as you build it so that the dimensions are correct.
5. Using boards C and D, assemble the outer frame around the inner frame as shown in the schematics.
    a. The schematics show the recommended placement of screws.
        i. The screws used in the building of the frame are galvanized 2in decking screws with a star bit
    b. The outer and inner frame are now assembled together.
6. To install the top of the frame, use Boards A and B to hold the solar panel in place and insure it is a good fit.
7. Pick a place to install the weather proof outlet in the frame.
    a. This will be the location of the USB charging ports.
8. Cut out a hole and attach the outlet cover.
9. The top is installed and the solar panel is able to fit in and out of the frame with ease.

10. Sand and seal the cracks.
    a. Rounded off any sharp edge or area with the possibility of splintering.
    b. Add an outdoor chalking/weather proofing to the cracks where each of the boards meet.
        i. This helps isolate the electronics below the solar panel from the elements.
    c. After the chalk has dried go back and sand excess residue off creating a smooth surface.
11. Stain or paint the surface to your liking.
12. Paint the entire frame with a waterproofing seal.
    a. This will help prolong the life of the frame.
    b. This will protect the electronics further.
13. Place the solar panel and other electronics in the frame.
    a. The converters have areas on the side that allow you to attach them with screws to the frame.
    b. Attach them on the under-side of the frame close to the outlet covers so the cords can reach the outlets.
14. Attach the Plexi-glass top to create a smooth working surface.
    a. This will help protect the solar panel and electronics.
15. Connect the circuit and place the cover over the picnic table of your choice.
16. Test the system to insure that everything is working properly.
17. Attach the two tie down Boards E to the bottom side of the frame
18. Test the system to insure that everything is working properly.
19. Enjoy!

VITA

CASEY B. POTTS

Education:	Northview High School, Duluth, Georgia
	B.S. Electrical Engineering Technology East Tennessee State University, Johnson City, Tennessee, 2014
	M.S. Technology with a concentration in Engineering Technology East Tennessee State University, Johnson City, Tennessee, 2015
Professional Experience:	Graduate Assistant, East Tennessee State University, College of Business and Technology, 2014 - 2015
	Electrical Engineering Intern, MAHLE Engine Components, Morristown Tn, 2015
	Electrical Engineer, MAHLE Engine Components, Morristown Tn, 2015 - Current