Adaptive Fast Charger and Power Pack

Project Proposal

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1. Introduction

1.1 Objective

Rapidly charging smartphone batteries leads to unnecessary battery degradation due to increased heat during charge and a greater amount of time spent at 100% SOC. Additionally, existing power packs rarely include rapid charge functionality.

We will create an AC/DC wall adapter with an intelligent charge rate limit and a built in rapid charging battery. The device will have a button for the user to select a charge rate limit manually and indicators to display charge rate mode and an SOC of the internal battery.

1.2 Background

All iPhones in the US and other countries have shipped with 5W wall chargers, however iPhones since at least the 8th generation (iPhone 6, september 2014) support increased charge currents that can be delivered by higher power chargers. Although the iPhone supports faster charging, this isn't without detrimental effects to the battery. Increased charge currents of around 2.4A charge that battery at a rate approaching 1C, which can cause increased wear on the battery according to Battery University [1].

Additionally, faster charging causes increased power dissipation from the phone's internal charge electronics, resulting in increased heating to the device. This can be shown to increase the device's temperature beyond the manufacturer's recommended charge temperature, especially when cooling is physically restricted by a phone case or pillow. According to Apple, battery degradation will occur when devices are exposed to ambient temperatures about 95F (35C) [2].

We have found in our personal experience that consumers are generally aware that fast charging degrades battery health and would respond positively to a solution such as this one.

1.3 High-level requirements

- The device shall be capable of automatically limiting USB charge current to 1.0A and have a maximum output of 2.4A.

- The device shall be capable of charging its internal battery from 20% - 70% SOC within 30 minutes.

- The device shall have a size constraint, with a maximum volume of 200 cm^3

2. Design

2.1.1 Modular Design

The device is comprised of three main subsystems: and AC/DC converter, a logic board with USB output, and a battery system. Each of these parts is dependant on every other part but can be designed modularly and independently. The AC/DC provides power to the device and receives control input from the Control Unit. The Control Unit regulates USB power output and sends commands to the other blocks. The Battery Unit manages the batteries and acts as a second power source to the Control Unit.

2.1.2 Block Diagram

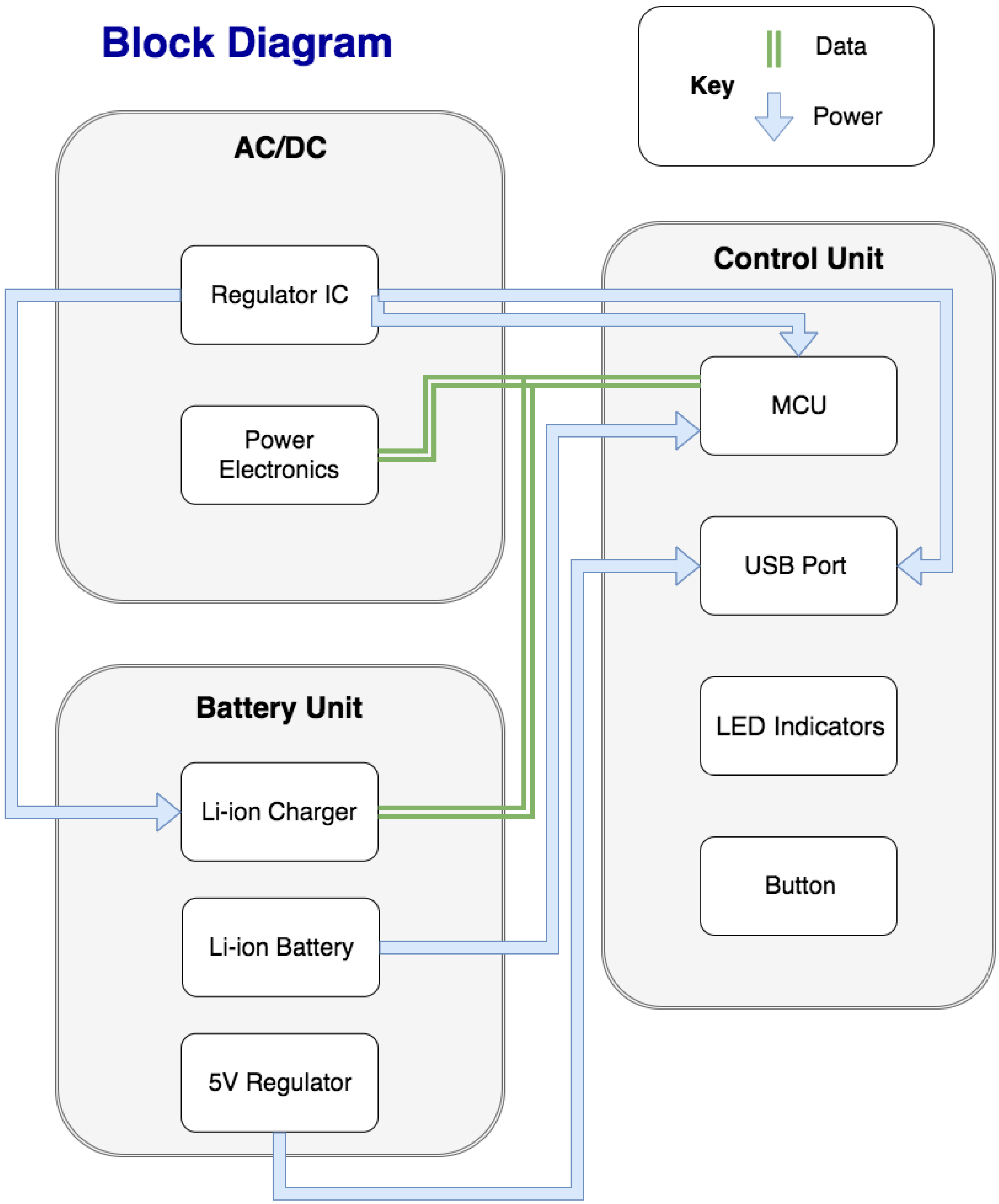

Figure 1. Block Diagram

2.2 Physical Design

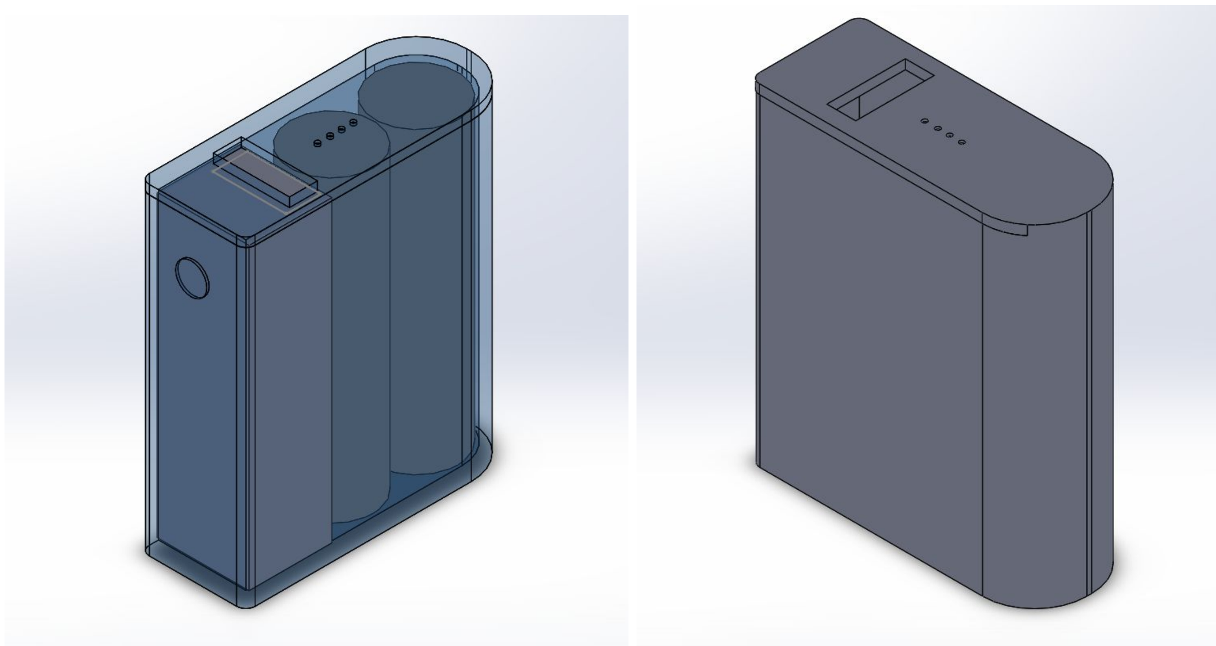

Figure 2. Preliminary CAD Mockup of Project

This device will resemble other common “charging cube” designs, having a rectangular shape and a single USB port output. There will also be LED indicators on the exterior and a single button to control charge mode. Our design requirement is to have a total exterior volume of 200 cm^3 or less.

2.3 Functional Overview

2.3.1 AC/DC

This block will take 100-240V AC power from a wall outlet and convert it to 5V DC for the other blocks to use. The power conversion will be done by utilizing a full wave rectifier and a primary side switch. A transformer will step down the high voltage AC to low voltage AC. This voltage will be smoothed to create a regulated DC voltage.

This block will also feature a vampire protection circuit. When given a standby command from the MCU, the switching regulator(s) will be shut down and the MCU will be powered by the battery. This will reduce parasitic load by the wall adapter when not in operation. In low power mode, the MCU power consumption will be negligible compared to battery self-discharge.

2.3.2 Control Unit

This block will control the current output of the USB port. This will be achieved by a microcontroller and a current limiting circuit. Additionally, the control unit will contain LED indicators for charge current, mode, and internal battery SOC. The only user input will be a single button that toggles fast and slow charge modes.

2.3.3 Battery Unit

This block will contain Li-ion battery cell(s) and a charge controller. The charge controller will charge the battery from the 5V power rail at a rate commanded by the control unit. There will be a 5V DC/DC converter to allow the battery to power the MCU and USB port.

2.4 Block Requirements

The following are specific requirements that pertain to each sub-block outlined by the Block Diagram (Figure 1). These requirements will be adhered to throughout the design process.

2.4.1 AC/DC

Switching regulator: This regulator must output 5.25V to 4.55V DC at up to 10A from a 100-240V AC source.

Power Electronics: The regulator must be capable of shutting down when commanded by the MCU and must default to active when the MCU is unpowered.

2.4.2 Control unit

MCU: Must have at least one input from the button and at least 3 outputs for LEDs, regulator shutdown, and current limiting. Must be capable of communicating with the charge controller(s).

LED Indicators: Must be visible by a user in a bright environment.

Button: Must be capable of triggering on input on the MCU.

USB Port Regulator: Must be capable of limiting USB output current to 1A when commanded by the MCU, and must be capable of supplying 2.4A.

2.4.3 Battery Unit

Li-ion Charger: Must be capable of charging a Lithium ion battery at up to 5A and must limit charge current in response to increased temperature. Must accept 5V DC from the AC/DC block.

Li-ion Battery: Must have at least a 2000mAh capacity.

5V Regulator: Must output 5.25V to 4.55V DC at up to 2.4A to the USB port.

2.5 Risk Analysis

The battery unit poses the largest risk to the completion of the project. This is largely due to the amount of precautions that must be taken in the design and implementation to ensure safety. Lithium ion batteries are potentially dangerous if overcharged or overheated during charging. Our fast charge circuitry must be capable of accurately measuring the temperature and voltage of the battery to prevent a thermal runaway. Our circuit will not be capable of being demonstrated if we cannot create robust and safe fast charge circuitry.

3. Ethics and Safety

3.1 Safety

As our project deals primarily with charging and batteries, there are significant potential safety hazards that could present themselves in our project. Because of this, it is important to take the necessary safety precautions to properly and safely test all of our modular blocks in the project.

The battery unit will be the most volatile part of our project in terms of safety. We will be dealing with Lithium-ion batteries, which can potentially explode if overcharged or are subject to undue stress from heat. Because our project will be testing the behavior of these batteries at higher temperatures (>35C), it will be paramount to ensure that we are working in a safe environment for testing. The health of the battery is also important in our project, so these precautions work both ways for us.

In order to prevent short circuiting of the batteries, we will store it in a secure location with terminals partially insulated, as recommended by the battery safety document. We will also make sure that we use Charging ICs in our design in order to make sure we are using li-ion batteries safely. Industry standards and safety regulations surrounding products that include batteries and charging are quite stringent, and rigorous safety testing will be followed to make our project a viable product.

In terms of federal and state regulations, Title 40 of the code of Federal Regulations (CFR), part 273, deals with universal waste regulations, including provisions for batteries. Because li-ion batteries are a volatile chemical device, if we must dispose of them we will do so in a safe manner [3].

Additionally, because we will implement fast charging circuitry in our project, it is important that we do not ruin any batteries by overcharging or overheating (not to mention any smartphones). While working with live higher voltage circuits, we will be sure to take the necessary precautions to mitigate risk. Basic examples include having multiple people in the lab at one time, properly grounding any test experiments, and limiting currents to lower values when possible [4].

3.2 Ethics

On the purely ethical side of this project, it is very important that we make a safe product and follow safety regulations. Because we are dealing with li-ion batteries and fast charging, safety is a critical factor in our project, and the ethics surrounding every decision concerning safety are very clear. It is the duty of the engineer, as stated in the IEEE Code of Ethics, #1: "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public..." [5].

Providing for a safe work environment during development and testing is the right and ethically correct thing to do. Additionally, since the basis of our project is rooted in the belief that we can make a more adaptive and modern charger, specifically one that may solve issues of battery degradation, it is important that we report our findings without any omission for the sake of furthering our own points. This is detailed in the IEEE Code of Ethics, #3: "to be honest and realistic in stating claims or estimates based on available data;" Whether or not our data supports our hypothesis, we must report our findings from experiments factually.

In summation, our project has safety precautions that must be taken, primarily concerning use of a li-ion battery cell and high voltages. Taking these safety precautions is the wise and ethical thing to do in this project.

4. Citations

[1] Battery University, ‘Fast and Ultra Fast Chargers’, 2012. [Online]. Available: http://batteryuniversity.com/learn/article/ultra_fast_chargers

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[5] IEEE, ‘IEEE Code of Ethics’, 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html