

**Universal 12V Battery Charger
Team 1
Final Report
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Responsible Engineers

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Table of Contents

1 Introduction	4
<i>1.1 Problem Statement</i>	4
<i>1.2 Market Research</i>	4
2 Product Specifications	6
<i>2.1 Customer Requirements</i>	6
<i>2.2 Specifications</i>	6
3 Design Approach	8
<i>3.1 Architectural Description</i>	8
<i>3.2 Module Definition</i>	9
3.2.1 Input Selection	9
3.2.2 Surge Protection.....	9
3.2.3 Voltage Boosting	10
3.2.4 AC to DC Conversion.....	10
3.2.5 Voltage Regulation	10
3.2.6 Charging	10
4 Product Results	11
<i>4.1 Product Functionality</i>	11
<i>4.2 Product Form</i>	11
<i>4.3 Solar Problem</i>	11
5 Cost Analysis	14
6 Failure and Hazard Analysis	15
7 Next Steps and Recommendations	16
8 Conclusion	17
Appendix A	29

List of Tables

Table 1:Electricity Production of countries with comparable population	5
Table 2: Manufacturing Parts List	26
Table 3: Prototype Parts List.....	28

Table of Figures

Figure 1: The Functional Block Diagram	18
Figure 2: Artistic Sketch	19
Figure 3: The Final Schematic	20
Figure 4: The Boost	21
Figure 5: Charging Circuit	22
Figure 6: Solar panel V-I curves	23
Figure 7: AC input selection	30
Figure 8: Battery Charger Team 1	31
Figure 9: Output connection	32
Figure 10: Top view of the Circuit	33

1 Introduction

For seven weeks we have been working to design a battery charger for our class EE2799 and Design That Matters (DtM), a non-profit organization that hopes to promote literacy through out the world—especially in Mali. The purpose of this report is to fully inform the reader of every detail necessary to understand this project and take it to the next level.

1.1 Problem Statement

Our objective for this project, given by Design That Matters, is as follows:

“You are to design a universal 12 Volt battery charger that can take various forms of electrical energy and charge a typical 12 Volt lead-acid (automotive) battery. The charger must be able to handle the following inputs: a solar panel, a pedal generator, and standard AC power (both American and European standards). The charger must not overcharge the battery, and must indicate the state of charge. In addition, the circuit should not drain the battery. The charger must be affordable in the community it is used in, and should be suitable for applications such as the Kinkajou Projector. Prototype cost should not exceed \$50.”¹

1.2 Market Research

Design that Matters hopes to sell its low cost projectors to teachers in Mali. Utilizing information provided by DtM, along with search engines on the World Wide Web and print encyclopedias, we learned several important things about Mali. This information gave us the required background for determining if Mali is a viable market for our product.

Mali is a west-African country with an estimated population of 11.62 million (2003), 53.6% of which are illiterate². This makes Mali a perfect market for the Kinkajou.

¹ <http://ece.wpi.edu/~vaz/courses/ee2799/b03/Labs/universal.htm>

² <http://www.odci.gov/cia/publications/factbook/fields/2103.html>

The Kinkajou, however needs to be powered, and there is a tremendous lack of electric infrastructure for the education sites targeted for the Kinkajou. When compared to countries similar in population, Mali doesn't fare well in terms of production of electricity. The statistical information regarding the electricity production of countries with populations comparable to Mali is given below in Table 1.

Country	Population(millions)³	Electricity Production(kWh)⁴
Cuba	11.26	14.38 billion
Malawi	11.65	769.2 million
Mali	11.62	480.2 million
Niger	11.05	242 million

Table 1:Electricity Production of countries with comparable population

Due to this lack of available power, an alternative source is needed. Consequently, in Mali, there is a huge reliance on car batteries, which are rechargeable, to power various electronic devices. The Kinkajou will have to be powered using this source. Thus there is an inherent need for a device to recharge these batteries.

³ <http://www.odci.gov/cia/publications/factbook/fields/2119.html>

⁴ <http://www.odci.gov/cia/publications/factbook/fields/2116.html>

2 Product Specifications

Our device has a clearly defined purpose and market. To complete this project successfully, we need to draw a framework for the rest of our work to fall into. This framework is manifested in the product specifications. As a first step toward this goal we formulated key customer requirements and from that we came up with detail specifications for our prototype.

2.1 Customer Requirements

Using the information we gathered from market research and information given to us from DtM, we can conclude that users of our charger would expect the following:

The charger must:

- accept solar power, pedal generator, and standard AC power (American and European). This will make the charger universally useable.
- indicate state of charge. This will let the user know the status of the battery.
- not overcharge the battery. This will prevent the battery from exploding.
- not drain the battery when not in use. This will prolong the battery life.
- be locally affordable. This will help the over all cost of promoting literacy in Mali.

Common sense tells us that in addition to the requirements listed above, our charger should also be:

- rugged and water-resistant. This will make the charger last longer in rough conditions.
- lightweight. This will provide portability.
- shock-resistant. This will improve the charger life.
- capable of being assembled/repared locally. This will bring down the charger cost.
- marked with basic graphical instructions. This will make it user friendly.

2.2 Specifications

- AC input terminals

- AC input switch (between us and euro)
- Solar input terminals
- Pedal input terminals
- Output connector cables
- Power LED
- Full LED
- Casing
- Max weight 15lbs.
- Max Volume 440 cubic inches
- Max Operating temperature 45°C.
- AC input voltage 110/220⁵
- AC input frequency 60/50Hz⁷
- Solar input must accept a max of 3A DC
- Pedal input must accept a max of 40volts DC⁶

In summary, our Charger will take three inputs, AC with 110V/220V, pedal generator, and solar power. The inputs will be selected through radio buttons, thus giving the user only one input to select at a time. All the inputs will be labeled graphically and in multiple languages. The battery charge status will be indicated through two LEDs, indicating ON and FULL status. The Charger will not exceed 15lbs and 440 cubic inches, in weight and volume, respectively. It shall withstand a temperature of 45°C. It will also have alligator clips connecting the output. The casing will be of light color to reduce absorption of sunlight. Our artistic sketch is shown in Figure 1.

⁷ Nations of the World: a Political, Economic & Business Handbook. Lakeville, CT: Grey House, 2003. [REF HC10 N37 2003]

⁶ <http://users.erols.com/mshaver/bikegen.htm>

3 Design Approach

Our charger will follow a two-step charging algorithm. Our design is broken down into three subsystems. They are input selection, conversion to certain DC voltage, and the charge cycle.

- **Input Selection:** Input selection will be done by using radio buttons, which will allow a user to only select one input at a time. Other options were one knob selection, no switch, and auto sensing. These options were discarded due to possible implementation difficulties, safety, and cost, respectively.
- **Conversion to Certain DC voltage:** All of the inputs will be, if needed, converted to certain DC voltage, which may also require some amplification. This will be done using the least number of integrated circuits as possible.
- **Charge Cycle:** It will be a two-step charge cycle, Bulk Charge and Float Charge. Two-step cycle was chosen over three-step and four-step cycles due to its less circuitry, complexity, and cost.

3.1 Architectural Description

Our device completes its task by utilizing six discrete modules. Each module performs part of the overall function of the device. These modules include Input Selection, Surge Protection, Voltage Boosting, AC to DC Conversion, Charging, and Reverse Polarity Protection. They are presented in Figure 2, along with the internal connections of the device as well as the general energy flow (indicated with arrows.)

The user will connect an input source to the input terminals, connect a battery to the output terminals and then select the appropriate input button. At this point the current from the input source will flow through the selection buttons and into a surge protection unit. Each voltage path, AC and DC, has its own protection unit.

In the case of an AC source, it will flow into an AC/DC converter which will step down the voltage and approximate a DC output. For the DC input, the source will pass

into a Voltage Booster unit which will increase the voltage to a level usable by the rest of the device.

From here the current will pass into the Voltage Regulator unit which will regulate the voltage for output to the battery. First it will pass through the Charging unit which will detect proper current draw from the battery and pass along the first regulated voltage. Once the current draw from the battery drops to a preset level, the second voltage regulator (part of the charging module) will output a lower regulated voltage to finish the charging process.

3.2 Module Definition

Each of the modules in our system has a unique set of input/output specifications along with operation details. These discrete specification allow each module to perform independently while working together to accomplish the overall task of charging the battery. Each module is shown as part of the entire system in the schematic, Figure 3.

3.2.1 Input Selection

Our device features an array of push buttons. These allow the user to select the type of input they are connecting to the charger. This is necessary as there are three different types of inputs, each requiring different internal circuitry. These push buttons are radio style, meaning that only one button can physically be pushed in at once. This provides a safety feature allowing only one input source to be internally connected, to the device at one time.

Given the mechanical nature of this module, any and all input voltages will simply be passed through to the next module.

3.2.2 Surge Protection

At this point the inputs will be connected to a surge protector. This device will be a Metal Oxide Varistor, absorbing any spikes and surges on these inputs without damaging the successive modules. Surge protection helps reduce cost and time issues associated with repairing internal parts of the device by reducing and/or eliminating unhealthy surges and spikes inside the system.

3.2.3 Voltage Boosting

The DC input will now be connected to a boosting circuit. This task will be performed by a step-up voltage regulator. This module will accept voltages in the range of 5 Volts to 20 Volts and output a common 23.5 Volts. Without this unit we cannot properly regulate the output voltage to the battery and therefore we cannot control the charging process effectively.

3.2.4 AC to DC Conversion

This module will consist of a Dual Primary Transformer that will step down the AC voltages from 220, and 110, to 25.4 Volts-peak. Then this will pass through a Full Wave Bridge Rectifier and then a filtering capacitor to achieve close to DC voltage of 23.5 Volts. Without this unit we cannot use the AC input source and the charger would be next to useless.

3.2.5 Voltage Regulation

This module will consist of a voltage regulator that will provide a constant voltage to be used for charging the battery. The output voltage from the regulator is determined by selecting values for two resistors attached to the output and adjustment pins on the regulator.

The output voltage from this unit will be 18.5 Volts DC. This will first pass through the Charging module. This step is necessary because it allows the device to accurately control the charging process. Unregulated voltage would cause problems related to the state of the attached battery.

3.2.6 Charging

The charging module includes another voltage regulator and a current sensing unit. If the battery is drawing over 150mA, the regulator charges at 15 Volts. Once the current drops below this point, the second regulator outputs 13.4vDC to perform a float charge and finish off the charging process. This will help extend the life of the battery while it conserves the charging time required.

4 Product Results

4.1 Product Functionality

We were able to demonstrate proof of concept for three of the four required inputs: American AC, European AC and the pedal generator. Unfortunately we were not able to construct circuitry for the solar input. A detailed explanation is included later in the Solar Problem section.

If we step down onto the modular level, we were very successful. All of the modules required for the three working inputs were constructed and verified through testing. These modules include: AC to DC conversion, voltage boosting, voltage regulation, two-step charging and reverse polarity protection. The input selection module was not included in our prototype and therefore not tested. Pictures of our prototype can be found in Appendix A.

4.2 Product Form

As it stands, our prototype fits within the physical limits from our product requirements, see Appendix A. If the device was mass produced, using printed circuit boards and surface mount parts, we could greatly reduce our device's footprint.

4.3 Solar Problem

One of the inputs to our charger comes from the solar panel. We originally thought of the solar panel as a voltage source, comparable to our other input sources. With this idea we decided to use our boost converter to step-up the voltage for use by our charging circuit. This is because we found the open circuit voltage from the panel to be 21 Volts DC. Therefore we could easily regulate it to 23.5V and be able to take in voltages anywhere from 5 Volts to 21 Volts DC.

Later on in the term we found out that the solar panel acts more like a current source than a voltage source. This was from the V-I characteristic of the solar panel, shown in Figure 6. This shows that the panel outputs constant current of 7.5 to 8 amps, this is determined under optimum conditions, from around 0-12 Volts DC. As the voltage increase the current drops dramatically. The solar panel works most effectively, while performing at the upper bend in the curve, between 15 and 17 Volts DC. We do not believe that our boost circuit can handle an input source with these characteristics.

However, we came up with another solution for charging the battery with solar power. This involves connecting the solar panel directly to the battery in a “take what you can get” method of charging. This will quickly charge the battery up to approximately 80 percent. Although charging the battery by hooking up to the battery directly to the solar panel could overcharge and damaged the battery. To prevent this harm we need some sort of overcharge protection. Our first idea was to use a shunt regulator. This circuit, essentially, allows all of the current to pass into the battery while monitoring the voltage across the battery. Once the voltage across the battery reaches a set voltage the circuit shunts the current to ground. The integrated circuit is only able to dissipate one watt. Unfortunately, the integrated circuit that will be used must be able to handle up to 3 amps of current, therefore dissipation 40 Watts of power at 13.3 Volts—the fully charged battery voltage. This means it is necessary to find another way to implement the solar input stage of our charger. Moreover, this realization has occurred much too late in the stage of this project in order to design and implement another method. Even if our shunt regulator could dissipate the necessary power, it would greatly increase the temperature inside our charger which could adversely affect our other circuitry

However, we have another idea for realistic way to deal with this input. We suggest designing the solar input regulation using a voltage comparator circuit and a MOSFET. The idea is that the circuit compares the voltage of the battery to a desired reference voltage. When the voltage across the battery is less than the reference voltage,

the comparator output is high and the MOSFET is “off”. When the voltage rises above the reference, the comparator output becomes low which turns the MOSFET “on” and shorts the solar panel to ground. Solar panels have the ability to be shorted without any damage to the panel itself. Since the MOSFET has almost no resistance when it is “on”, conducting, which cause no power to be dissipated through it. Another good aspect of this idea is that it will not be wasting any power coming into the control circuit, thus, having a very high efficiency.

5 Cost Analysis

We were asked to design a prototype that costs no more than \$50. We ended up spending \$53.04 on our prototype. Our client supplied us with a rough estimate of 800+ units being sold in the first retail cycle. Therefore we have re-evaluated our component costs and factored in casing and manufacturing costs. Our final unit cost, including casing and manufacturing is \$32.35. All the figured related to the prototype and manufactured unit cost can be found on Table 2 and Table 3, respectively.

6 Failure and Hazard Analysis

It's an absolute certainty that our device will wear out with time. What's not so certain is what will cause this failure. Ignoring the boundaries of our subsystems and looking at the device as a whole, there are two main areas. The first is what we call the power chain. This is the chain of components that lead directly from the input source to the battery. All of the energy the battery will absorb must pass through this chain and thus the components along the way are under the most stress. The transformer and rectifier were specifically chosen with this application in mind, so they are well suited to the conditions our device will see. The voltage regulators on the other hand are designed for a wide variety of applications. In our device a metal heat sink is needed to dissipate heat that develops from the regulator. The likelihood of these parts overheating is far greater than the rest of the circuit. Environmental temperature along with deterioration of the heat sink will contribute to overheating. The other components can be expected to age normally and their failures cannot be accurately predicted.

When one of our voltage regulators fails, it will typically burn out and thus eliminate any connection to the battery. There is a possibility, however, of a short circuit being formed between the input and adjustment pins. This could cascade high current into sensitive areas of the charging circuit and in turn could destroy the operational amplifier and several resistors and a transistor. This poses no immediate threat to the user and would most likely result in smoke emitting from the device.

7 Next Steps and Recommendations

In an ideal situation, the design process would never end. Continued improvements, evaluation of options and rethinking can always be done. In the real world, however, there are deadlines and limits on resources. With that in mind we'd like to make some recommendations to any who might take on the project and continue from where we left off.

The most important aspect of our design to be improved upon concerns the solar panel energy source. As we have discussed in our Solar Problem section earlier, we have not arrived at a means to utilize it. Thus, there needs to be some work done in this area. This include testing all of the ideas we presented in our Design Approach section, conducting research into further options and taking a hard look at devices that currently charge batteries using solar panels.

Other areas of continued work involve extensive testing of current design. We haven't had enough time in the lab to stress test our system, and no field testing has been done yet. These kinds of tests will yield important information about how well our choice of components will endure the rigors of the real world.

The final area we would like to see explored is the realm of parts. We chose parts based on conservative estimates so that our prototype would work, and work well. Over all cost could be reduced by investigating cheaper parts that still meet our specifications.

8 Conclusion

After 7 weeks of hard work we are excited that the majority of our circuit is functional. We are proud of the fact that after sifting through many design options for all aspects of our device, the ones we selected did the job, and did it well. We have learned many things about being an engineer, things that could not be taught in a normal text-book/lecture type of course. The long nights, lack of sleep, and hours of debugging were easily balanced out by the jokes—and their resulting laughs, the small triumphs over the soldering iron in the lab and the broad smiles on evaluation day. In short, it was a long and difficult journey but was well worth it.

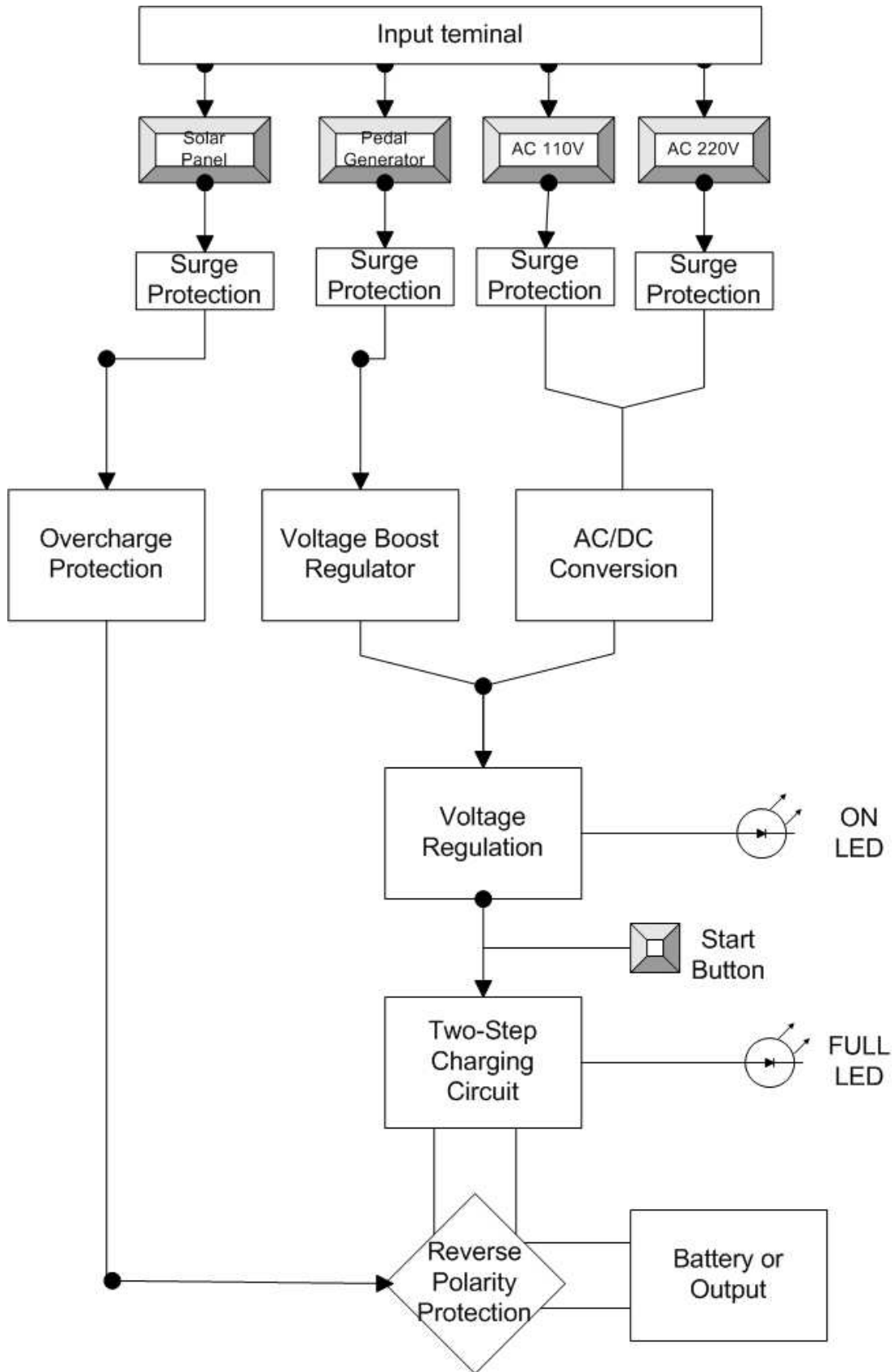


Figure 1: The Functional Block Diagram

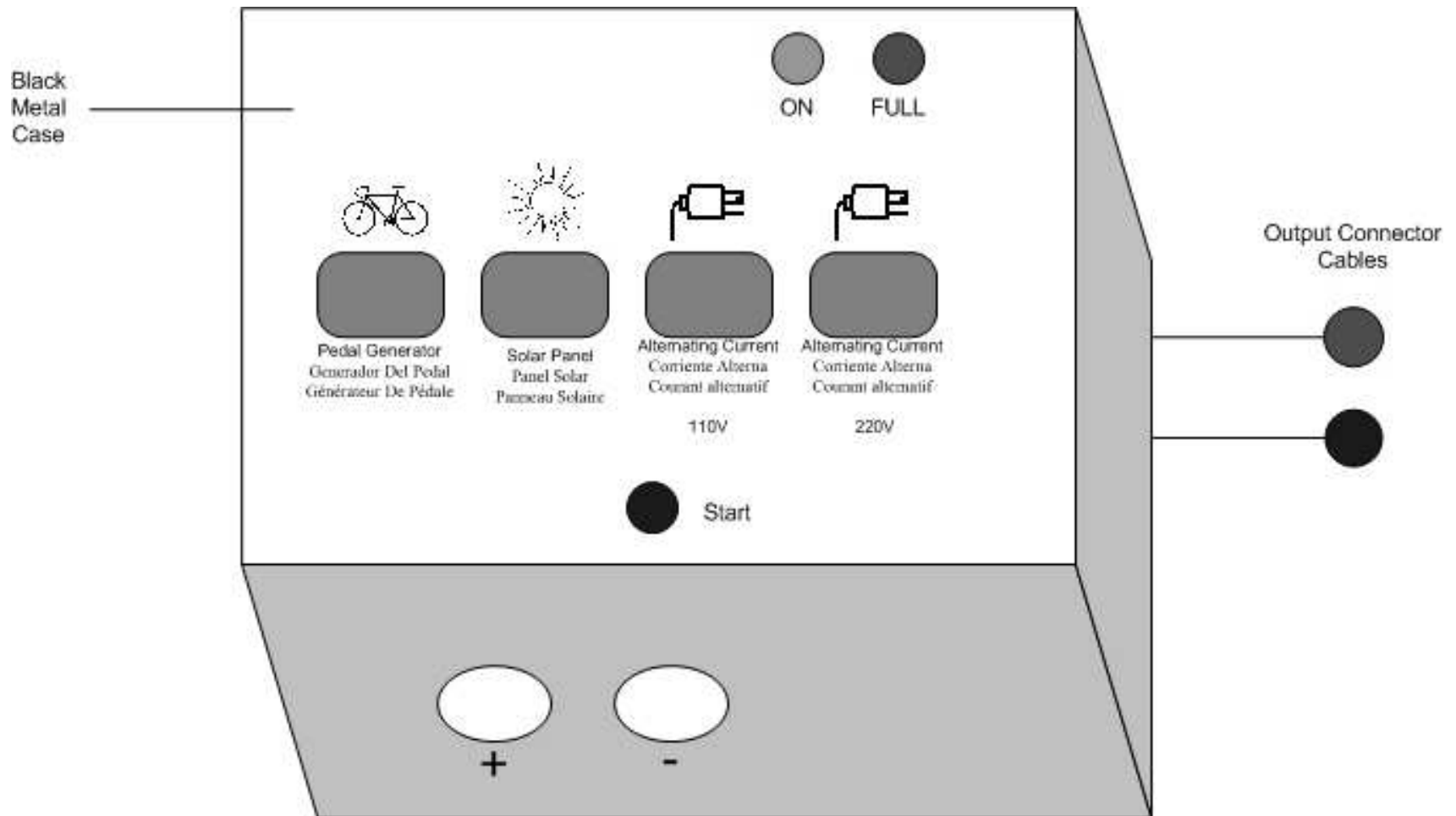


Figure 2: Artistic Sketch

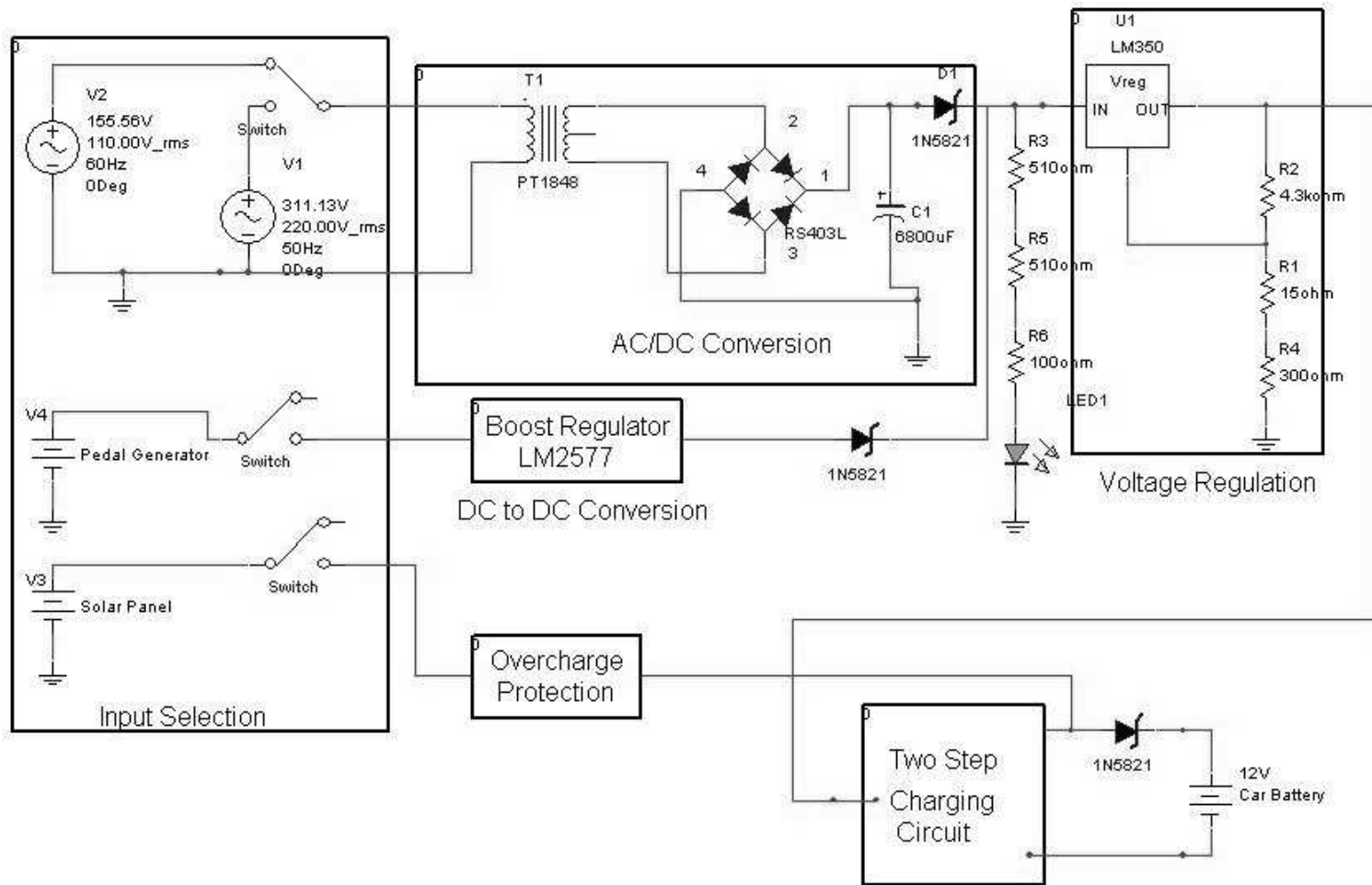


Figure 3: The Final Schematic

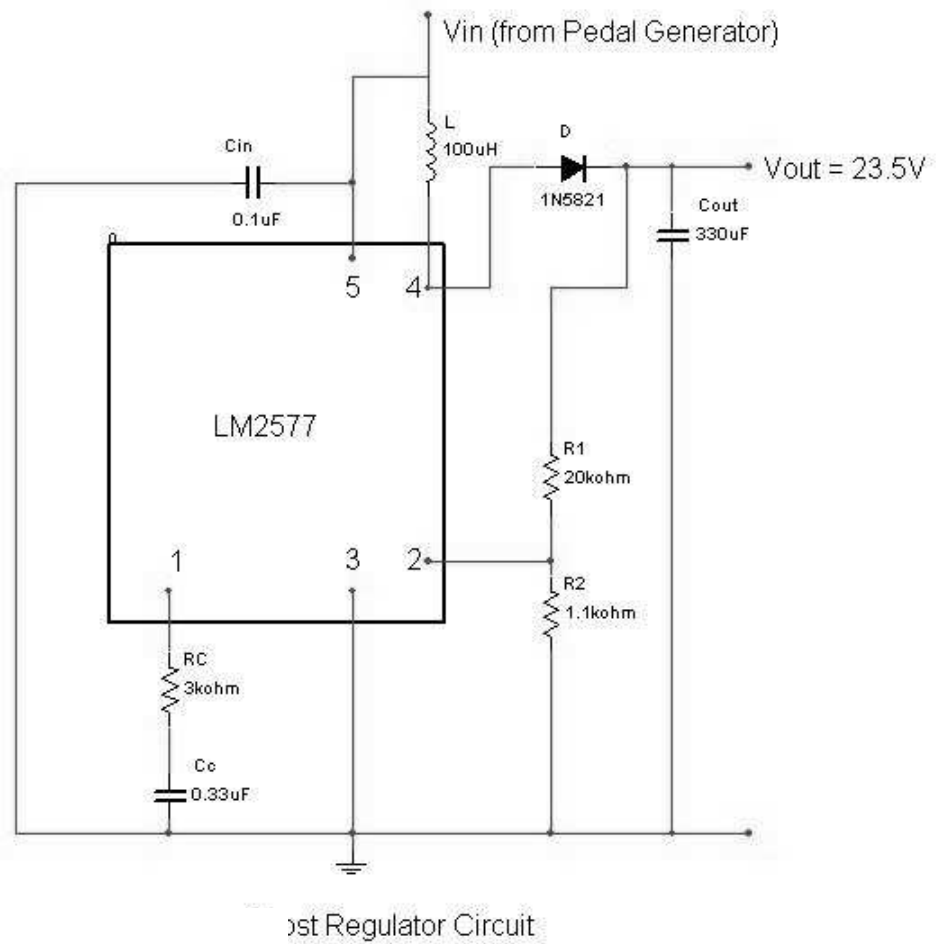


Figure 4: The Boost

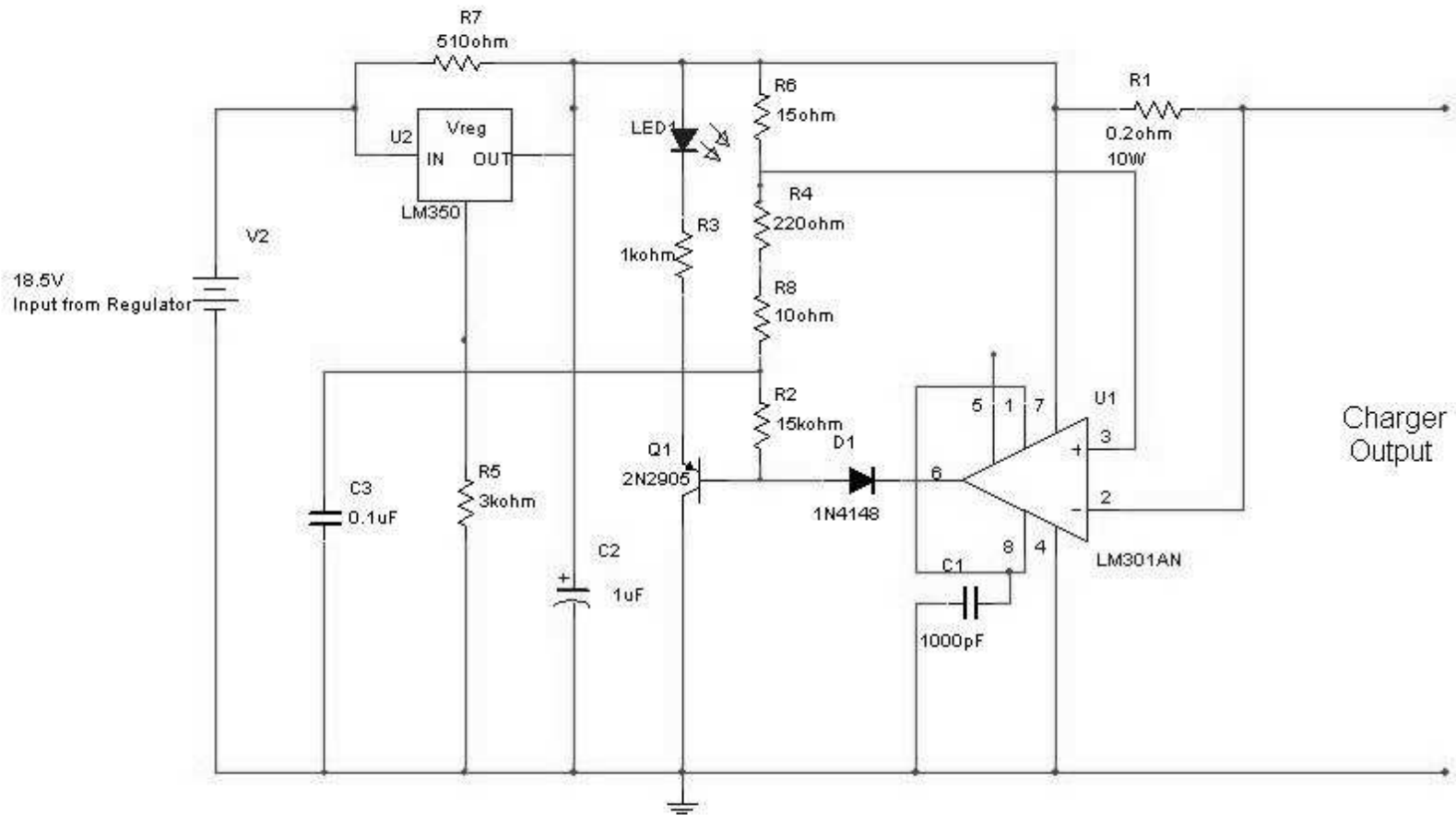
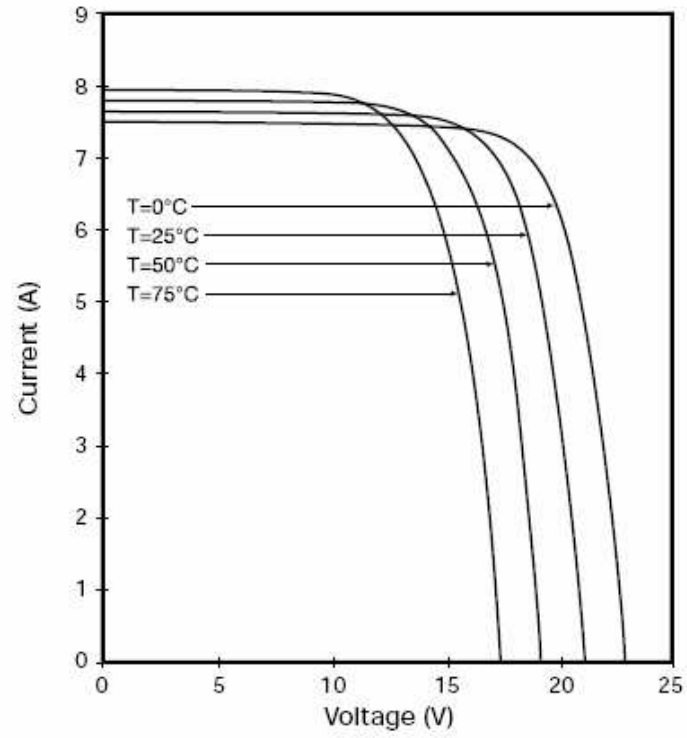


Figure 5: Charging Circuit

SX 120S I-V Curves



7

Figure 6: Solar panel V-I curves

⁷ (<http://www.bpsolar.com/ContentDocuments/84/BP%20SX%20120S.pdf>)

Manufacturing Parts List

Item	Qty	Value	Description	Distributor	Part No.	MFG	MFG Part No.	Unit	Sub	Min. QTY	500+ Cost	New Sub
1	1	PT184 8	Transformer, 18Vct @ 2A	Jameco	149956		PT1848	\$8.95	\$8.9 5	1	\$6.95	\$6.95
2	1	LM257 7	3A Step-up voltage regulator	Digikey	LM2577T-ADJ- ND	National	LM2577T-ADJ	\$5.42	\$5.4 2	1	\$3.23	\$3.23
3	2	LM350 T	Adjustable Linear Regulator 3A	Digikey	LM350TNS-ND	National	LM350T	\$2.29	\$4.5 8	1	\$0.96	\$1.92
4	1	RS403 L	Bridge Rectifier 4A 200V	Digikey	RS403LMS-ND	Diodes Inc.	RS403L	\$1.56	\$1.5 6	1	\$0.98	\$0.98
5	2	-	T0-200 Heatsink 2.5 °C/Watt	Digikey	HS276-ND	Aavid Thermalloy	529802B00000	\$1.38	\$2.7 6	1	\$0.83	\$1.65
6	1	100uH	100uH Inductor Axial	Digikey	DN7425-ND	API Delevan, Inc.	2474-25L	\$2.94	\$2.9 4	1	\$1.34	\$1.34
7	2	-	Leaded Varistor, Surge Protection (38Vac max)	Digikey	BC1449-ND	BC Components	2322 595 51416	\$0.67	\$1.3 4	1	\$0.48	\$0.96
8	1	-	Leaded Varistor, Surge Protection (140Vac max)	Digikey	BC1449-ND	BC Components	2322 595 51416	\$0.67	\$0.6 7	1	\$0.48	\$0.48
9	1	-	Leaded Varistor, Surge Protection (275Vac max)	Digikey	BC1433-ND	BC Components	2322 594 52716	\$0.53	\$0.5 3	1	\$0.38	\$0.38
10	6	1N582 1	Schottky Diode 3A 30V	Digikey	1N5821DICT- ND	Diodes Inc.	1N5821-T	\$0.68	\$4.0 8	1	\$0.24	\$1.46
11	2	1N414 8	Small Signal Diode 100V 200mA	Digikey	1N4148FS-ND	Fairchild Semiconductor	1N4148	\$0.06	\$0.1 2	1	\$0.02	\$0.03

2	1	2N2905	2N2905 Transistor PNP	Digikey	497-2572-5-ND	STMicroelectronics	2N2905A	\$0.95	\$0.95	5	1	\$0.42	\$0.42
13	1	LM301A	Operational Amplifier	Digikey	LM301ANNS-ND	National	LM301AN	\$1.20	\$1.20	0	1	\$0.43	\$0.43
14	2	-	8 pin Sockets	Digikey	A24794-ND	AMP/Tyco Electronics	2-640463-2	\$0.36	\$0.72	2	1	\$0.18	\$0.36
15	1	-	Red Led	Digikey	67-1064-ND	Lumex Opto/Components Inc.	SSL-LX3044HD	\$0.10	\$0.90	8	10	\$0.08	\$0.08
16	1	-	Green Led	Digikey	67-1062-ND	Lumex Opto/Components Inc.	SSL-LX3044GD-5V	\$0.33	\$3.30	0	10	\$0.26	\$0.26
17	1	330uF	50V Electrolytic Capacitor	Digikey	493-1343-ND	Nichicon	UVZ1H331MPD	\$0.60	\$0.60	0	1	\$0.23	\$0.23
18	1	.33uF	50V Radial Ceramic Capacitor	Digikey	399-2174-ND	Kemet	C322C334M5U5CA	\$0.32	\$0.32	2	1	\$0.12	\$0.12
19	1	6800uF	Capacitor 35 Volt Electrolytic Radial	Digikey	P6660-ND	Panasonic -ECG	ECO-S1VA682BA	\$4.11	\$4.11	1	1	\$1.53	\$1.53
20	1	1000pF	100V Ceramic Disk Capacitor	Digikey	1383PH-ND	BC Components	D102K20Y5PH63L6	\$0.08	\$0.70	7	10	\$0.04	\$0.04

21	1	1uF	50V Radial Electrolytic Capacitor	Digikey	P993-ND	Panasonic - ECG	ECE-A1HKS010	\$0.14	\$1.40	10	\$0.11	\$0.11
22	1	15kΩ	1/4W Resistor	Digikey	15QBK-ND	Yageo	CFR-25JB-15K	\$0.06	\$0.28	5	\$0.02	\$0.02
23	2	3kΩ	1/4W Resistor	Digikey	3.0QBK-ND	Yageo	CFR-25JB-3K0	\$0.06	\$0.28	5	\$0.02	\$0.04
24	1	4.3kΩ	1/4W Resistor	Digikey	4.3QBK-ND	Yageo	CFR-25JB-4K3	\$0.06	\$0.28	5	\$0.02	\$0.02
25	1	20kΩ	1/4W Resistor	Digikey	20QBK-ND	Yageo	CFR-25JB-20K	\$0.06	\$0.28	5	\$0.02	\$0.02
26	2	15Ω	1/4W Resistor	Digikey	15QBK-ND	Yageo	CFR-25JB-15R	\$0.06	\$0.28	5	\$0.02	\$0.04
27	1	300Ω	1/4W Resistor	Digikey	300QBK-ND	Yageo	CFR-25JB-300R	\$0.06	\$0.28	5	\$0.02	\$0.02
28	1	.2Ω	10W Resistor	Digikey	20JR20-ND	Ohmite	20JR20	\$1.96	\$1.96	1	\$1.08	\$1.08
29	1	1.1kΩ	1/4W Resistor	Digikey	1.1KQBK-ND	Yageo	CFR-25JB-1K1	\$0.06	\$0.28	5	\$0.02	\$0.02
30	1	10Ω	1/4W Resistor	Digikey	10QBK-ND	Yageo	CFR-25JB-10R	\$0.06	\$0.28	5	\$0.02	\$0.02
31	1	220Ω	1/4W Resistor	Digikey	220QBK-ND	Yageo	CFR-25JB-220R	\$0.06	\$0.28	5	\$0.02	\$0.02
32	3	510Ω	1/4W Resistor	Digikey	510QBK-ND	Yageo	CFR-25JB-510R	\$0.06	\$0.28	5	\$0.02	\$0.06
33	1	100Ω	1/4W Resistor	Digikey	100QBK-ND	Yageo	CFR-25JB-100R	0.056	\$0.28	5	\$0.02	\$0.02
34	1	1kΩ	1/4W Resistor	Digikey	1.0KQBK-ND	Yageo	CFR-25JB-1K0	\$0.06	\$0.28	5	\$0.02	\$0.02
35	1						Assuming Case/Manufacturing Costs		\$8.00		\$8.00	\$8.00
											Total Parts	49
											Prototype Cost	\$60.62
											500+ Cost	\$32.35

Table 2: Manufacturing Parts List

Prototype Parts List

Item	Qty	Value	Description	Distributor	Part No.	MFG	MFG Part No.	Unit	Sub	Min. QTY
1	1	PT1848	115Vac Transformer,12.6Vct @ 1.2A	RadioShack				\$7.99	\$7.99	1
2	1	LM2577	3A Step-up voltage regulator	Digikey	LM2577T-ADJ-ND	National	LM2577T-ADJ	\$5.42	\$5.42	1
3	2	LM350T	Adjustable Linear Regulator 3A	Digikey	LM350TNS-ND	National	LM350T	\$2.29	\$4.58	1
4	1	RS403L	Bridge Rectifier 4A 200V	Digikey	RS403LMS-ND	Diodes Inc.	RS403L	\$1.56	\$1.56	1
5	2	-	T0-200 Heatsink 2.5 °C/Watt	Digikey	HS276-ND	Aavid Thermalloy	529802B00000	\$1.38	\$2.76	1
3	1	100uH	100uH Inductor Axial	Digikey	DN7425-ND	API Delevan, Inc.	2474-25L	\$2.94	\$2.94	1
7	1	-	Varistor, Surge Protection (140Vac max)	Digikey	BC1449-ND	BC Components	2322 595 51416	\$0.67	\$0.67	1
3	1	-	Varistor, Surge Protection (275Vac max)	Digikey	BC1433-ND	BC Components	2322 594 52716	\$0.53	\$0.53	1
3	6	1N5821	Schottky Diode 3A 30V	Digikey	1N5821DICT-ND	Diodes Inc.	1N5821-T	\$0.68	\$4.08	1
0	2	1N4148	Small Signal Diode 100V 200mA	Digikey	1N4148FS-ND	Fairchild Semiconductor	1N4148	\$0.06	\$0.12	1
1	1	2N2905	2N2905 Transistor PNP	Digikey	497-2572-5-ND	STMicroelectronics	2N2905A	\$0.95	\$0.95	1
2	1	LM301A	Operational Amplifier	Digikey	LM301ANNS-ND	National	LM301AN	\$1.20	\$1.20	1
3	2	-	8 pin Sockets	Digikey	A24794-ND	AMP/Tyco Electronics	2-640463-2	\$0.36	\$0.72	1
4	1	-	Red Led	Digikey	67-1064-ND	Lumex Opto/Components	SSL-LX3044HD	\$0.10	\$0.98	10
5	1	-	Green Led	Digikey	67-1062-ND	Lumex Opto/Components	SSL-LX3044GD-5V	\$0.33	\$3.30	10
6	1	330uF	ElectCapacitor	Digikey	493-1343-ND	Nichicon	UVZ1H331MPD	\$0.60	\$0.60	1
7	5	.1uF	50V Radial Ceramic Capacitor	Digikey	399-2143-ND	Kemet	C317C104M5U5CA	\$0.16	\$0.80	1
8	1	6800uF	Capacitor 35 Volt Electrolytic Radial	Digikey	P6660-ND	Panasonic -ECG	ECO-S1VA682BA	\$4.11	\$4.11	1
9	1	1000pF	100V Ceramic Disk Capacitor	Digikey	1383PH-ND	BC Components	D102K20Y5PH63L6	\$0.08	\$0.77	10
0	1	1uF	50V Radial Electrolytic Capacitor	Digikey	P993-ND	Panasonic - ECG	ECE-A1HKS010	\$0.14	\$1.40	10
1	1	1.5kO	1/4W Resistor	Digikey	1.5KQBK-ND	Yageo	CFR-25JB-1K5	\$0.06	\$0.28	5
2	1	3kO	1/4W Resistor	Digikey	3.0KQBK-ND	Yageo	CFR-25JB-3K0	\$0.06	\$0.28	5
3	3	4.3kO	1/4W Resistor	Digikey	4.3KQBK-ND	Yageo	CFR-25JB-4K3	\$0.06	\$0.28	5
4	1	20kO	1/4W Resistor	Digikey	20KQBK-ND	Yageo	CFR-25JB-20K	\$0.06	\$0.28	5
5	2	15O	1/4W Resistor	Digikey	15QBK-ND	Yageo	CFR-25JB-15R	\$0.06	\$0.28	5
6	1	300O	1/4W Resistor	Digikey	300QBK-ND	Yageo	CFR-25JB-300R	\$0.06	\$0.28	5
7	2	.1O	10W Resistor	Digikey	20JR10-ND	Ohmite	20JR10	\$1.96	\$3.92	1
8	1	51O	1/4W Resistor	Digikey	51QBK-ND	Yageo	CFR-25JB-51R	\$0.06	\$0.28	5
9	1	10O	1/4W Resistor	Digikey	10QBK-ND	Yageo	CFR-25JB-10R	\$0.06	\$0.28	5
0	1	220O	1/4W Resistor	Digikey	220QBK-ND	Yageo	CFR-25JB-220R	\$0.06	\$0.28	5
1	5	510O	1/4W Resistor	Digikey	510QBK-ND	Yageo	CFR-25JB-510R	\$0.06	\$0.28	5
2	1	1kO	1/4W Resistor	Digikey	1.0KQBK-ND	Yageo	CFR-25JB-1K0	\$0.06	\$0.28	5
3	1	2kO	1/4W Resistor	Digikey	2.0KQBK-ND	Yageo	CFR-25JB-2K0	\$0.06	\$0.28	5
4	1	30kO	1/4W Resistor	Digikey	30KQBK-ND	Yageo	CFR-25JB-30K	\$0.06	\$0.28	5

Total Parts 55
Prototype Cost \$53.04

Table 3: Prototype Parts List

Appendix A

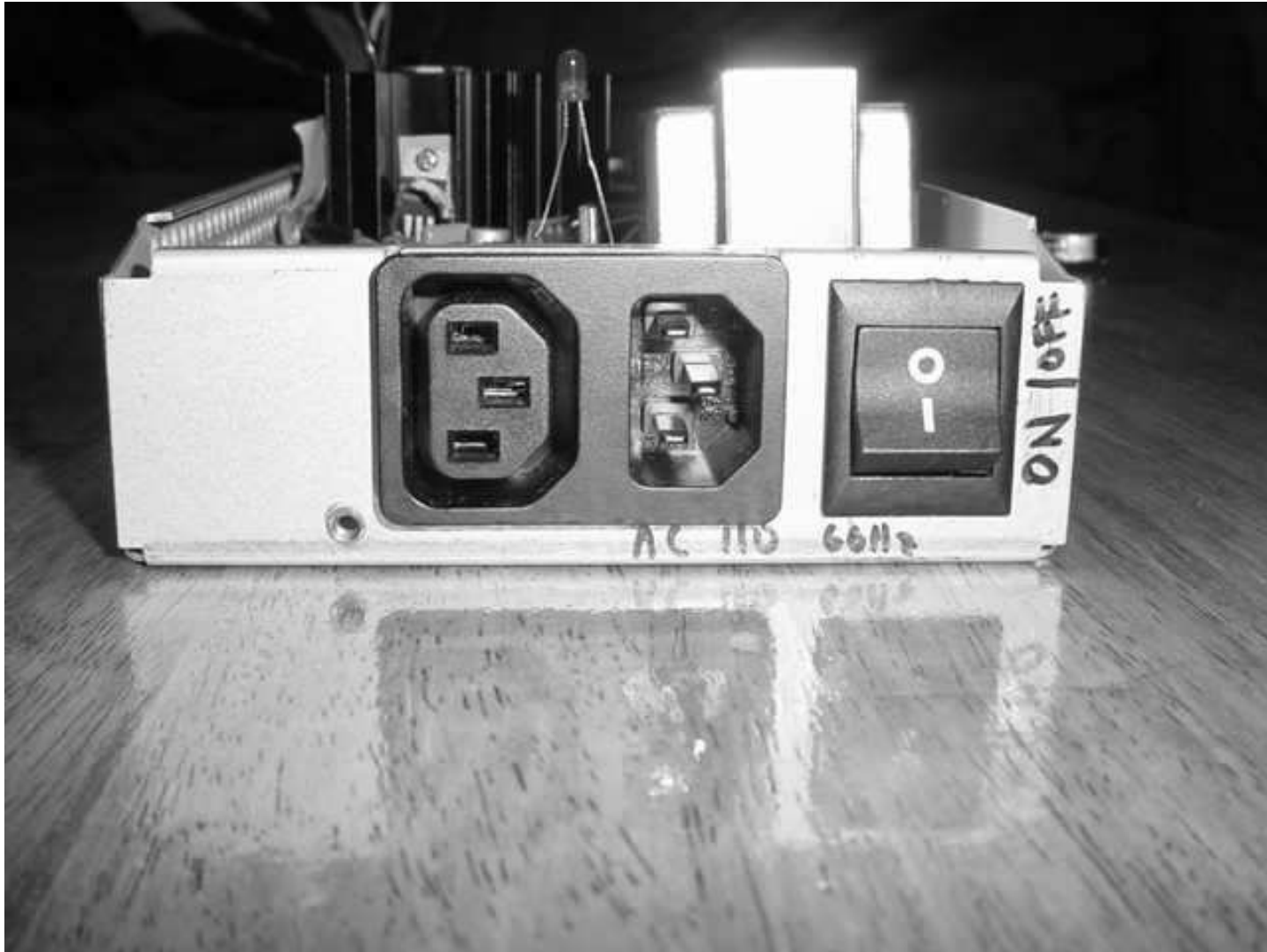


Figure 7: AC input selection

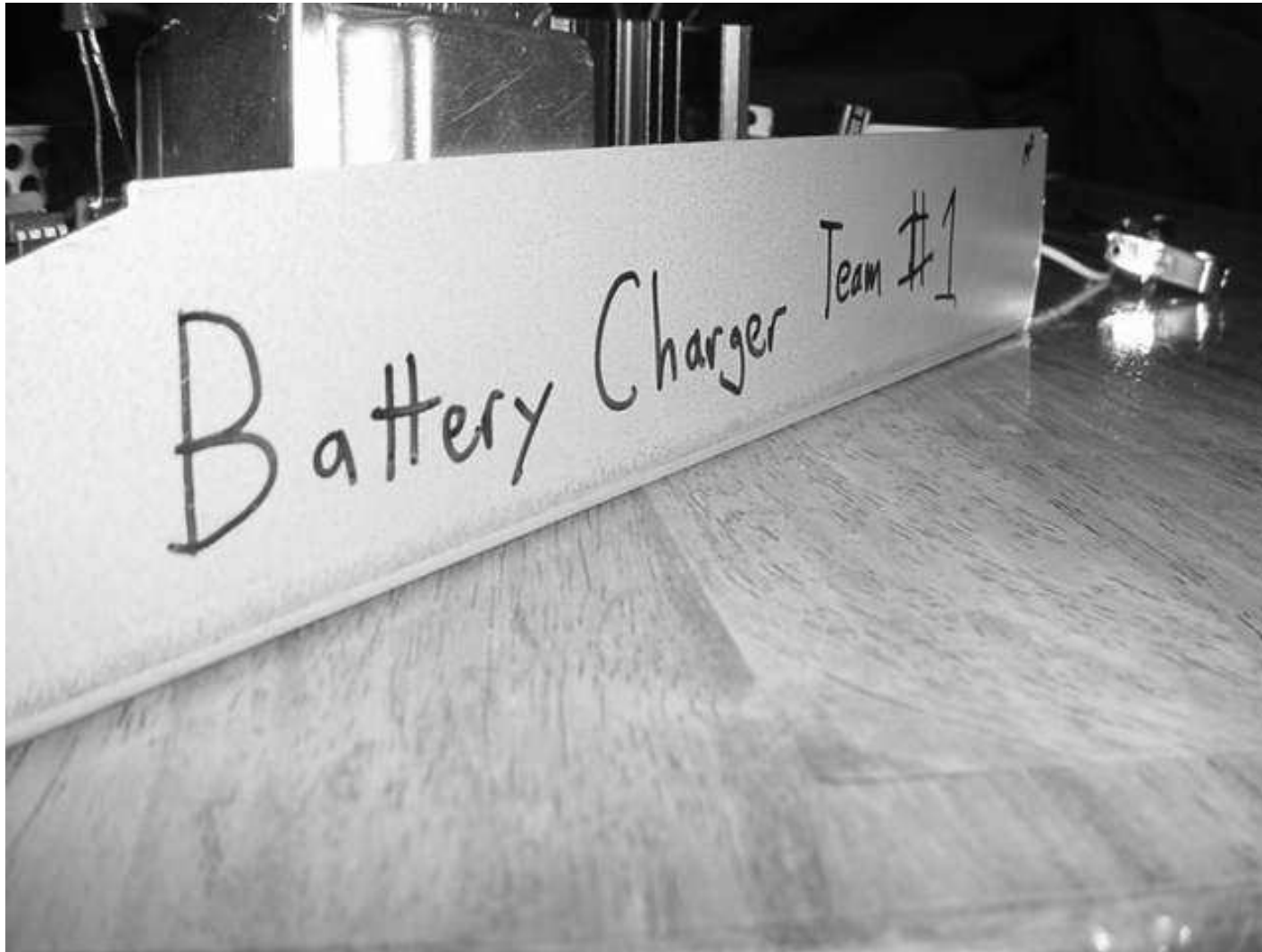


Figure 8: Battery Charger Team 1

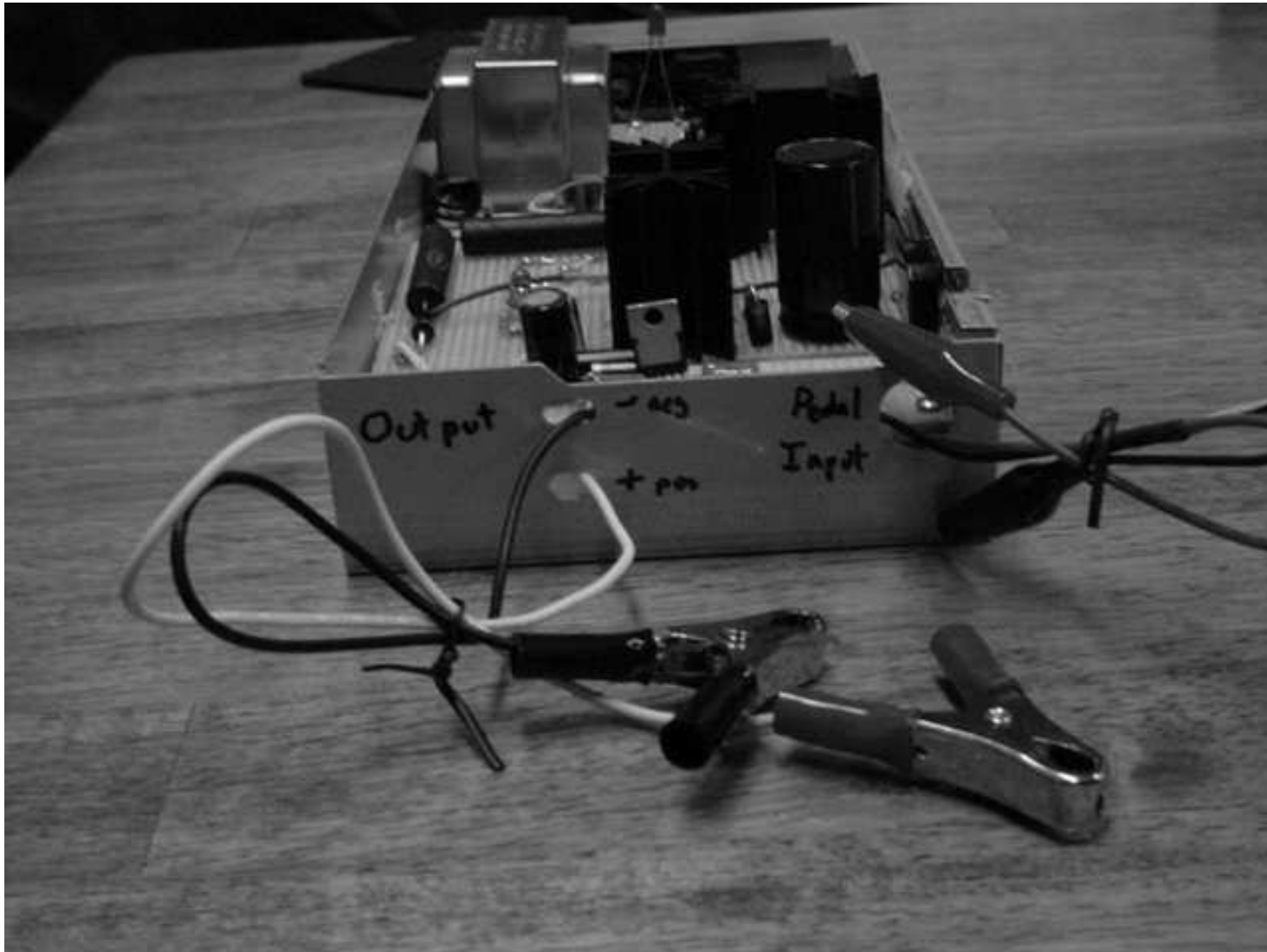


Figure 9: Output connection

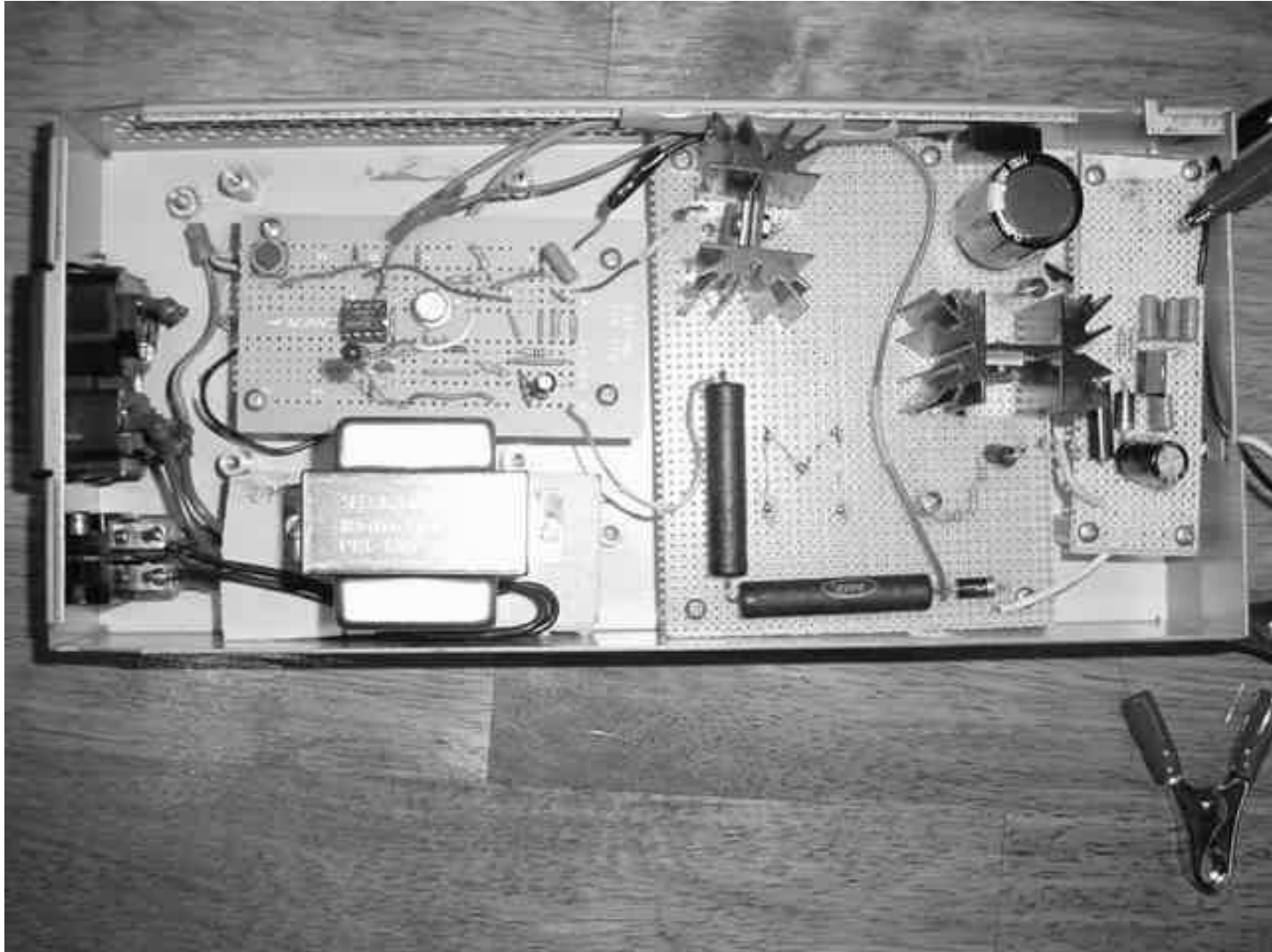


Figure 10: Top view of the Circuit