Degree project

A Lithium-ion Battery Charger

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Summary

This thesis elaborately explores the circuit and theory of a Lithium-ion charger which can control the charging current and voltage. The main tasks of this charger can be divided into three parts: Charging theory explanation, charging circuit designing and explanation and simulation and measurements.

The charging theory is an important part in our thesis. The charging process should be divided into three parts: Pre-Charging, Constant Current Part and Constant Voltage Part. In the PC and CC phase, people use current to charge the battery, the difference being that in the PC phase, the current should be low (approximately 1/10 of the maximum rated current), while in the CC phase the current should be the rated current, the CC phase takes 30% of the full charging time. In CV phase, people use voltage to charge the battery. The current in the circuit should be decreased gradually before the charger is switch off.

This Lithium-ion charger is constituted by four parts: transformer, rectifier, voltage regulator and current regulator. A programmable support should be included, e.g. Arduino. This was not implemented in the project.

As for the transformer, we use one that converts 220V AC voltage to 18V AC voltage. As for the rectifier, we use a bridge rectifier, four diodes and on filtering capacitor can convert the 18V AC voltage to almost 18V DC voltage. As for the voltage regulator, we use the LM317 circuit. It can convert 18V DC voltage to the rated battery voltage.

As for the current regulator, we use a voltage controlled current circuit. It directly connects with LM317. The input voltage of the current regulator is given by LM317. Through adjusting the current control resistor we can control the output current, and use the current to charge the battery.

In the CV phase, we use a classical current regulator circuit. The input voltage is provided by the Arduino, through the amplifier and control resistor we can control the current of the circuit while keeping the output voltage constant.
Abstract

**Abstract:** Nowadays personal small electronic devices like cellphones are more and more popular, but the various batteries in need of charging become a problem. This thesis aims to explain a Lithium-ion charger which can control the current and voltage so that it can charge most kinds of popular batteries. More specifically, Li-ion battery charging is presented. The charging circuit design, simulation and the measurements will also be included.

**Keywords:** Li-ion battery, charging theory, current control, voltage control.
Preface

One day in February, I remembered, my cellphone’s battery run out. When I wanted to charge it, I found my charger was broken. I could just ask my partner to borrow a charger, but the rated voltage and current is difference. I did not notice it, so after charging my battery was gone. At that time an idea occurred me: I want a special charger which can adjust the voltage and current so that I can charge various batteries. After the idea, this project was born.

At first time, I just want to make a simple circuit without any chip to control the current and voltage, unfortunately, we could not find an efficient way to solve it, we find we cannot avoid the chip. But fortunately, finally we made a product support by Arduino. Actually we met many difficulties, because no company support us, we can just search the information in internet and library. But the most fortunately is that our supervisor Pieterella gave us really a lot of help. In fact we cannot finish this project without her help.

Here we give our great thanks to our beautiful supervisor Ellie, wish you can happy forever.

Hanwen Xing
Five years ago, the EU enforcing the entire cell phone manufacturer product the same species mobile interface which is MicroUSB, the charger of mobile still cannot be a common charger.

So far as I know, the chargers of mobile phone have not improved so much during these years. It can only charging one fixed mobile phone. Because of selling job of cell phone manufacturer, the customers need to pay extra money for the chargers which have almost same operating principle.

It is not very hard to unite all different kinds of mobile charger, set the rated voltage and rated power to a default value in order to match all kinds of mobile phone by one charger. If this charger could mass production, it can not only reduce serious environmental pollution and huge waste of social wealth and resource, but also protect the interests of customers.

This is the reason why I want to choose this topic as the graduation thesis. In my opinion, the next generation of mobile charger is Non-charger life. People just bring their mobile to an area and the mobile phone could charge by itself. Like the Wi-Fi. No longer have to find multitudinous charger.

Thank for great help for my supervisor Ellie Cijvat. All my thinking and direction of study are inspired by her, every word are full of her focus and precious time.

Xin Liu
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1. Introduction

As for one of great inventions that have changed the world, the battery has experienced a fairly complex development processing. Since 1800, the first battery was invented by Alessandro Volta. The wheel of history began to roll forward: In 1888, Dr. Gassner invented the first dry battery. Two years later, inventor Thomas Edision made a chargeable nickel iron battery. Based on the previous results, in 1899, Waldmar Jungner invented the nickel-cadmium battery which was produced commercially in 1910, the miniaturization and lightweight of the battery being established started. In 1991. The second electronic revolution was coming: Sony Company producing of the chargeable Li-ion battery. Until now Li-ion battery plays an important role in the battery industry, pushing the miniature electronic component going forward. [1]

Nowadays, the number of personal electronics become more and more popular, but the various types of batteries become a kind of trouble. There is a need for general charger which can control the output voltage and current. This bachelor thesis elaborates the charging theory with focus on Li-ion battery. A kind of Lithium-ion charger which can be automatically controlled by arduino/PLC will also be showed. The main tasks of this charger can be divided into three parts: Charging theory, design of a charging circuit and simulation and Measurements. This Lithium-ion charger is constituted by four parts, transformer and rectifier: bridge rectifier, voltage regulator and current regulator. The simulation by LTspice and measurements will also be included.
2. Charging Theory

Several years ago it was hard to imagine that people could use their electronic products.
While the market of electronic products such as mobile phones and portable devices grows rapidly, the demand of lithium battery for fast charge, long duration, and long life cycle increases significantly as well.
But the invention of high capacity battery changed all the situation and led people to the portable age. Nowadays everyone can run their phone or mp3 the whole day and does not need to worry about power supply, much thanks to the development in battery technology.
As aiming to get the best performance out of a battery, the controller for a battery charging system plays an important role. There are several charging methods for a lithium battery, such as constant current (CC) and constant voltage (CV) charge.
A battery is a kind of electrochemical power source. This will discuss in more details later. In a general way, battery is a kind of electrochemical power sources. They are formed from of two electrodes which are electrically linked by active materials and immersed in an electrolyte with a porous separator to retake between them to prevent electric contact, but it will allow ionic through.
The positive (+) terminal of a battery is connected to an electrode covered with an aggressive oxidizing material which is capable of extracting electrons from different materials. The negative (–) terminal of a battery is connected to an electrode covered with a strong reducing material which is rich in lightly bound electrons and can easily give them away. Figure 2.1

The list below gives the most important characteristics of most batteries:

![Figure 2.1 Schematic of an electrochemical power source](image-url)
Below we will present the three points:

### 2.1 Chemical Capacity

Different materials determine the capacity and energy of a battery, and also have its own EDV, end of discharge voltage. When a battery is discharged, its voltage will gradually decrease until it reaches the EDV. If the battery keeps continuing the discharge. The battery will be damaged.

To compare batteries of different sizes, the capacity is represented in Ah/kg or in relation to volume (in Ah/l). These representations have their benefits depending on what is more important for a particular application.  

**Figure 2.2**

![Voltage profile during low-rate discharge of battery](image)

**Figure 2.2 Voltage profile during low-rate discharge of battery**

### 2.2 Battery Internal Resistance

A practical electrical power source which is a linear electric circuit may be represented as an ideal voltage source in series with an impedance. This impedance is termed the internal impedance of the source. Impedance is defined as resistance to AC current flow.
The internal resistance of a battery is defined as the opposition to the flow of current within the battery. Two main basic components that impact the internal resistance of a battery are electronic resistance and ionic resistance. The electronic resistance plus the ionic resistance will be the realistic total effective resistance.[4]

The electronic resistance encompasses the resistivity of the actual materials such as the metal covers, internal components and the relative effect between each other. Ionic resistance is the resistance to current flow within the battery owning to various electrochemical elements such as electrolyte conductivity, ion mobility and electrode surface area.

In summary, internal resistance could increase during discharge due to the active materials within the battery being used.

An example is given. As the charging time goes on the impedance of battery will change. An experiment named Total Effective Resistance Dual Pulse Method (Fig. 2.3) reveals the charging curve. This measurement technique should only be used as a general estimate of internal resistance, because many other factors should also be listed, like temperature, technical quality, humidity and age of battery.

![Resistance vs SOC](chart.png)

Figure 2.3 The variation of battery impedance corresponds to state of charge (SOC)

**2.3 Usable Power Capacity**

The integrated capacity when is lower than the load condition, also reaches the EDV is called usable power capacity. Because it depends on current and temperature, it needs to be specifically evaluated for each application.

Minimal system voltage will be reached earlier, therefore reducing the “usable” capacity that the battery can deliver, as illustrated in Figure 2.4. The chart shows the process of battery charging.
Temperature plays an important role to consider the actual environment of a device. Because the strong temperature dependency of impedance. In many cases battery self-heating (particularly if combined with heating for the device itself) can provide a reasonable run time even at quite low outside temperatures. If a device can survive without shutting down during the initial period before its battery has had a chance to warm up, it can continue operating almost at room temperature.

![Battery voltage profiles under load (dotted line) and without load (solid line).](image)

Figure 2.4 Battery voltage profiles under load (dotted line) and without load (solid line).

Figure 2.3.1 shows the three main phases of battery charging, which is pre-charge, fast charge constant current (CC) and constant voltage (CV) phase.

In the pre-charge phase, the battery is charged at a low rate when the battery cell voltage is below 3.0V. This phase might recover the passivating layer from a deep discharge state and prevent overheating. Note that the pre-charge phase is used to avoid the rapid raise in the temperature of the battery which is based on the characteristics of the battery’s internal resistance.

Ideal pre-charging method/constant current/constant voltage. Charging sequences and charge characteristics are showed in Fig. 2.5 and Fig. 2.6.
The proposed charging way with the designed charger could effectively raise the battery life for battery based electronic devices, such as mobile phones.

When the battery cell voltage reaches the typical 3.0V, the charger enters the CC mode. The reason why the current in CC mode increases slowly is to prevent overheating and delay the accelerated degradation. The fast-charge current makes the battery to be charged more quickly and translates the electrical energy into electrochemical energy in the battery. For normal charge rate, a battery charger usually takes about 30% of the charging time, for CC phase whereas it can charge 70% of its total power.

The charger starts to regulate the battery voltage and enters the CV phase while the charge current the charge current exponentially drops to a point of predefined termination current. The charge current is reduced by degrees with an increase within the battery’s resistance.
The battery charging time is very important. The fast-charge way allows the battery to be charged very quickly and translates the electrical energy into electrochemical energy in the battery. The lower the battery internal resistance is, the shorter the battery charging time is.

Figure 2.6 Ideal constant current/voltage charging sequences and charge characteristic
3. Conceptual Model

The battery charger as a conceptual model is presented below:

![Diagram of battery charger conceptual model]

**Figure 3 Whole circuit conceptual model**

The functions of the blocks are:
- Transformer: Reducing the voltage for charging circuit.
- Rectifier: Converting AC to DC.
- Voltage Regulator: Adjusting the voltage to adapt for various batteries.
- Current Regulator: Adjusting the current to adapt for various batteries.
- Arduino: Providing the voltage for CV phase and regulating the charging stages.
- Constant Voltage Charging Part: Controlling the voltage for the CV stage.
4. Transformer

4.1 Transformer Theory: Coil Transformer

![Coil Transformer Diagram](http://baike.baidu.com/link?url=PABrNsGAK0vLPqfT51taLV02XIh0SI18wKhTt0I_LP2qoB6xhkk8qj8oIwomzRRw1Eu0ozKFKxM1gSXWL-a0DK)

This is a kind of traditional coil transformer. The transformer is composed of coil and iron core (or magnetic core). The role of the core is to strengthen the magnetic coupling between the two coils. The principle of the transformer is the Electromagnetic Induction Principle.[5]

One coil connected to AC power is called the primary coil, the other coil is called the secondary coil. When the primary coil connects to the AC power, the alternating flux will be generated in the core. Assume the alternating flux is $\phi$, the number of windings of the coil are $N_1$ and $N_2$. From Faraday’s law of electromagnetic induction, the induced electromotive force in the primary coil and send coil is given by:[5]

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$e_2 = -N_2 \frac{d\phi}{dt}$$
As for the voltage $U_1 = -e_1$, $U_2 = e_2$. The phase difference of the primary and second coil is $\pi$, so we can easily see:

$$U_1 : U_2 = N_1 : N_2$$

### 4.2 Reason for Choosing Coil Transformer

The traditional coil transformer is the most widely used transformer. The technology is mature. The feasibility and safety is almost perfect. The volume and cost of the charger also must be considered. Based on the above reasons, compare with other transformers, the coil transformer is the most suitable transformer for our charger.

### 4.3 Practical Application Design

![Transformer in circuit](image)

Figure 4.3 Transformer in circuit

The rated voltage of most cellphone batteries is between 3.7V and 4.2V. The rated voltage of most Ipad and other personal small electronic devices is between 5V and 5.2V, so 18V input voltage can satisfy most of batteries, even some storage battery.

$$U_1 : U_2 = 220 : 18 = N_1 : N_2 = 110 : 9$$

The turns ration of the primary and second coil should be 110:9 in order to get 18V (RMS) at the secondary coil.
5. Bridge Rectifier

5.1 Circuit diagram and theory

The bridge rectifier is one of the most popular rectifier circuits, it converts AC voltage to DC voltage by using the unidirectional continuity of the diode. [6]

The bridge rectifier contains four normal diodes and one filter capacitor.

When the A is the positive pole and B is the negative pole of the input voltage, D1 and D3 pass current, D2 and D4 cutoff, and the current follows the red line:

For the load resistor $R_{\text{load}}$:
- C is the positive pole.
- D is the negative pole.
When the B is the positive pole of the input voltage and A is the negative pole, D2 and D4 pass current, D1 and D3 cutoff, and the current follows the red line:

For the load resistor $R_{\text{load}}$:
- C is the positive pole.
- D is the negative pole.

As the figure shows: C is always the positive pole and D is always the negative pole.
After the rectifier, the filter capacitor C can make sure the ripple of the output voltage is strongly reduced. The AC voltage becomes almost a DC voltage.

**5.2 Characteristics**

![figure 5.2.1 Rectification. Signal shapes before and after the rectifier diodes](image)

For an ideal bridge rectifier, the frequency of the ripple of the voltage is two times that of the AC input signal.
The AC voltage go through the filter capacitor, the circuit can get an efficient DC voltage.
figure 5.2.2 Rectification. Signal shapes when a filter capacitor is included at the output.
6. Voltage Regulator Circuit: LM317

6.1 Circuit Diagram and Theory

![Circuit Diagram](image)

Figure 6.1 Schematic of the voltage regulator circuit using LM317

LM317 is a three-terminal integrated voltage stabilizing unit. It is widely used in various electronic devices. Normally the LM317, a three-terminal chip (IN, OUT, ADJ), uses one fixed resistor and one adjustable resistor. The output voltage \( V_o \) can be calculated using the equation: [7]

\[
V_o = 1.25 \times (1 + \frac{R_2}{R_1})
\]

Because there must be some quiescent current which goes through the device, the equation will show a slight error:

\[
V_o = 1.25 \times (1 + \frac{R_2}{R_1}) + I_q \times R_2
\]

But in some cases, the error can be ignored.

6.2 Main characteristics

From the datasheet for the LM317 the following characteristics can be seen, see table1
<table>
<thead>
<tr>
<th>Range of the output voltage</th>
<th>1.25V - 37V DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of the output current</td>
<td>5mA - 1.5A</td>
</tr>
<tr>
<td>Typical linear adjustment rate</td>
<td>0.01%</td>
</tr>
<tr>
<td>Typical load regulation</td>
<td>0.1%</td>
</tr>
<tr>
<td>Power Supply Rejection Ratio</td>
<td>80dB</td>
</tr>
<tr>
<td>Output overload short-circuit protection</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Characteristics of LM317 [7]

### 6.3 Development and redesign

In practical applications, the voltage regulator usually needs some filter capacitor to get more stable DC voltage.

![Filter for the LM317](image)

Figure 6.3.1 Filter for the LM317

With the joining of the two filters, a problem is produced: When the regulator is working, the two filter capacitors are charging. If something wrong happens in the source V1, and the input voltage shuts down, C1 and C2 will discharge, and the current from the capacitor may go backward to the OUT terminal, which may burn the LM317. So the circuit needs some protection, this is shown in Figure 6.3.2: [8]
When the input voltage is stopped, C1 and C2 discharge, $V_A > V_C$, $V_C > V_D$, which means that the current will go through diode D1 and D2. They can make sure the current flows back to node D and to the IN terminal.

### 6.4 Reason of choosing LM317

Compared to other voltage regulators, the LM317 has the following advantages:[8]

1. Wide voltage range.
2. Stable
3. Low noise
4. High Power Supply Rejection Ratio
5. Cheap.
7. Current Regulator: VCCS

7.1 Circuit Diagram and Theory

The current regulator is used to implement a voltage controlled current model. The core idea is: When the input signal is a certain voltage, the output signal is current, only controlled by a control resistor and the input voltage. [9]

![Circuit Diagram](image)

Figure 7.1.1 Schematic of the current regulator

This current regulator contains two operational amplifiers, two transistors and some resistors. The current region is from 0mA to 250mA. The output current whose maximum value is 250mA can be used for most kinds of batteries. Also, this kind of regulator is very cheap and safe.

Because of the negative feedback of the operational amplifier, the voltage on the two inputs of the amplifier is the virtually same. The two transistors can make sure the output current is not effect by the output voltage of OA1. The current regulator can be simplified like:
Figure 7.1.2 Simplified schematic of the current regulator

R1=R2, so that based on voltage division, the voltage on node C is given by:

\[ V_x = \frac{V_{in} + V_{out}}{2} \]

R5=R6, so that based on voltage division, the voltage on node D is given by:

\[ V_D = 2V_x = V_{in} + V_{out} \]

The output voltage is divided into the battery, so the voltage over RP is given by:

\[ V_{RP} = V_D - V_{out} = V_{in} \]

We can easily see that the output current is \( V_{in}/R_{RP} \). Thus the voltage at the output of the voltage regulator described in chapter 6 determines the charging current.
7.2 Output Current Control Part

Figure 7.2 Schematic of the current regulator control part.

For the pre-charging phase and constant current part, the battery needs a stable current. The circuit uses a single-pole double-through switch to differentiate these two parts. The switch can be automatic controlled by PLC/ARDUINO program based on the charging time and the battery voltage when starting the charging. The pre-charging time should be very short, just 5-10 minutes. The constant current part should take 30% time of the whole charging processing.
8. Constant Voltage Charging Part

Figure 7.2 Schematic of the constant voltage charging part.

In this part, we use Arduino to give the input voltage. The voltage $V_{\text{out}}$ can be used to slowly reduce the current while the battery voltage is constant.

Based on virtual open principle, the voltage on $R_2$ is $V_{\text{in}}$, so the current on $R_2$ is given by:

$$I_{R_2} = \frac{V_{\text{in}}}{R_2}$$

Because the current on $R_2$ is same as $R_1$, so the output voltage $V_{\text{out}}$ is given by:

$$V_{\text{out}} = \left(\frac{V_{\text{in}}}{R_2}\right)(R_1+R_2) = \frac{V_{\text{in}}(R_1+R_2)}{R_2}$$

If $R_1$ and $R_2$ are equal, this gives:

$$V_{\text{out}} = 2V_{\text{in}}$$

In this part, the voltage of battery is close to 4V, and the current through $R_3$ is given by:

$$V_{R_3} = \frac{(V_{\text{out}} - V_{\text{Battery}})}{R_3}$$

From the formula before, we can deduce the input voltage from the Arduino backward:

$$V_{\text{in}} (\text{Arduino}) = \frac{V_{\text{out}} \times R_2}{(R_1+R_2)}$$
The current in the battery is the same as in R3, so we just write a program to let the output voltage of the Arduino decrease gradually, so we can get a gradually decreasing current of the battery. This process should last about 1-1.5 hours and take 70% time of the whole charging process.
9. Complete Circuit Model

The input AC voltage should be 18V, so its amplitude is $18\times\sqrt{2}=25V$.
Assume the specified battery’s rated voltage is 4V and rated current is 100mA.
Then for $V$ (voltage regulator) = 4V we can get

$$4 = 1.25 \times (1 + \frac{R2}{R1})$$
$$R2/R1 = 2.2:1$$

Based on the current range of LM317 and quiescent current error, we choose $R5=50\Omega$, $R3=120\Omega$.
For the current regulator part, in the CC phase the current battery needs to be 100mA. We can get:

$$RP = \frac{V(\text{voltage regulator})}{I_{\text{out}}} = \frac{4V}{100mA} = 40 \Omega.$$ 

The details are shown below:
Figure 9.2 Rectifier circuit.

Figure 9.3 Voltage regulator circuit.
Figure 9.4 Current regulator circuit.

Figure 9.5 Battery model

The battery model is adapted from a N-H battery model to provide a reasonable battery charging curve. The time scale is reduced significantly.
10. Simulations using LTspice

10.1 Rectifier Simulation

Figure 10.1.1 Rectifier circuit in LTspice.

Figure 10.1.2 Simulation result of rectifier circuit.
In Figure 10.1.2, the green line is the input sinusoidal voltage, the amplitude is 25V.
The blue line is the output voltage on R1, through the rectification by the four diodes and the filtering by the capacitor, it is changed to DC voltage and the amplitude voltage is about 20V.
The simulation of the rectifier is successful.

10.2 Voltage regulator Simulation

![Figure 10.2.1 Voltage regulator circuit in LTspice including LM317.](image)

![Figure 10.2.2 Simulation result of the voltage regulator circuit.](image)
In figure 10.2.2, the red line is the input DC voltage, the amplitude is about 20V, the green line is the voltage on R3, it is a stable 1.25V voltage, which means the LM317 works normally.

The blue line is the voltage of R1 (R-load), it is about 4.5V, and the output voltage is stable, meaning that the simulation of LM317 is successful.

### 10.3 Whole Circuit Simulation

Figure 10.3.1 Charging curve for the CC circuit.
In figure 10.3.2, the green line is the input DC voltage from the voltage regulator, the amplitude is about 4.4V. The blue line is the voltage of the battery. It increases first and then stabilized at 4V, the orange block shows the charging process, that means the battery is charging. However, the model is only a theoretical model where charging occurs much faster than in reality. The red line is the current of the battery. The bright yellow block shows it finally reaches about 105mA. It also shows an increasing curve. Compare with the blue line (voltage on battery), we can see a complete charging process and it fully embody the characteristics of the CC stage: Constant Current, Increasing Voltage. Figure 10.3.2 also means the simulation of the whole circuit is successful.
11. Measurements

11.1 List of Components

While the simulation with LTspice is in an ideal condition, the real components may have different values compared with the simulation.

Below is the list of the components:

<table>
<thead>
<tr>
<th>Type</th>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Circuit</td>
<td>LT1086 (LM317)</td>
<td>1</td>
</tr>
<tr>
<td>Capacitor (F)</td>
<td>470u</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>22u</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>300u</td>
<td>1</td>
</tr>
<tr>
<td>Resistor (Ω)</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>18k</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1k</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>Amplifier</td>
<td>Op741 (LT1001A)</td>
<td>1</td>
</tr>
<tr>
<td>Transistor</td>
<td>2N3904 (NPN)</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2. List of the measurement components

11.2 Measurement Results

Figure 11.1 shows the original breadboard, to show how the charging circuit builds up.

In this circuit, the CC phase is being implemented. The CC phase charges most electric energy to the battery, but it also decides the success of the charging process.

The first part is the rectifier to convert AC to DC, getting the input signal from a standard AC transformer for commercial applications. The adapter shown in figure 11.2 is being used.
After the rectifier, the voltage will be approximately 25V. Normally, the efficiency of a bridge rectifier is 96%. But this circuit is a no-load circuit, and the output voltage is 29.8V, as shown in figure 11.3.

Figure 11.2 220V to 18V AC adapter.
The second part is the regulator, including the Lm317. The output voltage of the second part is 5.8V, as shown in figure 11.4 and 11.5.

The third part is the current regulator circuit, the last part of the CC circuit, as shown in figure 11.6. It can be seen as a voltage controlled current source and determines the charging current of the battery. Because the Li-ion battery is the most widespread used in electronics equipment, the rated voltage of a Li-ion battery, 4.2V is the final voltage. This is shown in figure 11.7 and Figure 11.8.
Figure 11.4 Output voltage of the voltage regulator.

Figure 11.5 The rectifier and the voltage regulator circuit.
Figure 11.6 The constant current circuit.

Figure 11.7 Li-ion battery.
The result for the output current can be calculated by *Ohm’s law*. Using different output voltage and different load resistance we get the same output current.

Figure 11.9 (3.1V) and Figure 11.10 (5.4V) is the output voltage when the resistors are 22Ω and 39Ω. After calculating the current as $I=\frac{U}{R}$, both of them output the same numerical value.

<table>
<thead>
<tr>
<th>$R_1$ (Ω)</th>
<th>Vout(V)</th>
<th>Iout(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>3.1</td>
<td>0.141</td>
</tr>
<tr>
<td>39</td>
<td>5.4</td>
<td>0.138</td>
</tr>
</tbody>
</table>

Also, the current was measured separately, see Figure 11.11.

It means the changes of internal resistance will not product any effect on the final result. The output current could always stable to make sure the safety of charging process.
Figure 11.9 The output voltage by use 22 Ω internal resistance.

Figure 11.10 The output voltage by use 39 Ω internal resistance.
The measurements show that the CC circuit is operating correctly.
12. Conclusion

Nowadays, the personal electronics become more and more popular, but the variance of batteries becomes troublesome. There is a need for a general charger which can control the output voltage and current. That is why we chose this topic.

Referring to the battery, this thesis mainly researches the charger for personal electronics. The Li-ion battery plays the most important role, so we chose the Li-ion battery as the model to design the charger for.

For the Li-ion battery, the charging process is divided into three stages: Pre-charging phase, Constant Current phase and Constant Voltage phase. In the pre-charging phase and constant current phase, people use a controlled current to charge the battery. The difference is: In the PC stage, the battery just needs a very low current approximately 1/10 of the maximum rated current. It aims to activate the battery, and should just take a few minutes. In the CC stage, the battery needs the rated current. This is the main charging part. This part takes 30% of the charging time but the battery can get 70% of the energy. In the CV phase, the battery needs constant voltage to stabilize the chemical reaction inside of the battery. This part is aimed to protect the battery. With time passing by, the circuit should maintain the constant voltage and decrease the current gradually. This part takes 70% of the charging time but the battery can just get 30% of the energy.

As for the PC and the CC phase, we designed a circuit which contains four parts: transformer, rectifier, voltage regulator and current regulator. The power supply is the 230V AC voltage. The transformer is a traditional coil transformer, converting the 230V AC to 18V AC. After the transformer, the rectifier converts 18V AC to 25V DC. For this part we use a bridge rectifier, containing breach four diodes and one filter capacitor.

In the voltage regulator circuit, we choose the LM317. It is a popular three-terminal integrated voltage stabilizing unit. Through adjusting the control resistor, we can get the voltage needed. In the current regulator, we used the concept of voltage controlled current, which means that the input signal is voltage, and the output signal is a current. We designed a special circuit that makes the output current controlled by the input voltage and a control resistor. A programmable with such as Arduino may be used to switch a suitable resistor so that it can control the output current.

Simulations by LTspice ware done, both the rectifier and the voltage regulator, as well as the whole circuit. The results show that our circuit design is successful. This simulation results agree with the theory.

We also did measurements on the CC circuit implemented on a breadboard. The measurements show that the circuit design is feasible.

In future, the charger may be developed further. First of all, the support program of Arduino should be done. The CV phase may be implemented too. Then, a fuse protector or other protection of the whole circuit is necessary. The type of the amplifier and transistor also should be considered more.
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