Universal Charger for Car battery

Design Modifications and Progress Report

Team 7

December 5, 2004

Responsible Engineers

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EE2799
Battery
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Project
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	Ideal	Actual
CONTENT	50	44
WRITING	30	26
FORMAT	20	15
GRADE		**85**

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1. Introduction

This report explains to the reader all of the design modifications and progressions that have taken place since the last progress report was submitted on November 24, 2003. As part of the design process, some elements of the universal battery charger have changed. Other elements, which we did not have time to consider before that date, have now been added to the design. After reading this report, the reader should have a good understanding of all of the revisions to our project, including the overall design and our project schedule.

The original design for the battery charger consisted of three main modules: the AC/DC conversion circuit, the charging circuit, and the overcharge protection circuit, which were to be supported by other important modules such as the cooling system and casing. This remains our overall design approach. However, extensive revisions have been made to each of the three main modules based on new information about the components we have selected and the inputs we will be receiving. In addition, the cooling system and casing designs, which were considered secondary to the charging circuitry a couple of weeks ago, have now materialized. All in all, the design changes made do not reflect a departure from our original design, but rather a fluid progression toward implementing it.

2. Design Modifications

Several small changes were made to each of the three main circuits. The AC/DC conversion circuit remains essentially the same. After discussing the circuit together, we found that the possibility of voltage spikes had not been addressed by our design. Thus, the only real change made to this circuit was the inclusion of a voltage suppressing device to handle power surges.

The corrections of the errors in the regulation circuit were essential to ensure appropriate functionality of the circuit. First, we realized that the input current and voltage going into the regulator being reduced to the output current and voltage was going to dissipate substantial power, and we needed to compensate for excessive heat production. We chose to implement a heat sink on the surface of the voltage regulation IC. Fortunately, the package of the regulator, TO-220, is very common and gave us some flexibility in choosing the most suitable heat sink. Furthermore, the voltage regulator was originally configured to output 15 volts, and when the battery drained the maximum current of 2 A, it would be charging at 14.8 volts because of the voltage drop across the sensor resistor. However, this was higher than our original intended charging voltage of 14.7 volts, and even worse, when the battery started to draw less and less current, the voltage applied to it could raise as high as 14.95 volts, or the high charging voltage might force the battery to draw more current than it should for a longer period of time than it should. In this situation, by the time the overcharge protection circuit kicked in, it might be too late. This problem can be fixed by changing the adjustable resistor values. Another problem we had to overcome was that we used resistor values and a capacitor value that were not available in the ECE kit or ECE shop. While these will be fine for our final design, we would like to use more common, available resistors for our prototypes. The first resistor value that needed modification, a 2.5kΩ resistor, was one that was activated by the trickle charge relay. The second resistor value that was not available was the 13.7kΩ, which required equivalent circuitry that was in stock as well. The capacitor value that needed modification, a 3.3uF capacitor, was the capacitor that was positioned at the output of the regulator. Section 3.2 of this document describes the operation details of this circuit and the changes we made.

The overcharge protection circuit underwent extensive re-configuration, but the basic principle behind its operation remained the same. Section 3.3 gives an overview of the operation of this circuit, and within that section, Figure 5 shows the circuit schematic. The circuit senses the current going to the battery, and when the current drops below 400 mA, the circuit re-configures the charger by activating a relay. One problem was that when engineering this circuit, we designed the difference amplifier portion to amplify the difference by a factor of -10, without realizing that the op-amps used cannot produce a voltage below that of their negative supply rail, which in this case is ground. Therefore, a voltage gain of -10 was impossible to achieve, since the op-amps are incapable of outputting a negative voltage. Simply wiring the circuit to have a gain of positive 10 presented a new problem, since the Schmitt trigger sub-circuit cannot have a low activation threshold that is higher than the low output saturation voltage of the op-amps used, which is 0.1 volts (For a precise explanation of how the Schmitt trigger works, refer to our 4th report, the Overall Design Progress Report, section 3.4.2.). The final problem we discovered with the circuit as previously designed was that if someone hooked a load up to the battery while it was charging, it would draw extra current from our charger. This would trick the overcharge protection circuit into thinking that the battery needs to be charged more, since the circuit assesses the battery's charge based on the amount of current leaving the charger. The charger would then continue to charge the battery at a high voltage, possibly overcharging and ruining it.

To overcome these problems, we first hooked up the difference amplifier portion of the circuit the opposite way of how it was hooked up before. This overcame the problem of producing a negative voltage by simply inverting the "terminals" of the difference amplifier across the sensor resistor. The problem of the activation threshold of the Schmitt trigger was solved by re-configuring the difference amplifier to have a gain of only 2, and re-configuring the Schmitt trigger such that its activation threshold was 80 mV instead of -400 mV. This was done by changing the configuration resistor values for both sub-circuits. Now, when the current reaches the desired switching value of 400 mA, it produces a 40-mV voltage drop across the 0.1-ohm sensor resistor, which is amplified by the difference amplifier to be 80 mV, which activates the Schmitt trigger at its new threshold. The final problem, which occurs when someone hooks up a device to the battery while it is charging, was solved by adding a user option in the form of a switch. When the user wishes to connect a device to the battery while it is charging, the switch must be toggled. It activates the relay which re-configures the charging circuit to charge at the safe trickle voltage. Essentially, this switch is the manual counterpart to the automatic overcharge protection circuit.

3. Overview of Revised Design

The block diagram in Figure 1 shows that the top-level design of our battery charging unit has not changed. The signal flow from input to output of the device remains the same, along with the same basic approach, which utilizes an AC/DC conversion circuit, a cooled charging circuit, and an overcharge protection circuit to turn the input power into power that can charge our battery. The environment in which these subsystems operate is regulated by the cooling system of the charging circuit and the casing.

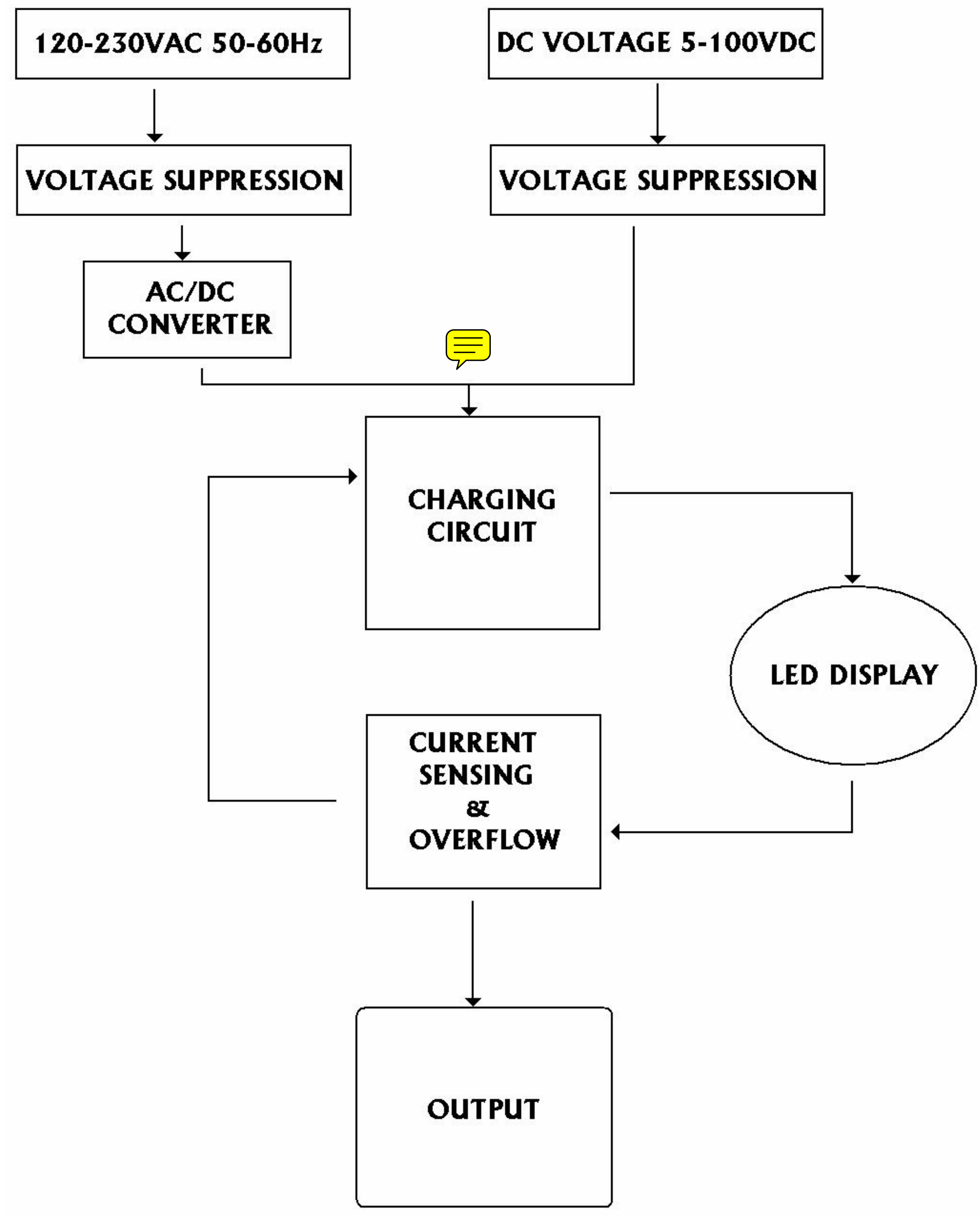

Figure 1: System Block Diagram for the Universal Car Battery Charger

3.1. AC/DC Conversion Circuit

The original design for the AC to DC converter was a good concept in theory. It effectively converted an AC voltage to a DC voltage for the voltage regulator (see Figure 2).

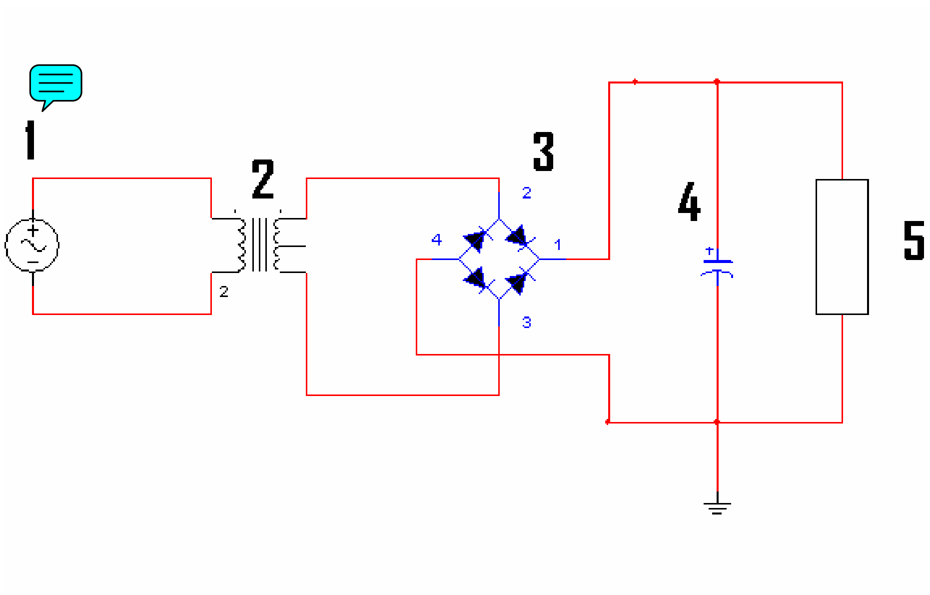

Figure 2: Original AC/DC Conversion Circuit

Number one in Figure 2 represents an AC voltage in the form of a sine wave, either 220 V at 50 Hertz or 120V at 60 Hertz, from a “wall outlet” source. Number two represents a transformer. It will be able to convert either of the two possible input sources, and output a stepped-down sine wave of 18 volts rms at 1.944 amps. There will be mechanical switches to allow the user to select 120V or 220V, which will be labeled and easy to use. Number three is a full wave bridge rectifier. The full wave rectifier will be used because the sine wave still has negative components, but the desired power output needs to be positive. The full wave bridge rectifier is able to convert the signal to an entirely positive signal. It is also able to handle up to 4 amps, which is double what out system is outputting, and is able to withstand a peak inverse voltage of about 100V, which is far more than our system would ever generate. Number four is a high pass filter; in this case it is just a capacitor. The capacitor is rated at 6800 micro Farads because our calculations revealed a 4100 micro Farad capacitor was needed. The size difference exists to address tolerance issues. The capacitor, acting as a filter, is able to convert the signal from the rectifier to a saw tooth output that is almost a constant voltage. The minor ripples will then be converted in the next portion of circuit. Number five represents the next sub-system.

There is one major design omission that cannot be accounted for in most simulations or calculations, and that is voltage suppression. The voltage and current of a simulation can account for maximums and minimums as well as tolerances, but it does not generate spikes, severe drops, or blackout conditions that are common to the power grid in which our device will be used. A voltage suppressor, number two in Figure 3, will suppress large spikes that may come from "wall outlets" and protect the rest of the circuit. The suppressor will be rated to suppress any voltage above 315 V. This is because the peak voltage from a 220V AC source is about 310 V.

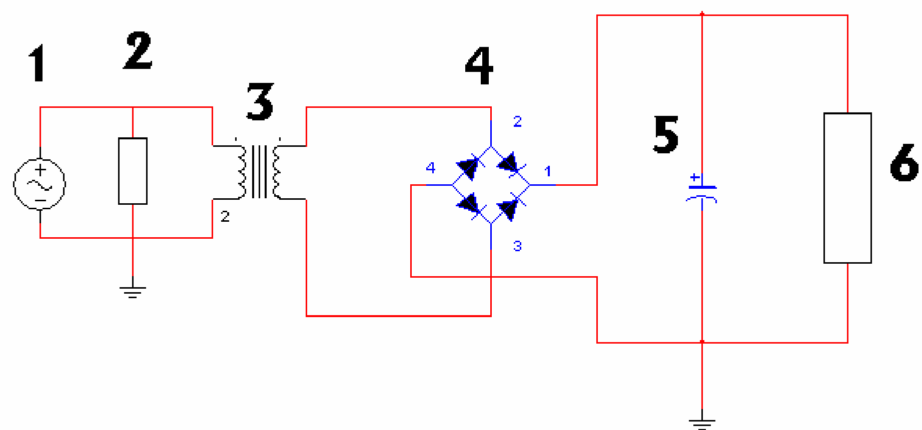

Figure 3: Revised AC/DC Conversion Circuit

Even though the transformer would probably be able to handle some voltage spikes, it is superior design to include a suppressor. This will make the signal going to the transformer cleaner and easier for the transformer to handle. If there was a spike large enough and the suppressor was to be destroyed it would be beneficial to destroy the suppressor, not the transformer. The suppressor is less than a dollar in cost, and it would be very easy to replace. The transformer, however, has numerous wires and two switches, which would be much harder to repair or replace, and would cost over fifteen dollars.

3.2. Charging Circuit and Cooling

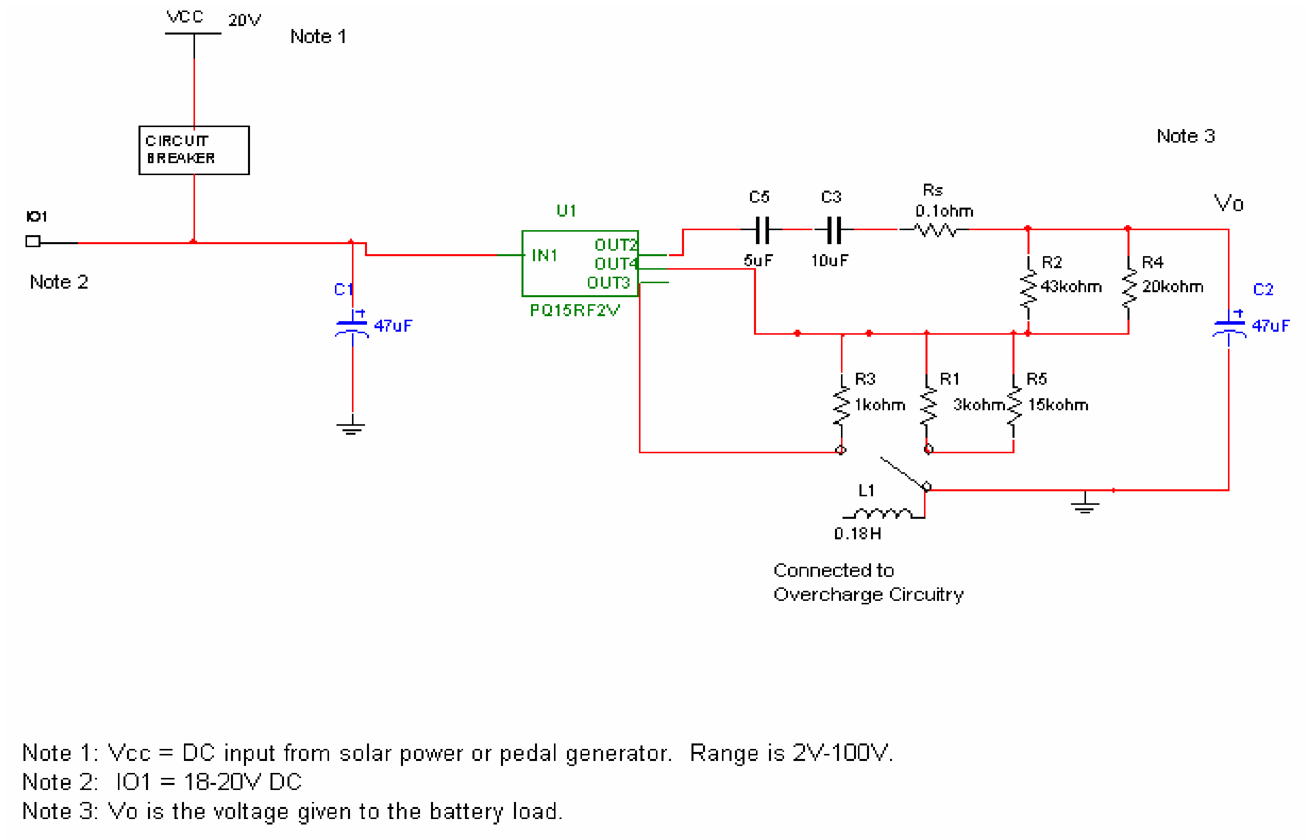

Figure 4: Revised Regulation Circuitry

The revised charging circuit is shown in Figure 4**.** The first set of changes made was on the external circuitry of the voltage regulator. First, the issue of lowering the output voltage of the regulator so the overcharge circuitry can be activated was solved by reverting back to a previous design where we chose resistor values to output 14.8 volts instead of 15 volts. This way, the lowest charge voltage applied across the battery would be 14.6, and the highest would be 14.75, values which are much closer to the charging voltage recommended by manufacturers (www.panasonic.com). The adjustable resistances were changed to 1k Ω and 2.5kΩ to produce the desired output. The trickle charge relay will switch between these two resistances depending on the charging state. Also, to be able to use resistances and capacitances in the ECE lab kit and in the ECE shop, we chose some different values and used parallel and series combination laws to calculate equivalent values. For the 2.5kΩ resistor above the trickle charge relay, we used the following calculation to determine an equivalent combination:

$[\ (1/15k\Omega) + (1/X)\ ]^{-1} = 2.5k\Omega$

$X = 3k\Omega$

We implemented the 3kΩ and 15kΩ resistors, which are in parallel in order to equal 2.5kΩ. Most importantly, these values are in our ECE kit, so the ease of repair is very high if one of the resistors becomes faulty. The same formula was used to choose the equivalent resistances for the 13.7kΩ:

$[\ (1/43k\Omega) + (1/X)\ ]^{-1} = 13.7k\Omega$

$X = 30k\Omega$

The 43kΩ and 30kΩ resistors are in the ECE lab kit and will benefit our design in the same fashion as the 3kΩ and 15kΩ. Next, to choose an equivalent capacitance for the 3.3uF, we applied the law that capacitances in series are equivalent to resistors in parallel. Using the following formula we determined the capacitances:

$[\ (1/10uF) + (1/X)\ ]^{-1} = 3.3uF$

$X = 5uF$

The capacitances 5uF and 10uF will be placed in series and are available in the ECE kit and shop. Just like the resistors, we expect complications to arise in testing our circuit and we need to make sure that backups are immediately available. Lastly, for the appropriate heat sink for the voltage regulator, we needed to take the following specifications into account: power dissipation, package size, thermal resistance (heat sink to air), and cost. The most difficult specification to determine was the thermal resistance. Assumptions needed to be made regarding the thermal resistance from junction to case and from case to heat sink. Using the specification from a similar voltage regulator we chose the junction to case resistance to be 5 *˚C/watt.* To determine the case to heat sink resistance we assumed that we would not be making an ideal connection between the case and heat sink, so chose a safe estimate of 2 *˚C/watt.* Using the following formula we determined the thermal resistance Θ_{HA}:

$$P_d = \frac{T_j - T_a}{\Theta_{JC} + \Theta_{CH} + \Theta_{HA}} \rightarrow 10 \text{ watts} = \frac{150^{\circ}C - 30^{\circ}C}{5^{\circ}C/watt + 2^{\circ}C/watt + \Theta_{HA}}$$

$$\Theta_{HA} < 5^{\circ}C/watt$$

To be in a safe range in order to not damage the regulator, we found a heat sink with a 4 ˚*C/watt* thermal resistance. The package size of the regulator is TO-220 so the heat sink package is TO-220. With these two specifications we were able to find a heat sink with suitable power dissipation, 15 watts. Our regulator will not be dissipating more than 10 watts so this value is fine. The lowest cost for a heat sink that matches these criteria is $3.21, which is not excessive but not very cost-effective. This is a forced tradeoff we decided to make.

3.3. Overcharge Protection Circuit

The overcharge protection circuit prevents possible damage to the battery by switching the charger to charge the battery at a lower charging voltage when it is sensed that the battery is already mostly charged. The battery will naturally draw less and less current as it replenishes its charge. Therefore, the current flowing from the charger to the battery is a good indication of the amount of charge stored in the battery. Figure 5 shows the circuit we have designed to sense and process this information.

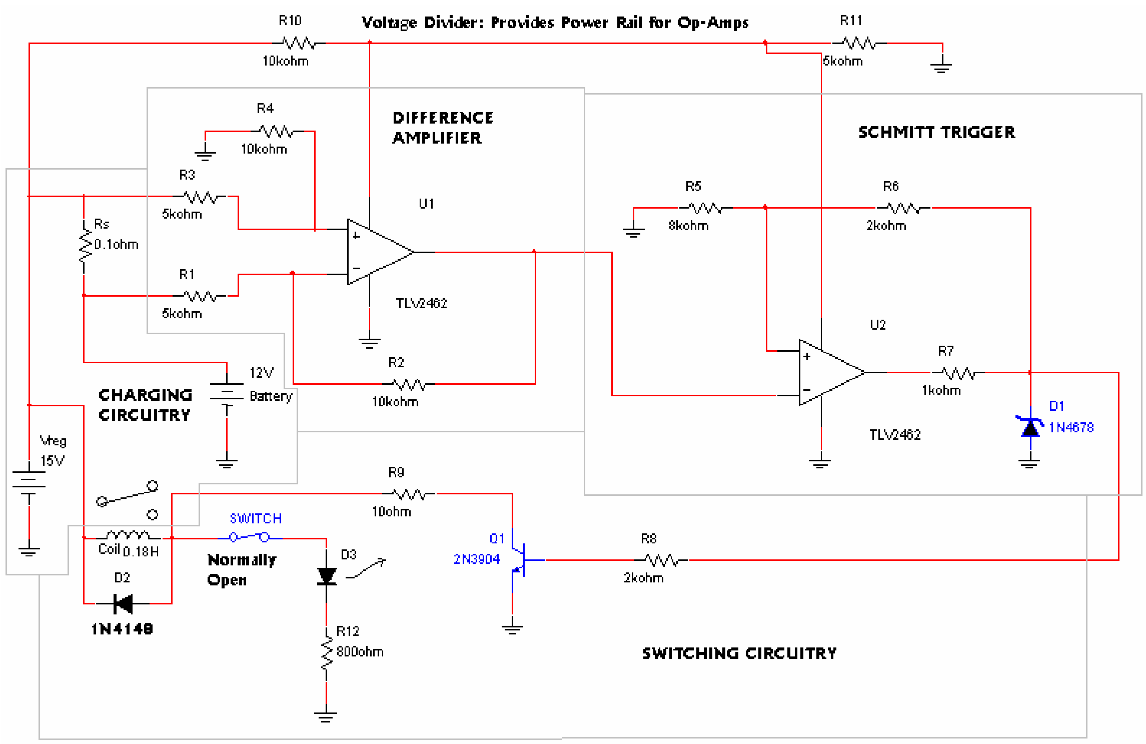

Figure 5: The Overcharge Protection Circuit

The circuit consists of three stages, each of which is crucial to its functionality. The current flowing from the charging circuitry (labeled as Vreg) to the battery goes through sensor resistor Rs, producing a voltage drop. This voltage, which is a positive difference because of the new way we hooked the resistor up, is amplified by the difference amplifier stage, which is configured by resistors R1 – R4. Because of the configuration change we made, this amplifier now has a gain of 2. When the amplified voltage at the output of the difference amplifier drops below the new threshold of 80 mV, the Schmitt trigger, re-configured by resistors R5 and R6, will output a logic high of above 4.6 volts. This voltage will activate the switching circuitry by being applied to the base of transistor Q1. This will turn the transistor on, which will in turn draw current through the coil, which will switch the relay to set the charging circuit to trickle-charge mode. The addition of the normally open switch at the base of the coil provides an alternate path for current to go through if the user of the charger decides to hook up another device to the battery while it is charging. This switch, when closed, will activate the relay in the same fashion as the automatic circuitry, preventing the battery from being overcharged by a high voltage.

For precise details of the operation of the overcharge protection circuit, see Section 3.4 of the 4th report, our Overall Design Progress Report. The design changes made to this circuit as of the publication of this report are certainly to our advantage. The re-configuration of the difference amplifier and Schmitt-trigger stages absolutely had to be done, since our previous configuration was based on faulty knowledge of the use of op-amps. The addition of the toggle switch for hooking up a device to the battery while charging is also a very important precaution, for the overcharge protection system was not designed to compensate for additional current drawn by outside devices other than the battery.

3.4. Casing

There was a variety of casing options available to choose from. Possibilities included steel, aluminum, titanium, plastics, wood, and marble. After further research it was realized that the most plausible and cost effective enclosure was plastic because it is durable and lightweight. Some characteristics that needed to be accounted for besides durability were temperature ranges, whether it is waterproof (if possible), and whether we could drill holes and maintain structural integrity. We were able to do all of these modifications with a plastic case, and most importantly, we could do them cheaply. There are a variety of chemical compositions of plastics that result in different strengths and appearances. For example, a nice transparent plastic box like the one in Figure 6 would allow for a more visually stunning product.

Figure 6: A Visually Impressive Case

However, this container is designed to house model cars, and although it would be adequately durable, it has a many drawbacks. This was made to showcase die-cast cars, not to be used as protective casing in harsh environments like Mali. Also, there is the fact that it will collect unwanted attention and unnecessary handling, since people will want to see all the inner workings. This could lead to people dropping or shaking it, or kids playing with it, and the charger is not a toy.

A more realistic enclosure would be like the one in Figure 7.

Figure 7: Our Case

This enclosure is designed to house electrical components (according to Radio Shack), and having used these boxes in the past, we are confident of its ability to withstand the nominal wear and tear that it will encounter. The plastic is durable, and from experience with past boxes, we are confident about its ability to maintain structural integrity after holes and other modifications are made to the box.

3.5. Display

The display is being implemented as a series of LED's, although the information they will convey is much different than we originally envisioned. At first, we imagined that we would have an array of four to eight LED's that would somehow convert a current or voltage signal from the battery into a readable output. However, after modeling this type of display, we found that it would draw more power than we were comfortable with giving up. Eight LED's drawing a typical 15 mA each would make for a current drain of 120 mA, or 0.12 A. While this might not sound like much, we must take into account that some car batteries can be charged safely with an initial current of 0.15 C amps, where C is the capacity of the battery in amp-hours ("VRLA Batteries", www.panasonic.com). This means that even a small lead-acid battery with a capacity of only 60 amp-hours could potentially be charged with 9 amperes, and our charger only manages to use 2. Therefore, we would like to conserve as much current as possible and not waste it in the display.

Instead of an array, we will implement a series of LED's that tell the status of the charger, and not the battery itself. For example, we envision an LED to indicate that the battery is currently charging, another one to indicate the charge mode of the charger (high float voltage or trickle voltage), and perhaps another to warn the user of errors, such as hooking up the charger with the reverse polarity. One LED, to indicate that the user has activated the switch to charge the battery with a device hooked up to it, is already provided for (see Section 3.3, Figure 5). These LED's, though numerous, are only turned on when the battery charger is not in its high float voltage charging mode, with the exception of the "ON" LED. Therefore, they do not draw power when we need it most.

We realize that this is somewhat of a sacrifice compared to our old plan of a more extensive LED array that would actually give an indication of the amount of power in the battery, but we feel that it is well worth it. The customer specification for a charge indicating display was determined at the beginning of the project to have much lower importance than the customer specifications of low cost and high efficiency (refer to Progress Report #2). Thus, to sacrifice some of the functionality of the display in an effort to cut cost and especially raise efficiency is a wise move from the overall perspective of the project.

4. Revised Project Schedule

We are very satisfied with our progress thus far on this project, and are right on schedule to have a working prototype by December 17, 2003. We have updated our Gantt chart, shown in Figure 8, to reflect our progress so far and to be more flexible with the way we get things accomplished. There are specific start dates for each sub-project, but our contingency plan provides for them all to be done by December 14, 2003.

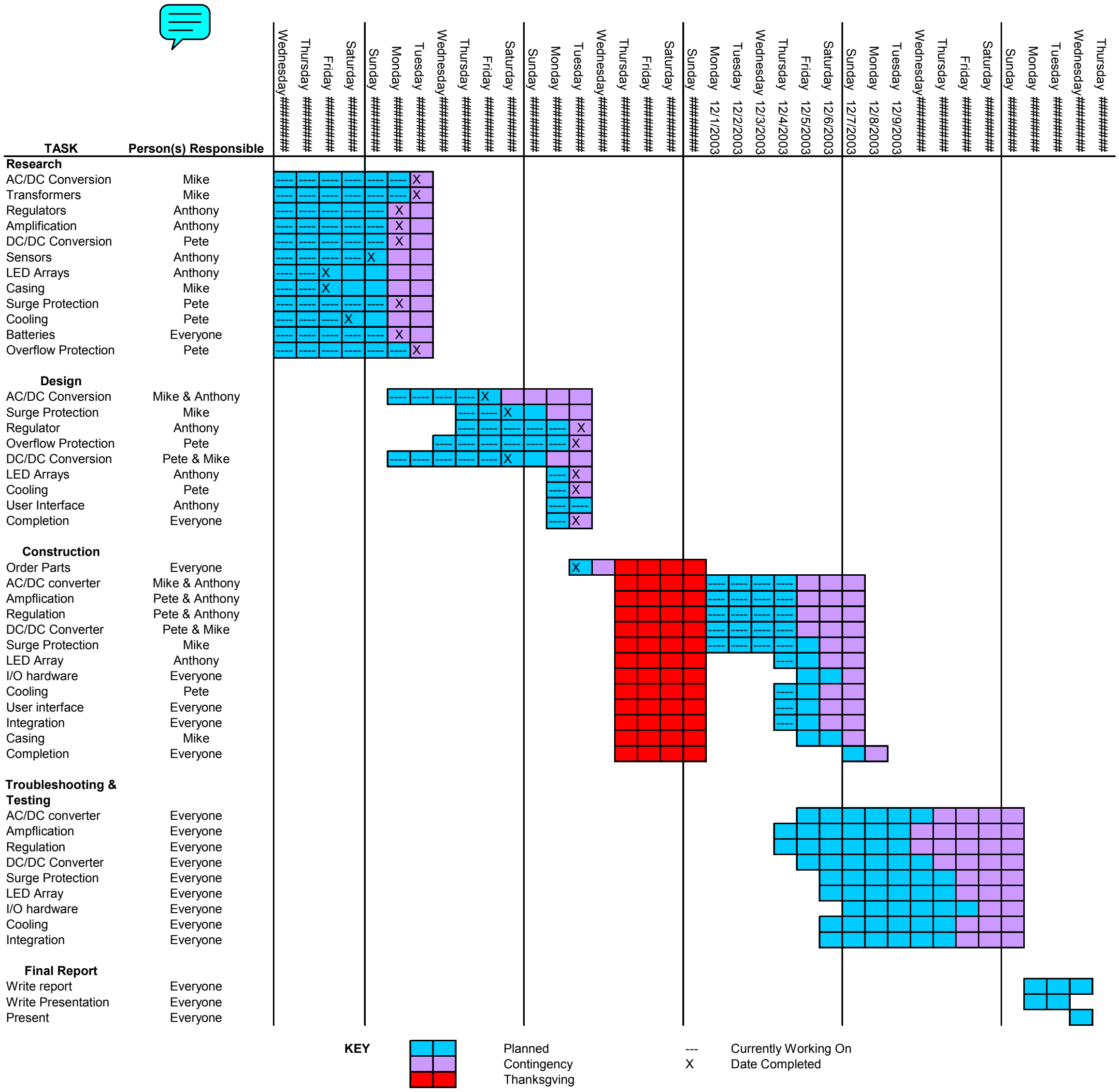

Figure 8: Our updated Gantt Chart

As our Gantt chart indicates, we are presently in the construction phase. With the exceptions of a heat sink and a transient voltage suppressor, all of our parts are ready for prototyping. Our goal is to complete the construction phase by this Sunday, but this deadline may be pushed up a couple days depending on when our late parts come in. Because we are planning for many problems to arise in testing, we comfortably allotted all of next week to test and troubleshoot. If parts that are available through ordering-only happen to become damaged in the testing process, then we will certainly be experiencing EE2799 "crunch time" to the fullest extent. As indicated in our chart, we will all be active in the testing and troubleshooting process next week. It is our contention that problems will be solved more practically and quickly with three brains at a lab bench, instead of one or two. The last three days of school before the final report and presentation are due will be spent composing our final report. We have found that the ideal process to finishing a report is to have all three partners working at computers next to each other with one member designated with the task of putting all the parts together (Anthony). This process results in expeditiously completing reports with high quality content.

5. Conclusion

This report has enlightened the reader as to all of the progress we have made since Progress Report 4 was submitted almost 2 weeks ago. There are a good amount of design changes that we made at the circuit level of construction, but from a top-level, subsystem perspective, our design has not changed. We still feel that our overall scheme for implementing the charger is well thought-out and a solid design. In addition to the changes made to the existing circuits, we have developed ideas of how to implement the remaining support sub-modules, such as cooling, casing, and the display. We believe the design process is working out well for us, and as our revised Gantt chart shows, we have progressed according to plan.

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