FunBox Classic (FBC)

Senior Design II - Project Documentation
August 7, 2015

Group 14

Stephen Caskey **Anna Iskender**
Nick Johnson **Kyle McCleary**

Contents

1. Executive Summary

The following documentation outline, in full detail, the processes, procedures, and means by which we completed our project: The FunBox Classic. It lists and describes the goals, objectives, specifications, research, designs, testing procedures and administrative content of the project. The final FunBox Classic prototype brings back memories of a simpler time, when games did not have gigabytes of resources and content to work through. It acts as a simple, but pleasing, way to play classic Nintendo games. The project does not attempt to break new ground, but it endeavors to make it as simple as possible for any user, even without advanced technical knowledge, to just pick up and play, wherever they might be.

The end goal of our project was to produce a functioning prototype. This conformed to a variety of specifications. The device operates at a resolution of 640 x 480 on a 4.3-inch screen. The buttons for the internal controller were placed at optimum positions, ensuring proper ergonomics. The device fits comfortably in the hands and weighs little, allowing for hours of gameplay without fatigue. It is able to connect with a wide variety of external controllers via Bluetooth, allowing for multiplayer on the device. The device charges using a standard Micro USB port, albeit with a wall charger instead of through a computer. Note that it still charges through a computer, but much more slowly. The device also charges through solar panels on the back of the case. This allows for a little more power to get a user through the day. The casing is custom designed and 3D printed, ensuring the tightest fit for the internal components.

There were many ways to meet the requirements set out in the requirements, but it was decided to use trusted, proven components and technologies, to maximize efficiency and minimize wasted time and money. A Raspberry Pi 2 was selected as the core of the device, allowing the FBC to run a full Linux operating system for maximum software compatibility. Bluetooth 4.1 LE was selected to ensure the fastest speeds at the lowest power cost. Composite video was chosen to output to the screen of the device, which helped to ensure compatibility with the Raspberry Pi without adding on the additional hardware costs of HDMI. The PCB and buttons from a USB SNES controller were reused for the internal controller, ensuring that classic responsiveness and feel. Hardware volume control is on the case, allowing the user to control the volume level even when the device is turned off or unresponsive. By combining these technologies together, the FunBox Classic is sure to delight and satisfy gamers of all ages.

2. Project Description

The FunBox Classic (FBC) is a portable game console that emulates five Nintendo systems: GameBoy (GB), GameBoy Color (GBC), GameBoy Advance (GBA), Nintendo (NES), and Super Nintendo (SNES). The main workhorse of the FBC is a Raspberry Pi 2 (RP2) which runs the operating system and software needed to support the emulators. Games can be loaded to the FBC by uploading them directly to the SD card in the Raspberry Pi 2 or using a portable storage device in the USB port inside the case. A screen is attached to the RP2 and will display the emulated games when the device is turned on. The FBC also contains speakers and a headphone jack to allow users to choose how they want to hear their games. A game controller is attached to the RP2 directly and seated internally in the case for a single user. If multiplayer is desired the FBC also supports Bluetooth controllers. The FBC will operate away from a wall plug for extended periods of time due to the internal rechargeable battery. The solar panels that charge the device when it is not plugged in extend the life of the FBC even further.

2.1 Project Motivation

Our motivation for building the FunBox Classic was mostly due to personal desires. We wanted to build a device that would allow us to play the old classic games we loved on the go in a single all-inclusive portable console that is comfortable to hold and use. We also wanted the device to last long enough to allow us to actually be able to enjoy the game on a road trip or flight. Additionally, a device such as this allowed each group member to obtain design experience in various categories. The combination of electrical circuit design components, hardware/software interaction, and software design components was perfect for our group, as well as the ability to add or remove components as needed or desired.

2.2 Goals and Objectives

Our main goal was to accurately recreate the feeling of playing our old favorite games, while also allowing the player to move around freely while doing so. Ideally, the FBC will replace all of a user's old Nintendo consoles while also adding new features to them.

There were a variety of goals for the FBC that are necessary to the operation of the system. The FBC needed to have a battery system that would quickly charge a battery from a standard USB connection. The FBC needed to have an on-off switch that would control the power from the battery to the FBC components. The battery system also needed to keep the FBC powered for extended periods of time. The FBC had to be able to emulate GB, GBC, GBA, NES, and SNES games at their native speeds. Games needed to be able to be uploaded to the FBC through the USB port located in the case. The emulated games had to be

displayed on a screen housed in the case of the FBC and attached to the RP2. An audio system had to be attached to the RP2 that would play the sound from the games via speakers or headphones. A controller to operate the FBC had to be attached to the Raspberry Pi and needed to be comfortable to use. The case was required to house all the components of the FBC safely. The case needed to be sturdy enough to survive a drop and not allow the circuitry in the FBC to short or disconnect.

Additionally, there were a variety of supplementary goals for the FBC that were important to us. The FBC needed to have built-in Bluetooth to allow users to connect their Bluetooth controllers and keyboards to the FBC for multiplayer or if they would prefer to use that controller instead of the internal controller. The FBC had to also have solar panels that would extend the battery life of the device. The FBC also needed to have LED indicators for charging, completed charging, battery/charge error, low battery, and power on.

2.3 Requirement Specifications

This list of requirement specifications describes the minimum goals and objectives for our device in a more precise manner. Following the list, we explain our reasoning for our minimum requirement specifications.

- Screen Size of at least 3.5” but less than 6”
- Display rate of at least 50 FPS
- Bluetooth 4.0 LE or higher
- Flash Memory of at least 16 GB
- 3.5mm Headphone Jack
- 2 Speakers of at least 1 Watt at 8 Ohms
- Charging Voltage of 5V
- Operating Voltage of 5V
- Maximum system current draw of 700 mA
- Solar power charge current of at least 100 mA
- Battery of at least 2100 mAh

We chose the size of the screen to be between 3.5” and 6” for 3 main reasons. The first reason was to maintain the portability of the device. The larger the screen the less portable the FBC will become. The second reason was to keep the power draw of the system low. A larger screen meant shorter battery life. The third reason was to make the games look better. A smaller screen results in less stretching and will not distort the low resolution games of our consoles. We chose the display rate to be at least 50 FPS to conform to both NTSC and PAL standards.

Bluetooth 4.0 LE was our minimum requirement due to our device being battery powered. The newer Bluetooth LE devices draw significantly less current and will allow for a longer lasting battery life.

The flash memory of the device needed to be at least 16 GB due to it needing to be able to contain an operating system, systems software, emulators, and games. While 16 GB may not be necessary, we want to allow users to hold all of their games on the device.

A 3.5mm headphone jack is required because it is the standard size for headphones and we want the user to be able to plug in any of their own headphones into the FBC. The speakers need to be at least 8 Ohm 1 Watt speakers to ensure that their output through the case is audible and clear.

The charging voltage needed to be 5 volts so that the device could be plugged directly into a standard USB port, which operates at 5 volts. The user needed to be able to plug the device into their phone charger or computer to charge it. The power supply of the system needs to supply an operating voltage of 5 volts because the Raspberry Pi 2 is normally powered by USB.

The current draw of the system did not exceed 700 mA because the device aimed to be low power and long lasting. We settled on 700 mA as the cap because the only things drawing significant power in the device are the Raspberry Pi 2 and the screen. The RP2 did not exceed 400 mA and the screen did not exceed 200 mA. A 700 mA current draw maximum compensated for the 600 mA of the RP2 and screen and allows 100 mA for the rest of the components combined. The solar power charge current was at least 100 mA to partially alleviate the current draw of the rest of the system and to charge the battery at an acceptable rate when the device is not powered.

The battery needed a charge capacity of at least 2100 mAh. At the max current draw of 700 mA a 2100 mAh battery would last for three hours without any solar power. We wanted the device to last for at least three hours when not in sunlight.

2.4 Standards and Constraints

There are a variety of standards we adhered to in the design of our project, and constraints that affected both the design and use of our project. There are standards for pretty much everything, but we were primarily concerned with the standards related to the most important components of our device. Likewise, there are a vast amount of constraints that will have some effect on our project, but we focused on the ones that have a significant impact.

2.4.1 Standards

Engineering standards specify properties and technical requirements that must be met by systems that implement them. This ensures that minimum guidelines, such as safety, performance, reliability, testability, and interaction with other

complying equipment, are met. The following are standards that were implemented either by our project or components in our project.

2.4.1.1 Bluetooth 4.0.

Bluetooth 4.0 is a version of the Bluetooth wireless technology standard for exchanging data over short distances. It uses UHF radio waves in the ISM band to accomplish this. Bluetooth 4.0 uses half the power of Bluetooth 3.0, which makes it crucial for the developing mobile market. It was formerly maintained by IEEE, but they abandoned support. It is now maintained by the Bluetooth Special Interest Group.

2.4.1.2 NTSC

NTSC is the analog television system used mainly in the Americas. It can be transported in a variety of ways, such as coaxial cable or composite video cable. It was developed and standardized by the United States Department of Defense, as seen in document # SMPTE-170M: Television - Composite Analog Video Signal – NTSC for Studio Applications.

2.4.1.3 USB 2.0

USB 2.0 is the second main revision of the Universal Serial Bus standard. This increased theoretical speeds to 480 Mbit/s, 40 times faster than the 1.x standard. It has four pins: Vcc, Ground, Data+, and Data-. The specification was developed and maintained by the International Electrotechnical Commission (IEC) in document # IEC 62680-1: Universal serial bus interfaces for data and power – Part 1: Universal serial bus specification, revision 2.0.

2.4.1.4 Micro USB Revision 1.01

Micro-USB revision 1.01 was a new, smaller connection designed for USB 2.0. Micro-USB adds an ID pin to the previously existing four pins of USB. This allows for USB on-the-go technology, which turns a client device into a host. The specification was developed and maintained by the International Electrotechnical Commission (IEC) in document # IEC 62680-2: Universal serial bus interfaces for data and power - Part 2: Universal serial bus - Micro-USB cables and connectors specification, revision 1.01.

2.4.1.5 FAT32

FAT32 is a variation on the 1970s file system File Allocation Table, or FAT. The 32 stands for the size of the entries in the filetable which are each 32 bits. This increased the maximum volume size to 2TB, 1000 times more than the previous FAT16 (these both assume 512 byte sectors). It was developed, standardized, and maintained by Microsoft in the Hardware White Paper: “Microsoft Extensible

Firmware Initiative FAT32 File System Specification. FAT: General Overview of On-Disk Format. Version 1.03."

2.4.2 Identification and Review of Related Standards

Several standards pertaining to the components used in the FBC were adhered to and considered. The SMPTE-170M-1990 standard associates with the standard to the analog television system color bar test system, which corresponds to the display screen used. The formerly IEEE upheld 802.15.1 standard refers to the development for Bluetooth technology, such as the chip implemented in our design. To note, the Bluetooth standard is now upheld by the Bluetooth Special Interests Group (BSIG). The IEC 62680-1:2013 standard covers the interface data and power for USB technology, and in relation, the IEC 62680-2:2013 is the standard for micro-USB cables and connectors. The IEEE 928-1986 standard was recognized for the performance expected of photovoltaic power systems. Finally, the IEEE 1625-2008 observes the standard for the recharging of batteries for multi-cell mobile computing devices. Standards in battery charging and solar performance were heavily considered for the expected performance related to the efficiency of the FBC

2.4.3 Constraints

Design and construct considerations for the FBC must also take into accounts of the likelihood of realistic developmental impact constraints that will need to be addressed. Discussion of potential, if not already existing, implications will help identify legitimate concerns, as well as benign factors that do not pose actual issues in the execution of the project.

2.4.3.1 Economic Constraints

Economic and financial factors will be the most heavily focused constraints to anticipate moving forward with the project cycle. Given the many various components that comprise both the hardware and software aspects of the FBC, hurdles to consider include individual acquisition of building parts and materials, and the availability based on quantity need. One specific constraint would be the necessitation of individual components that do not require mass ordering. Certain FBC features utilize unique IC's and microcontrollers that need no more than one or two centralized components for implementations. Ordering such parts in singular quantity can conflict with manufacturer requirements that dictate quantity bulk order, and potentially limiting the availability to particular models. Another aspect to consider is the financial limitations of ordering components on the individual level as opposed to mass ordering. Bulk purchases generally tend to be at a better pricing figure than simply ordering one component, and having that component alone shipped for manufacturing. An evident challenge is that many of the FBC controllers and IC's are unique from each other and cannot be

substituted as a common factor piece. Therefore, the need for many different singular parts arises with the dilemma of specialized orders.

Additionally, an unforeseen economic constraint that was faced in the developmental phase of the FBC was in the form of reshaping in the technological consumer market. In particular, the standard for commercially sold electronic components, Radio Shack Corp., was forced into bankruptcy, thus resulting in multiple store locations closing. This factored into our ability to readily obtain necessary components for design and construction of the FBC, as well as generated refocus onto additional reliance in online ordering conventions.

Adding to ascertaining of parts, and their availability, another constraint in the economic sense is the means to build the FBC. Self-reliance on sectional building would require additional resources, such as soldering stations and specialized tools, like small-scale mounting instruments. Another option would be resourcing private venues that professionally construct the designated circuit boards needed, which would be another unanticipated fee. This must be factored into additional costs that do not directly go into the FBC, but must be used for achieving its realization.

2.4.3.2 Environmental Constraints

Availability of resources and surround requirements are to be taken into account when dealing with the FBC environmental constraints. Primarily, the conditions of building the device are to be considered first, with access to the proper work environment being essential. For testing and building of parts, we have a home-based work-bench that features amenities ideal for electrical-mechanical construction. However, the limitations facing our work-space include fundamentally scaled utilities that do not necessarily parallel to those of standardized research labs. The Senior Design lab located on UCF is another option that could provide a desired environment for project advancement, but would also require a constant transportation of parts, many of which are on the micro scale, to and from said location. Additionally, the Senior Design lab also has limited space and readily accessible utilities that can compromise work efficiency. Given that so many of the FBC building components are only a few millimeters in surface area, fabrication conditions should be favorable to an abundance of lighting and sizable work-surface area.

The secondary environmental constraint deals with the functionality of the FBC within its surroundings. This constraint directly refers to the operation of the FBC's battery charging solar panel circuit. Essentially, this component harnesses available sunlight into usable electrical energy to charge the internal source lithium polymer battery. For this to occur, operation and temporary storage of the device should be in a location accessible to direct sunlight. This can be a challenge, in particular, for in-use operation, as the solar cells capturing sunlight are located on the back of the FBC, opposite facing from the TFT LCD screen.

Due to this design specification, the solar cells are not likely to be directly exposed to environmental sunlight while the FBC is in use. However, the solar cells are capable of operation in indirect lighting, and full lighting can be achieved should the FBC not be in user operation, and is left, screen-side down, for additional battery charging. It is noted that the solar charging panel is the only natural-environment dependent aspect to the project.

2.4.3.3 Social Constraints

The identification of social constraints pertaining to the FBC project can be met with a subjective paradigm, considering the views society can hold on the roles of videogames in the social environment, let alone the advancement of a previously outdated console. The influencing factor of videogames as a household common component make the further advancement, such as the FBC, questionable under what society approves. In particular, social views that videogames can be a debilitating, and even destructive, factor to human behavior has been an argument used for most of the history of gaming consoles. And while indeed the discussion zeros in on the actual games used for the consoles, the FBC provides a vehicle by means to potentially deliver such disapproved games in the form of a portable handheld device. This brings up the social constraint of whether it is marketable to make readily available a device that can yield more potentially violent gaming platforms.

Additionally, the other social constraint to be discussed is the social reaction to recreating a console that was very popular at its release point in the early 1990's, and giving it new life under modern amenities. Society, to a scale, may have objections to hosting a compilation of emulated games on a private, unique gaming device. Additionally, modeling a device after such an iconic console can make it a tall task to live up to certain reviews if compared to its professionally manufactured predecessor. Although social constraints do not have a direct, immediate constriction to the design and building of the FBC, it sets conscious limitations going forward as to the overall design consideration, as well as final product reception.

2.4.3.4 Health and Safety Constraints

Concern for conditions of operation and safety quality of the product bring are considerations behind the health and safety constraints. While the FBC is a light, portable, low-powered device, potential hazards are to be assumed worth addressing. An immediate concern would be associated with the safeguards behind the device, and the minimization of malfunction risks. A lithium polymer battery, rated at 4.2 V, powers the FBC and the overall design of the FBC compacts all components, including the battery, into a close-quarters case. Lithium batteries, in of themselves, can be susceptible to catastrophic failures as a result from overcharging, with fires and explosions in extreme cases. Although the battery we are using comes with overcharge protection, and the FBC features

IC's to address the potential for battery overcharge, there is a small, but significant, risk of device failure that can pose as a safety hazard. This is especially relevant given that the FBC poses a dual-option charging system, and should a battery indication system fail, overcharge can be a realistic concern. Additionally, with the battery in close proximity to the rest of the hardware components, self-destructive behavior will likely damage the device as a whole, and even possibly a user while in operation. Such occurrences are unlikely, to say the least, but a disclaimer to the internal power source must also be brought to light.

Another safety constraint comes with the FBC construction process. The device is to be built utilizing multiple electronic and mechanical means for project realization, and a majority of work being conducted by amateur craftsmanship. Unfamiliarity with production tools, such as soldering guns, can lead to burn or shock injuries, as well as other physical injuries from hardware connections and case building. Proper safety procedures and protection apparel will need to be observed to avoid such risks. Furthermore, the device will be attempted to be assembled in a simulated professional manner, but will not be factory-grade work. Such results can mean potentially exposed electrical components that can pose isolated shock risks. Consideration for working on the device when connected to a power source should be taken to minimize risk of electrocution.
A health concern with the FBC comes from device operation by the user, especially the environment that pertains to the given situation. The console uses a 3.5" TFT LCD screen for visual transmission output of the video games being emulated for use. Although suitable for a portable device, the size limits the user to a small focus point for potentially extended periods of time. This may lead to the user bringing the illuminated screen into closer proximity to their eyes for better visual prowess. This can potentially lead to eye strain problems, and in isolated cases, myopia, that may require attention. Additionally, device operations in a darkened environment can lead to headaches and eye fatigue.

2.4.3.5 Manufacturability Constraints

The building process, along with the means to build of the project, yield manufacturability constraints to be aware of. A specific constraint encompasses the acquisition of parts and components for the FBC. Nearly all of the electrical components are diverse in origin, and require multiple shipping orders from various companies to achieve the materials needs. Also, bulk ordering is unnecessary, due to demand for mostly singular components. This makes the purchasing of parts a constraint to the production process, as locating the necessary parts can be tedious and diverse. Another manufacturability constraint to observe comes from the actual building of the device. The ideal design for the FBC specifies a centralized device that features components surface mounted to the printed circuit board. The two problems with this come from actual achievement of surface mount soldering, and actual restrictions given tight spacing. Surface mounting components, which are only a few millimeters in

dimensions, makes for tedious and limited manufacturing, even with the use of specialized low-scale and magnification tools. The actual components and models to be surface mounted are also constrained to what can be achieved under design specifications. Certain parts cannot be directly surface mounted to the location they need to be in due to either internal temperature specifications, or surrounding component conflicts. This limits the manufacturing process by hand, producing the need for production solutions that are achievable on the small, individual scale, given the FBC's manufacturing is done on the private, preliminary platform.

2.4.3.6 Sustainability Constraints

Energy sustainability, both within the device system and the surrounding environment, provides constraints for consideration. Primary restrictions for device energy allocation constitute as battery supply throughout the system, as well as both means of charging the battery, from a plug-in wall charger, and from attached solar panels. Parts sustainability must also be addressed, with the prospect of continual availability of components and specified models crucial for intended production. Power sustainability within the device is first observed, with the lithium polymer battery supply throughout the FBC being scrutinized for sustaining the necessary power to run all components. Various features of the console, from LCD screen display, to audio speaker output, and auxiliary controller connection all require diverse powering demands that must be met from the source battery. Sustainable power must be achieved equivalently for optimized performance, with proper voltage regulation and DC-to-DC conversion observed as needed.

Additionally, power sustainability constraints include means of charging the FBC's source battery. Two means of charging, the wall charger and the solar panel, are able to provide additional power to the system, but must be done so in a sustainable manner. The wall charger must utilize the given available power from whatever plug-in source while only supplying as much as needed to the FBC. Excessive power draw from the charging source will be wasteful and unnecessary, as well as potentially hazardous. Thus, the wall charger needs to draw current and voltage at an acceptable rating and have means to prevent over-draw. The solar panel charging circuit utilizes renewable energy for additional battery power, and must actually sustain a measureable amount of energy for significant charge. The sustainability constraint with the solar panel contribution comes from the concern of necessary photonic sources needed to supply the desired current for the system.

Sustainability of parts used within the project is also a constraint to recognize. Preliminary planning of parts to be used for the FBC can be compromised should the components not be sustainably produced or marketed. To date, there is no current concern that specific model components are being produced at an unsustainable rate that would produce foreseeable concern in the future.

However, constraints in market demand and availability bring to question the sustainable course of anticipation for achieving of parts at a later date for production.

2.4.4 Impact of Realistic Design Constraints

Throughout production of the FBC, innumerous constraints limited our efficiency and timeline in constructing a functioning prototype. These constraints, as analyzed prior to project implementation, were not always expected, and contributed to shaping the final design. The most debilitating constraints we faced were from financing and manufacturing the FBC. The economic constraints foreseen for the project were more pragmatic than initially considered, specifically the shipping costs. With design revisions, as well as emergency part acquisition from damaged components, the urgency resulted in numerous overnight shipping, which would yield a shipping cost many times more expensive than the part itself. Additional costs in manufacturing the project ourselves, including soldering irons, copper wires, support clamps and so on also added up in costs. Revised PCB productions also drove the cost up, with the final cost of the project far exceeding the initially predicted budget that was set. The manufacturing constraints can also be derived from the financial woes, as means to build the FBC were limited to what the group could afford and with the availability of resources. As predicted, surface mounted components proved difficult to solder with irons not designated for pin-point use. Professional manufacturers were an option sought to correctly mount our board, requiring searches and consultations.

Further constraints were encountered during the project, even if not as impactful as the financial and manufacturing dilemmas. Primary environmental constraints revolve around lack of ideal manufacturing working space. Construction of the project by members was often performed at a workbench in a garage, with limited space to work with and excess debris, such as dirt and dust that would settle on needed components. A secondary environmental challenge occurred during testing of the solar panels, with availability of direct sunlight being limited to morning hours. Based on member availability, afternoon summer rainstorms would compromise testing of the solar panels, creating setbacks for accurate results. Safety constraints were encountered with working on soldering components to the board. The soldering irons used by the members could exceed 600°F, not only making them dangerous to work with, but debilitating to use for long periods of time, as the heat coming off the iron would make even the padded handle of the iron uncomfortable to work with. Use of wire cutters and X-Acto knives for wires and traces also posed threats of injury when being used. There were no notable political, ethical, or social constraints that realistically affected the production of the FBC.

3. Research Related to the Project

Making old video game consoles portable is something that hobbyists and video game enthusiasts have done for years. Researching existing projects that are similar to our project allowed us to get a better understanding of what exactly we needed to do to make our system work, as well as warned us of potential issues that could have arisen during the design of our project. Additionally, research into various hardware components allowed us to select the components that best fit the needs of our device. Choosing appropriate components for our device was imperative in order to ensure low power consumption, reactive controls, effective charging and solar charging, and accurate rendering of games. Research into software for the FBC allowed us to determine the best way to emulate games and interact with user input.

3.1 Existing Similar Projects and Designs

There are quite a few projects that are similar to our device. Some of the projects choose to transplant an old console's circuit board into a portable device and natively play its games, while other projects choose to use computers to emulate multiple consoles and store the games on the device itself. We chose to examine three similar projects. Of these, one uses a disassembled console's circuit board and two use microcomputers to emulate a variety of systems. The two latter projects more closely relate to our device, but the first project contains some useful information as well. Sadly, we could find no projects similar to ours that supported Bluetooth or had additional battery charging via solar panels.

3.1.1 Instructables How to Make a Portable Game System by 1up

This project contains a lot of valuable information related to building our project. It explains the main differences between a few common types of batteries and how to choose between them. This project also shows how to take apart a screen and alter it to consume less power if necessary, information on how to make a custom controller for a NES console and on how to use the PCB from inside a NES controller. The tutorial for this project also contains a lot of basic wiring and soldering advice that will prove quite useful in the construction of our project. It also explains a variety of ways to design and construct a case. This information is invaluable to us because none of us have any experience with case design.

3.1.2 Adafruit PiGRRL

The PiGRRL, shown in Figure 3.1.2.1, is a project that is very similar to the device we aim to make. It effectively emulates the consoles that we want to emulate. The PiGRRL also has a small screen (2.8") and operates using batteries. The device also charges via USB. It is lightweight and portable and has a controller built into the case. While the PiGRRL does use multiple premade circuits that we will not use, such as a charger and DC-to-DC converter combo

circuit, it does help to give us a basic understanding of what kind of components we will need. The PiGRRL also has downloadable files for 3d printing. Examining these files will give us a much better understanding of how 3d modeling and 3d printing work. This project also gives us quite a bit of information on how to setup emulators on a Raspberry Pi. This information could prove to be invaluable. This project also gives even further insight into modifying old console controllers and using them for other purposes.

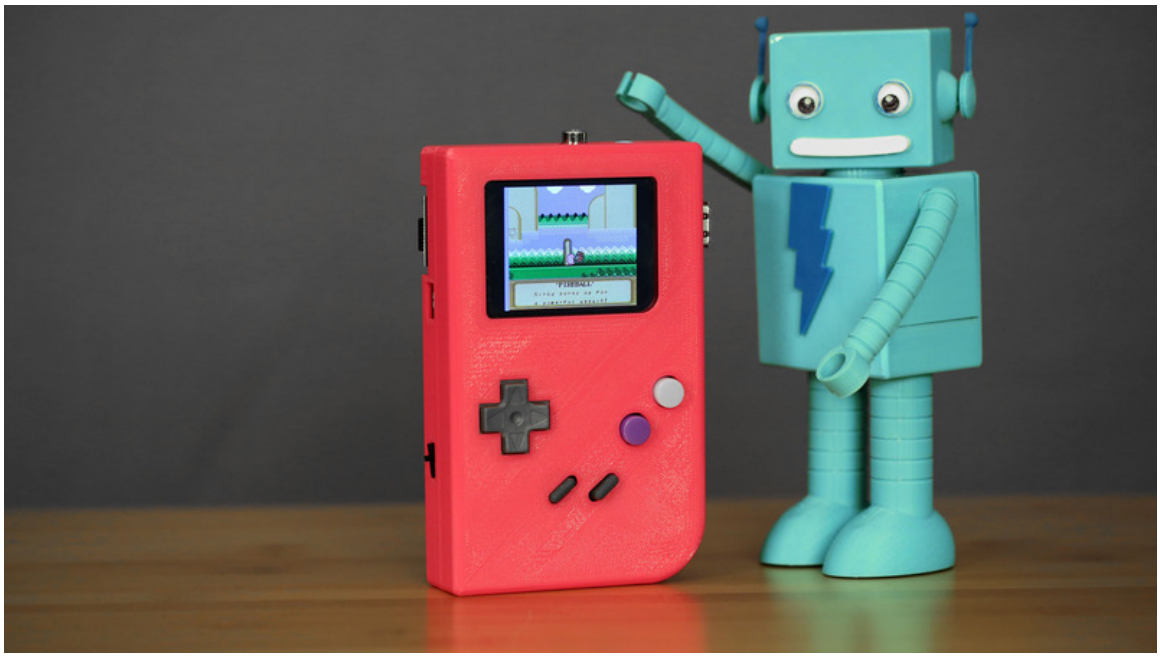


Figure 3.1.2.1 – Adafruit PiGRRL, reprinted with permission from Adafruit

3.1.3 The eNcade

The eNcade is another portable console that uses the Raspberry Pi. It has already raised $6629 on Kickstarter, which shows that there is at least a small market of people interested in a project like this. The eNcade is also very similar to the device we would like to make. Like our device, it is battery powered and has a custom case, onboard controller, built in screen, and a USB port. The software of the eNcade allows users to connect and play games with each other online. The eNcade, like the PiGRRL, uses many pre-built circuits instead of designing circuits around components, but they are connected in a very similar fashion as the PiGRRL. This was a great discovery for us because it shows how we would need to connect the components in our device and what kind of circuits we would need to design.

3.2 Hardware Research

Choosing the hardware that would make up the device was extremely important to the overall design and construction of the project. The components that make up the project dictate how they interconnect and the circuits that needed to be built around them. The research in this section compares different hardware components and was used to choose the best parts for our project.

3.2.1 System Processor

When deciding what would be the core of our project, we took many factors into consideration including: cost, resources available, size, extensibility, and developer support.

We mainly compared three types of devices: Microcontrollers, FPGAs, and micro-computers such as the Raspberry Pi and BeagleBone Black.

3.2.1.1 Microcontrollers

Table 3.2.1.1 shows a comparison of the different microcontrollers that we considered. The cost was a very appealing factor. Very cheap and very easy to get ahold of, microcontrollers gave us a lot of leeway when budgeting. For the size, the microcontroller boards were, of course, small. This meant that we could fit it in a smaller form factor case, leaving more room for other sub components. As far as extensibility went, it depended on the microcontroller board. Overall, there were some boards with a multitude of expansion capabilities and others with very little.
We felt confident we could find an extensible enough board to suit our needs. Developer support on microcontrollers varied, depending on the popularity of the chip. No one, however, had tried anything similar to what we were doing on a microcontroller, and this was a large negative.

Processor speed maxed out at 500 MHz, enough to run the emulation code, but not quickly, due to the extra load of interpreting every line of assembly code and translating it to the new architecture. Further, the RAM maxed out around 256 KB, not enough to emulate the 256 KB of the GBA, or the 128KB of the SNES, due to emulator and microcode overhead, as well as the Video RAM requirements of each system.

The processors themselves maxed out at 32-bit, which worked, but that was the absolute minimum a processor could have to process the emulation code. This is due to the fact that the Game Boy Advance had a 32-bit processor, thus a 16-bit or 8-bit processor would not have been able to run its code.

Furthermore, and perhaps more pressingly, the microcontrollers could only hold up to around 256KB of program code maximum, and that was on the higher

performance chips. This is definitely too small for even the smallest of our emulators (weighing in at 2.1 MB), let alone the crazy task of fitting an operating system capable of managing these emulators and their filesystems into that small space. This, we believe, is the reason that no one had tried what we were doing before: it was unfeasible with the resources available. For this reason, we were forced to no longer consider microcontrollers.

Company	Model Number	Price	Core Size	Memory	FLASH	Clock Speed
Atmel	ATSAMA5D36A	$17.53	32-bit	128 KB	160 KB	536 MHz
Atmel	ATSAM4N8AA-AURTR-ND	$6.08	32-bit	64KB	512KB	100 MHz
Microchip	PIC32MZ2048ECM144-I/PL	$16.03	32-bit	512KB	2MB	200 MHz
Texas Instruments	MSP430F5522IZQE	$7.04	16-bit	10KB	32KB	25 MHz
Texas Instruments	TMX320F28377SPTPT	$32.98	32-bit	82KB	1MB	200 MHz

Table 3.2.1.1 - Microcontroller Comparison

3.2.1.2 FPGAs

The cost was much higher, making it less appealing in that category. Size depended on the capability of the development board, so it wasn't really an issue. Extensibility was much better. Not only were there various expansion ports on the board, but just by the nature of an FPGA, the software capabilities were greatly expanded. This was a highly desirable property. Resources available were also greater than the microcontroller, so we thought we had a winner this time. Sadly, when we got to developer support, we were forced to abandon this idea. Another group of graduating students had tried this project in the past and it was left unfinished due to "unsolvable complexity" in the project. The FPGA just could not adequately support the strenuous requirements (often 10 times more than original specifications) of emulation, and so they hung what was equivalent to a "Abandon all Faith" sign in front of their project, as a warning to others to not go down that path.

We would have had to have found some way of programming in all the various processors of the consoles, a task which was impossible given time constraints. As evidence, it took a student a year to fully implement just the NES processor (a relatively simple 8-bit Ricoh 2A03 chip) for his master's thesis. As we had five systems, with five different CPUs (and supporting systems such as GPUs), we realized that this path would be unfeasible given the time allotted for the project. As a result, we had to abandon the idea of an FPGA.

3.2.1.3 Micro-Computers

Table 3.2.1.2 compares essential features between the two micro-computers that we primarily considered. The cost was relatively decent, costing between $35-$55, midway between the others. The size was fairly consistent as well, with the larger Raspberry Pi still only about the size of a credit card, albeit a very bulky one. Extensibility is massive, with a 40 pin GPIO header on the Raspberry Pi 2 and 65 pins on the BeagleBone Black. Developer support for both options were fantastic, with tons of projects similar to ours already fully completed and documented. Resources available were also large, with a quad core 1 GHz processor and 512 MB of RAM on the Raspberry Pi 2 and a 1GHz processor, 512 MB of RAM, and 4 GB of flash storage on the BeagleBone Black.

	CPU Type	Clock Speed	Cores	RAM	Onboard Flash	Native Audio
Raspberry Pi 2	ARMv7	900 MHz	4	1 GB	N/A	3.5mm or HDMI
BeagleBone Black	ARM Cortex-A8	1 GHz	1	512 MB	4GB	HDMI Only
	Native Video	USB Headers	Avg Power Draw	GPIO Pins	Cost	
Raspberry Pi 2	Composite or HDMI	4	650 mA @ 5V	40	$39.99	
BeagleBone Black	HDMI Only	N/A	460 mA @ 5V	65	$45	

Table 3.2.1.2 – Essential Features Comparison Chart

Both of these systems would have worked for our project, unlike the other options. Both were reasonably priced, with comparable features. We ended up choosing the Raspberry Pi 2 for the following reasons.

1. Parallelism is incredibly important in emulation. All graphics processing can be run in parallel, as well as a lot of the assembly interpretation and subsequent code optimization. For this reason, having the 4 cores of the Raspberry Pi 2 was a must, compared to the single core of the BeagleBone Black.
2. While the 512MB of RAM of the BeagleBone was sufficient, we felt more comfortable with the 1GB of RAM of the Raspberry Pi 2. It made us feel confident that we will not run out of memory recreating these games.
3. Due to reasons of extensibility, the BeagleBone only having HDMI was a minus. If we decided to use it, we would be forced into using an HDMI monitor, plug and all. This would raise our costs and lower our options. Having composite as a fallback, especially given the naturally low resolutions and original sizes of these games, was key.

4. For audio, having HDMI only killed it. Not being able to use audio without splitting the HDMI signal would have been a huge complication and inconvenience, greatly limiting our options for audio playback. We decided that the Raspberry Pi 2, with its easily replaceable audio jack, was the right choice for the job.
5. The lack of USB headers on the BeagleBone was a huge detriment. Even though we had planned to chop off the tall headers of the board regardless, we still planned to make use of USB connections via soldering wires, as transferring files to the system via USB would be essential to add the games and other bits of software at user convenience.
6. The Raspberry Pi 2 already had the excellent RetroPie backend, with EmulationStation frontend, ported to it perfectly. This would save us time and effort that could be focused on the hardware end of the project. Further, the software already looked very nice and works very well in our desired input configuration.

3.2.1.4 Raspberry Pi 2 Usage

We used the following features of the Raspberry Pi 2:
- Composite Video
- 3.5mm Audio
- USB
- GPIO Header
- Micro SD reader

3.2.1.4.1 Composite Video

Composite video was used to output to a screen, as we determined that this was sufficient for our needs. We decided that HDMI would complicate things and add cost, and that input solutions from the GPIO headers would be incomplete without driver overhauls. These are explained in greater detail further in the paper.

3.2.1.4.2 Audio 3.5mm

The jack was used for outputting the audio from the various games. We decided against using a custom DSP solution, as it would add complication without much benefit.

3.2.1.4.3 USB

The USB headers were used to attach external USB ports not soldered to the board. We used these headers to load games onto the device using a USB drive, to debug the system with an external keyboard, and for the Bluetooth dongle.

3.2.1.4.4 Micro SD

The reader was used to read the MicroSD card (64GB) that holds our operating system, our emulators, and all games.

3.2.1.4.5 GPIO

The header was used to connect the following devices:

- Screen: The screen was powered by the 5V Power on GPIO Pin 2 and connected to the ground on GPIO Pin 6.
- Bluetooth: The Bluetooth module was connected to Pins 8 and 10 on the header, which are for UART Tx and Rx
- Supporting board: Specifically Bluetooth, Internal Game Controller, and Audio Controller was powered by the 5V power on GPIO Pin 4 and connected to the ground on GPIO Pin 6.
- The internal game controller was connected to pins 1, 6, 7, 19, and 23.

These can be seen in Table 3.2.1.1 below.

GPIO Pin #	Function	Used By
1	3.3V Power	Controller
2	5V Power	Screen
4	5V Power	Peripheral PCB
6	Ground	Shared Ground
7	GPCLK0	Controller Data
8	TxD	Bluetooth Tx
10	RxD	Bluetooth Rx
18	GPIO	Bluetooth Wake
19	MOSI	Controller Clock
23	SCLK	Controller Latch

Table 3.2.1.1 – GPIO Header Map

3.2.2 Screen

In choosing a proper screen, we considered a variety of options on five different categories: connection type, resolution, size, touchscreen, and power consumption.

3.2.2.1 Connection Type

We had five different options: VGA, DSI, HDMI, SDI, and composite.

VGA was one of the simplest options, with a great deal of support and analog video, so we don't have to worry about digital signal processing. Unfortunately, connecting to VGA would have also added a lot of bulk, and since the Raspberry Pi 2 doesn't have a VGA port, we opted against this technology.

DSI was a technology which would allow us to directly connect a ribbon cable to the Raspberry Pi 2 without worrying about the bulk of larger connections that need to be soldered, like HDMI or VGA. It provided a more direct connection to the screen, but also came at the cost of being far more delicate and easy to break, such as if the ribbon cable had torn. We initially considered this technology due to the positives outweighing the cons, however we later learned that the Raspberry Pi does not fully support this technology natively. Thus we ended up not considering it. A more detailed comparison is shown in Table 3.2.2.1 below.

Screen	Nokia N8	iPhone 3GS	iPhone 4
Resolution	360X640	480x320	960x640
Cost	~$35	~$20	~$30
Cost for additional parts, such as driver boards	~$25	Not Found	Not Found
Conclusion	Costly	Unconnectible	Unconnectible

Table 3.2.2.1 – DSI Screen Comparison

HDMI is a nearly universal technology these days, combining video, audio, and even Ethernet in some cases, into a single cable. As it is a purely digital signal, we would not have had to worry about any digital to analog conversion and the signal loss that would allow. We realized that, although one of the screens seemed like it passed muster, that simply plugging in an HDMI screen would be no fun at all. Further, it would have been a little bit large for a portable game system at 5" and we could find no HDMI displays at lower resolutions. If we had wanted to, control chips were available to convert other standards for smaller

screens to HDMI, but this was not a cost we felt was warranted by the size of the screen and the resolution that we needed. A more detailed comparison is shown in Table 3.2.2.2 below.

Screen	Pixel Qi 10"	HDMI 4 Pi 7"	HDMI 4 Pi 5"
Resolution	1024 x 600	1280 x 800	800 x 480
Cost	$179.95	$114.95	$64.95
Conclusion	Costly	Costly	Good

Table 3.2.2.2 – HDMI Screen Comparison

After HDMI, we moved to SPI, a relatively well supported technology which the Raspberry Pi happened to support out of the box. We compared a number of different screens and finally decided on one to get. A more detailed comparison is shown in Table 3.2.2.3 below.

Screen	5" TFT LCD	3.5" TFT LCD	2.8" TFT LCD
Resolution	800 x 480	320 x 480	240 x 320
Cost	$29.95	$39.95	$29.95
Cost for additional parts, such as driver boards	$34.95	N/A	N/A
Conclusion	Costly	Good	Too Small

Table 3.2.2.3 – SPI Screen Comparison

Unfortunately, upon hooking it up, the jumper pad for the SPI header fell off. We solved this by routing the cable directly to a 3.3V source. Yet this did not solve our essential problem, namely displaying anything other than white light on the screen. We discovered that SPI was not quite as supported as we thought, as the built in driver only allowed SPI output and did not, as we thought, directly facilitate displaying the O/S screen. We would have to code separate drivers for the Raspberry Pi to transfer the display data. We decided against this, as it would have cost us even more already dwindling time.

Finally, we were left with composite. An older technology, it only supports NTSC or PAL video, clearly not HD. Thankfully, this fit our purposes exactly, as all the emulated consoles originally output NTSC or PAL video streams. Further, the maximum resolution of 480i (for NTSC) was, for most applications, fairly small, but perfectly suitable for our games, which maxed out as 512 x 448. A more detailed comparison is shown in Table 3.2.2.4 below.

Screen	3.5" NTSC/PAL	4.3" TFT LCD	4.3" TFT LCD
Resolution	800 x 480	640 x 480	480 x 272
Cost	$44.95	$17.57	$16.85
Conclusion	Costly	Good	Poor Aspect Ratio

Table 3.2.2.4 – Composite Screen Comparison

3.2.2.2 Resolution

We considered the need for the games from each console to still look crisp, without being too letterboxed. The largest required resolution was 512x448, which is only required for certain SNES games, and those that have it can be compressed. The smallest required resolution was 160 x 144 for the Game Boy and Game Boy Color. Based on numerous quality tests with each system and many games, we determined that any distortion of aspect ratio due to stretching or compression was negligible at 640x480 when considering the size of the screen. Thus, we opted for a screen with 640x480 resolution. The scaling comparison of the different resolutions is shown below in Figure 3.2.2.1.

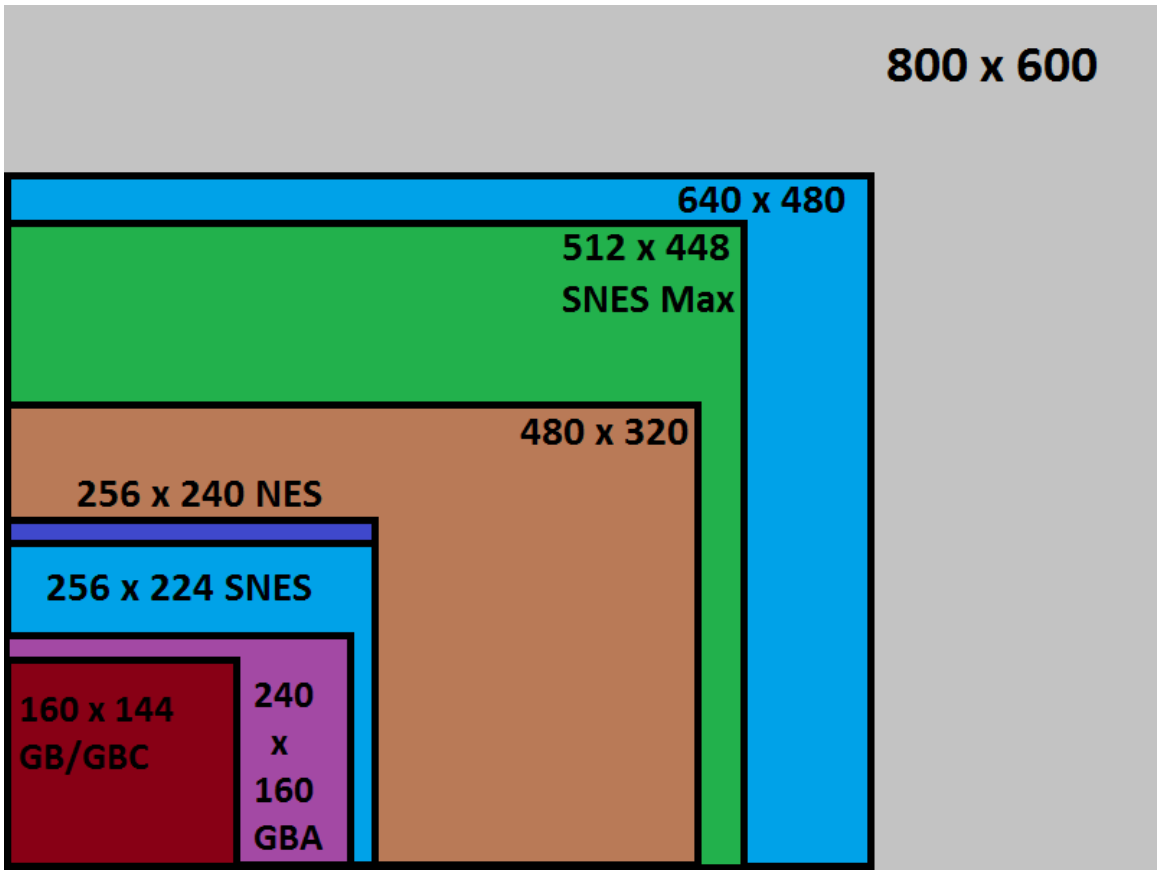


Figure 3.2.2.1 - Screen Resolution Comparison

3.2.2.3 Screen Size

We considered a variety of options, but settled between three major options: <5”, 5”, and 7”.

A <5” screen would be ideal for the resolution chosen. Much larger would produce too much stretching or aspect ratio distortion, leading to poor quality gaming. In addition, the smaller screen size provides for lower power consumption.

A 5” screen is just a little too big, and the resolutions on all compatible screens we could find exceeded our desired resolution. In addition, the additional power draw would reduce our battery life.

A 7” screen is, quite frankly, massive. Once we came to terms with just how unwieldy a 7” screen would be in a portable, not to mention the massive power draw and cost of the display, we quickly abandoned that idea.

For reasons of power consumption, desired resolution, and desired cost, we ended up deciding on a screen that was less than 5” diagonally.

3.2.2.4 Touchscreen

We considered both types of touch screens: resistive and capacitive vs. not having a touchscreen at all.

Resistive touchscreens would have had the benefit of allowing us a finer degree of control, using a thinner stylus over a much thicker finger. This would have precluded the need to redesign the interface to accommodate the larger finger. In addition, the technology is cheaper in general. However, the downside would be the need for a stylus, which might not be ideal for our needs.

Capacitive touchscreens would have allowed us to obtain a more responsive touchscreen, with no pressure really needed. In addition, the pointing device, one’s finger, would always be at hand. Unless of course one has lost all their fingers, in which case there are probably bigger issues at hand, like how to use the game console at all. Also replacement fingers. The downside, of course, is the necessity to redesign the interface to have more easily pressed (read: bigger) UI elements, and the greater cost.

Finally, not having a touchscreen would limit us to controller and other HID input. This would, however, not require us to include a stylus or increase the size of UI elements. Also, it would cut down on cost.

We researched the feasibility of implementing a touchscreen to our project. The touchscreen’s input would require 4 dedicated input pins: two for the flat plane

across the screen, and two for the depth of pressure with which we touched (resistive only). As we were going with resistive for cost reasons, we decided that this would use too many of our valuable GPIO pins. Furthermore, screens that we found using touchscreens and fitting our other requirements had custom, extended ribbon cables, which did not fit non custom driver boards.

As a result, we decided to go with a screen that did not have touchscreen capabilities.

3.2.2.5 Power Consumption

We ideally wanted a screen that drew <= 500 mA, with a backlight. This, of course, limited our size options as discussed above. Further, it made sure that we chose an efficient screen, and preferably one with an adjustable backlight, or that we made our own adjustable backlight.

For all reasons listed above, we went with a 4.3” TFT-LCD screen ripped out of a car rearview monitor. It provided the best bang for our buck, so to speak. It was the correct resolution, size, and met the power requirements, as well as being able to be directly soldered to the board. It was less than $20, a marked savings compared to screens designed for the Raspberry Pi 2. Additionally, it gives us the opportunity to have more soldering experience.

3.2.2.6 Backlight Controller

We planned to implement a twofold system:

First, the backlight will be controlled by a hardware switch linked to the Raspberry Pi 2’s GPIO ports, which will determine the level of PWM coming from other GPIO pins connected to the backlight control. This will allow the user to control the level of backlight to save power or to make the screen brighter when needed. We believe this will add significant battery life when desired, at a minor cost to usability.

Second, before the input for the backlight is even touched by the Raspberry Pi 2, it will be fed through a photo-resistor, which will automatically increase or decrease the relative backlight level to match the surrounding light. In this way, we can ensure power savings while not sacrificing much visibility.

These simple changes will ensure a better user experience at a minimal cost to develop and, as a result, we will want a screen with a backlight to control and, preferably, one that can be controlled directly with a PWM pulse, and not just an onscreen menu.

However, we decided against including this in the project.

3.2.2.7 Final Choice

We decided to go with the 4.3” TFT LCD that we will rip out of a pre-existing car backup display. This screen meets the resolution requirements, ensuring that it will not stretch or compress the image to the point where the games look “off”. It met the size requirements both in image quality and weight of the system. It meets the standard requirement, being a composite screen. It did not contain a touchscreen, reducing complication. The power consumption, even with backlight at full, is less than 500 mA, ensuring long battery life. The final screen is shown below in Figure 3.2.2.2.

Figure 3.2.2.2 – Final Screen Choice, reprinted with permission from Amazon

3.2.3 Microcontrollers

We started by comparing three microcontrollers: The Atmel ATtiny13, the Texas Instruments MSP430G2230, and the Microchip PIC12F1501.

3.2.3.1 Atmel ATtiny13

It is a simple, 8 pin chip with a 20MHz clock speed and 1KB of flash memory to program (as well as 64B of slower EEPROM and 64B of SRAM). It has two PWM channels and 32 general purpose registers. The version we are looking at takes 2.7 V to 5.5 V Vcc input and draws just 240 uA/MHz of oscillation. For our purposes, this will come out to around 3 mA, given our Vcc will be 3.3V at 8MHz.

The Atmel chip can be programmed in a variety of ways, including SPI and through a dedicated adapter/programmer. Code for the chip is written in C using the easy-to-use, and free, Atmel Studio. This also works with any Atmel AVR device, making it convenient to stay in the Atmel family when choosing chips.

Additionally, we have prior experience in programming ATtiny chips, which will make adoption time non-existent. We have also found related, though not identical, schematics to what we are trying to accomplish, assuring us that a backlight controller will be feasible using the ATtiny13. A programmer for the device can be obtained for only $22, which is a reasonable initial cost.

It costs $2.48 per chip, a little on the high side, but still perfectly feasible, even if we had to buy a few.

3.2.3.2 Texas Instruments MSP430G2230

The chip is a simple, 20-pin device with a 16MHz clock cycle and 2KB of flash memory to program (as well as 256B of slower EEPROM and 128B of RAM). It has two PWM channels and 16 general purpose registers. The version we are looking at takes 1.8 V to 3.6 V Vcc input and draws just 220 uA at 2.2V. For our purposes, this will come out to around 2.2 mA, given our Vcc will be 3.3V at 8MHz. We can see the supply current shown in Figure 3.2.3.2 below.

The TI chip can be programmed in a variety of ways, including SPI and through a dedicated adapter/programmer. Code for the chip is written in C using the free Code Composer. This also works with any TI Embedded device, thanks to TI created libraries, making it easy to stay in the TI family of chips.

Additionally, we have prior experience in programming the MSP430, thanks to Embedded Systems, which will make it very easy to pick up coding where we left off. Code Composer is also still installed, saving a tiny amount of time installing and configuring the IDE. The FET programmer, however, is $119, representing a significant initial cost hurdle to overcome if we do not build our own device.

It costs $2.37 per chip, a tad bit expensive, but still perfectly feasible, even if we had to buy a few.

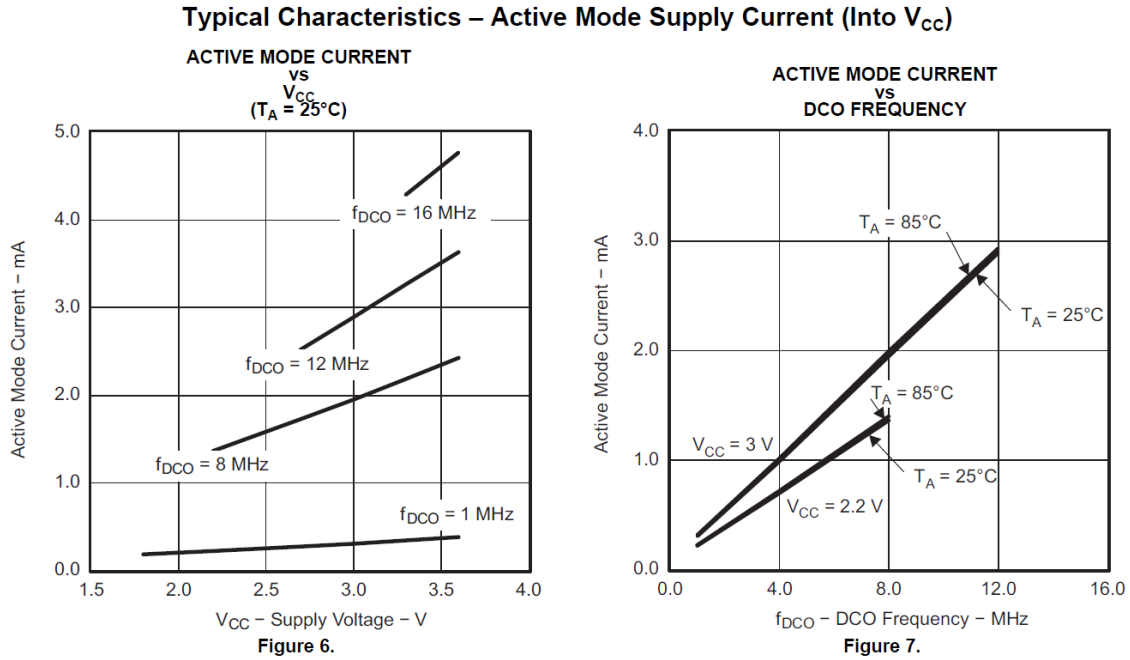


Figure 3.2.3.2 – MSP430G2230 Supply Current, Courtesy of Texas Instruments

3.2.3.3 Microchip PIC12LF1501

The MCU is a simple, 8 pin chip with a 5MHz clock speed and 1KB of flash memory to program (as well as 128B of slower HEF and 64B of RAM). It has four PWM channels and 12 general purpose registers. The version we are looking at takes 1.8 V to 3.6 V Vcc input and draws just 30 uA/MHz of oscillation @ 1.8V. For our purposes, this will come out to around .5 mA, given our Vcc will be 5V at 8MHz.

The Microchip chip can be programmed through a dedicated adapter/programmer. Code for the chip is written in C using MPLAB. This software disables certain features after 60 days of use, so it might not be ideal for our purpose. This also works with any Microchip embedded device, making it convenient to stay in the Microchip family when choosing chips.

We have no prior experience programming Microchip PIC chips, and thus the learning curve for the various libraries and the IDE might not be desired. Additionally, the programmer required for the device is $45, which makes the initial costs much higher than other options.

It costs $.89 per chip, which is a very reasonable cost to adopt, and it slightly offsets the initial high investment of the programmer.

3.2.3.4 Backlight Controller MCU Selection

Based on the information obtained, we decided to go with the Atmel ATtiny13. While the PIC and TI chips did have lower current draw, we decided this was negligible when compared to four other factors.

First, the ATtiny13 had a cheaper programmer that could be used for our surface mount final chips as well as our DIP testing chips.

Second, we considered using an ATmega as well, which would mean we would not have to buy another programmer or setup additional software.

Third, the Atmel chip was most popular among hobbyists. This led to much greater community support and, therefore, many more base schematics we could draw from. This would also give us a greater network for support, in case anything went wrong.

Fourth, the Atmel chip supported up to 5.5 V, giving us confidence that the chip would continue to operate if there were any sudden spikes in voltage, for instance if the power subsystem failed.

Based on these benefits, the Atmel ATtiny13 was the clear choice for the backlight controller.

However, we decided not to include a backlight controller in the project and thus none of these chips were necessary.

3.2.4 Communication Technologies

Fun Box Classic has a multiplayer capability. Two people can play at the same time on one console. This can be done in two ways. The first way is when two users have two players inside the game playing cooperatively against each other.

The other way is when the screen is divided into two parts and two users play the game side-by-side of each other. In order to connect a second user to the console, we have external controllers that communicate wirelessly with the console. We can implement wireless connectivity via two types of technologies – Wi-Fi and Bluetooth.

3.2.4.1 Bluetooth versus Wi-Fi

Both Bluetooth and Wi-Fi deliver good performance, security and functionality that are necessary for secure local wireless transaction communication. However, there are several key differences that have to be addressed for making a decision on which technology we should use in our design.

Wi-Fi provides higher range of wireless connection. It can cover up to 100 meters where Bluetooth based wireless connections generally designed to cover up to 30 meters. The range is varied based on the class of radio used in implementation. Bluetooth technology has three classes of range. A Class 3 radio has a range of about 1 meter or 3 feet; a Class 2 radios has a range of 10 meters or 33 feet; a Class 1 radios has a range of 100 meters or 300 feet.

If we were to use our console as the only media to display a game, we would choose a range of the Class 3 radios. However, we wanted the users to be able to connect the Fun Box Classic console to the big display of their choice such as TV display. For this purpose, we needed to use a bigger range of Bluetooth. Hence, a Class 2 radios will be an ideal choice.

The data transfer rate is not a big concern for our device. We rather have to make sure that our software implementation works good that the control commands over Bluetooth are processed in a way that there is no delay. We will need to take into consideration minimizing the processing delay. Bluetooth offers the security such as 16-digit PIN authentication, frequency hopping and data encryption. Wi-Fi security is higher than the security for Bluetooth. Wi-Fi is protected by different encryption protocols such as WPA (Wi-Fi Protected Access) and WEP (Wired Equivalent Privacy). Bluetooth security is pretty much limited to a key matching, but it is still very secure. Bluetooth devices “cannot be addressed by unauthorized Bluetooth devices because they do not “listen to” incoming messages from any other Bluetooth devices and are not configured to be “discoverable”.” (2) Bluetooth terminals are protected by 16-digit PIN codes. In order to make a Bluetooth device discoverable and connectible, a hacker will have to first guess a Bluetooth code, which is generated through the Diffie-Hellman key agreement protocol. According to the protocol, the code is 16-byte or 128-bit long and different for each base station, which means there can be over 3x1037 different possible PINs. Frequency hopping for Wi-Fi based networks is within 2.4, 3.6 and 5 GHz. Frequency hopping for Bluetooth is within a 2.4 GHz spectrum.

Wi-Fi enables a very fast connection, very big range from the base station, and very high level of security. Bluetooth wireless communications is a simpler technology. It can easily replace the cables that connect devices and, at the same, it provides relatively high levels of security.

Bluetooth is convenient to use when the information need to be transferred between two or more devices that are near each other and the speed is not an issue. Bluetooth technology also requires low power, low cost, and it is ubiquitous.

3.2.4.2 Candidate Bluetooth Module

Choosing the type of Bluetooth chip that is suitable for our device depended on several factors such as low power consumption, a range of the wireless single, and compatibility with other devices. We used the Bluetooth chip to interface it with Raspberry pi processor. After conducting some research, we found three Bluetooth chips that would be the most suitable for our design. We have to decide between BR-LE4.0-S2N that designed by Blue Radios, PAN1026 – by Panasonic and RN4020 – by Microchip modules.

3.2.4.2.1 BR-LE4.0-S2N Module

BR-LE4.0-S2N, part of Bluetooth version 4.0, is a low energy wireless technology module. The size of the chip is 11.8 x 12.6 x 1.9 mm. Approximately, it was $13 per chip if buying 10 chips minimum.

It covers over 150 meter or 500 ft distance with integrated antenna. It can be externally controlled via simple ASCII AT commands over the UART or programmed with custom applications embedded in the module.

BR-LE4.0-S2N has very low power consumption – 27mA 0dB TX, RX down to 19.6mA, .9uA sleep w/timer, and 0.4uA deep sleep. It is compatible with TI TPS62730 step down converter, which can extend battery life by up to 20%. It has 10 milliseconds connect time and low data latency. It supports software adjustable transmit power from short to long-range applications (Class1, 2 & 3).

The chip can handle between 2.4 and 3.6 Volts of power supply voltage. The recommended setting is 3.0Vdc. And it should be receiving less than 10mV pick-to-pick noise. Maximum voltage VDD on any pin is 0.3 V. Current consumption is 24 mA.

3.2.4.2.2 PAN1026 Module

PAN1026 part uses Bluetooth version 4.0. It has a dual mode – place-and-play RF module. Among its features are Wi-Fi coexistence and high-speed interfaces: USB 2.0 UART up to 4.3 Mbps. The size of the chip is 15.6mm x 8.7mm x 1.9mm, and it is fully shielded to improve immunity. A Digi-Key part number is P16771CT-ND. The cost is $15.3 per 1 chip.

The PAN1026 is a short-range Class 2 Bluetooth dual-mode module. The module is compatible with iOS and Android devices, wireless sensors, and can be used as a cable replacement. The embedded serial port profile frees application resources while the command set API creates a simple but flexible firmware interface. PCB layouts are simplified using available Gerber files and minimized with Panasonic's tiny footprint technology.

PAN1026 is a low energy module designed to create low data rate networks using a minimum amount of power. It provides an ultra-fast connection time of 3 ms. It can handle a single Vcc supply between 1.7 and 3.6 Volts.

3.2.4.2.3 RN4020 Module

RN4020 uses Bluetooth Version 4.1. It integrates RF, a baseband controller, and command API processor, making it a complete Bluetooth Low Energy Solution. The size of the chip is 11.5 x 19.5 x 2.5mm. A Digi-Key part number is RN4020-V/RM-ND. The cost is $10.61 per one module.

The RN4020 has a built-in high performance PCB antenna optimally tuned for long range, typically over 100 meters.

The small form factor, surface mount module has the complete Bluetooth stack on-board and is controlled via simple ASCII commands over the UART interface. The RN4020 can be remote controlled by another module over a secure connection and can be updated via the UART interface or over-the-air.
RN4020 is a low energy module for designers who want to easily add low power wireless capability to their products. It can handle a single operating voltage in the range between 3 to 3.6 Volts. Tx Power Consumption is 16 mA, Rx Power Consumption is 16 mA.

3.2.4.3 RN4020 Module Attributes

This module used the latest Bluetooth 4.1 version versus 4.0 that is offered for other two modules. Newer Bluetooth version has better performance and more features.

3.2.4.3.1 Cost

The cost of this module was a great standout point. The RN4020 was the cheapest Bluetooth module among its competitors. There was no requirement to buy some specific minimum amount of RN4020 modules. Digi-Key Electronics had 83 available modules in stock that could have been purchased at any time, and the price for a single unit was only $10.61.

The price for a single unit for PAN1026 module was $15.3. BR-LE4.0-S2N chip was only available for purchase when buying several units. Minimum 10 units have to be purchased with $13 per each unit.

3.2.4.3.2 Size

The size of RN4020 is 11.5 x 19.5 x 2.5 mm in WxLxH and weight is 1.2 grams. This size seemed to be pretty reasonable comparing to two other sizes of 11.8 x 12.6 x 1.9 mm for BR-LE4.0-S2N and 8.7 mm x 15.6 mm x 1.9 mm for PAN1026 modules. The widths of the module were a little smaller than the width of the BR-LE4.0-S2N chip. The length of RN4020 was a little bigger than length of the other two modules. The height was 0.6 mm taller than other two modules.

3.2.4.3.3 Power Consumption

Microchip's RN4020 Bluetooth Low Energy Module provided a highly integrated solution for delivering low power Bluetooth 4.1 solutions. The advanced command interface offered rapid time to market. The RN4020 module complied with Bluetooth specification version 4.1. It integrated RF, a baseband controller, and command API processor, making it a complete Bluetooth Low Energy Solution.

RN4020 had the best low energy power consumption among three modules. RN4020 could handle a supply voltage in the range between 1.8 and 3.6 Volts DC. We needed for our design an input voltage up to 3.3 Volts, which perfectly coincides with the modules voltage range.

A working current depends on profiles but typically 12 mA. A standby current is less than 0.5 mA. Current consumption for dormant mode is less than 700 nA, deep sleep < 5 uA, idle < 1.5 mA, Tx/Rx active is 16 mA at 0 dBm. (3)

3.2.4.4 RN4020 Interface

Hardware Interface

The primary communication interface between the Raspberry Pi MCU and the RN4020 Bluetooth Module consisted of a Universal Asynchronous Receiver/Transmitter (UART) bus. The UART allows asynchronous serial communication between the RN4020 peripheral module and the Raspberry Pi MCU.

The RN4020 Bluetooth Module has the capability to be commanded by the application software via the recommended and additionally provisioned hardware control lines. The additional provisioned hardware control lines were used to extend the utility of the RN4020 during development and/or for the final consumer product. The interface between a microcontroller and the RN4020 is shown in Figure 3.2.4.1 below.

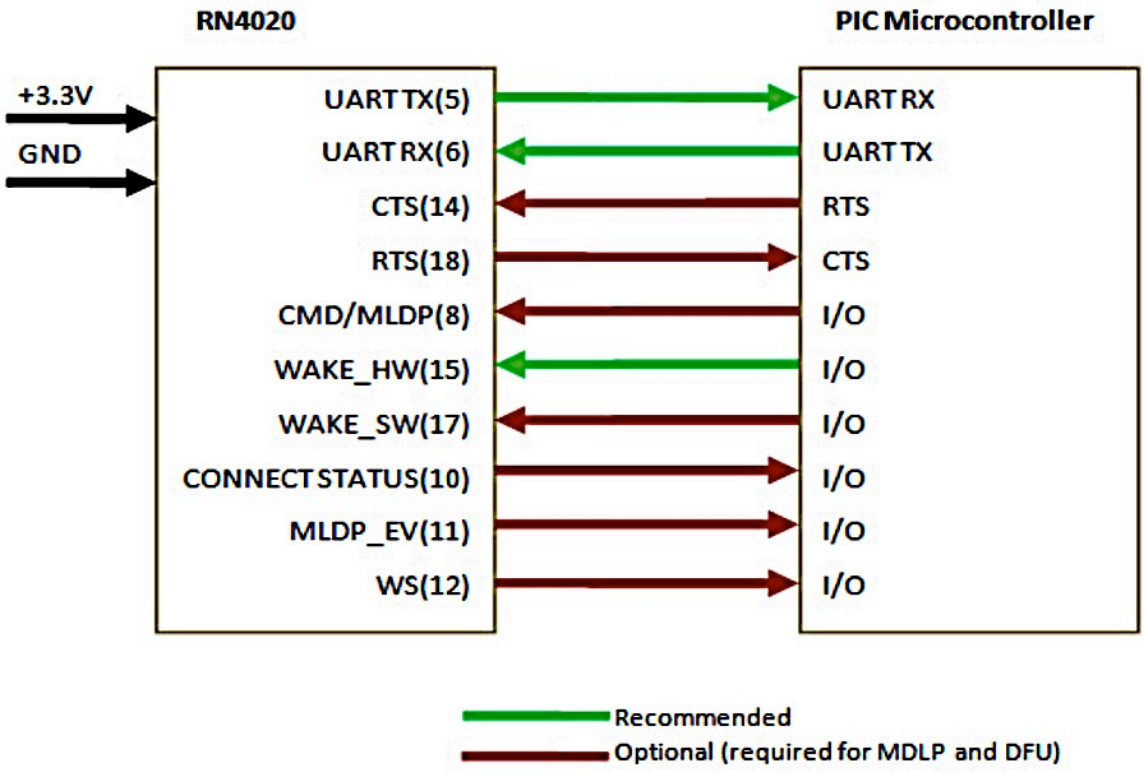


Figure 3.2.4.1 – Interface Descriptions, reprinted with permission from Microchip

Software Interface

The RN4020 Bluetooth Module utilizes the ASCII command Application Programming Interface (API) defined in the RN4020 Bluetooth Low Energy Module User's Guide. This document was the primary source of information regarding the RN4020 software command interface.

3.2.4.5 RN4020 Requirements

3.2.4.5.1 Hardware Requirements

The Main Board provides a voltage regulator circuit to regulate the operating voltage of the RN4020 Bluetooth Module.

The RN4020 Bluetooth Module voltage regulator resets the RN4020 module when the voltage is outside of the recommended operating range.

The RN4020 Bluetooth Module voltage regulator circuit provides a +3.3 $\pm$ 5% DC voltage source.

The Main Board provides a serial communication interface between the RN4020 Bluetooth Module and the Raspberry Pi MCU.

The Main Board provides the control lines for hardware flow-control between the RN4020 Bluetooth Module and the Raspberry Pi MCU.

The Figure 3.2.4.2 shows the module's pin-out. In this section, we specify the use of physical pins, and how they are connected on the circuit board. For our design, we do not need to use all the pins. Below is the description and discussion of pins that we will need to use.

We definitely needed to use the generally required pins such as GND and VDD. The hardware interface required the use of UART. UART_TX and UART_RX will be used to send or receive data that is coming from evaluation board.

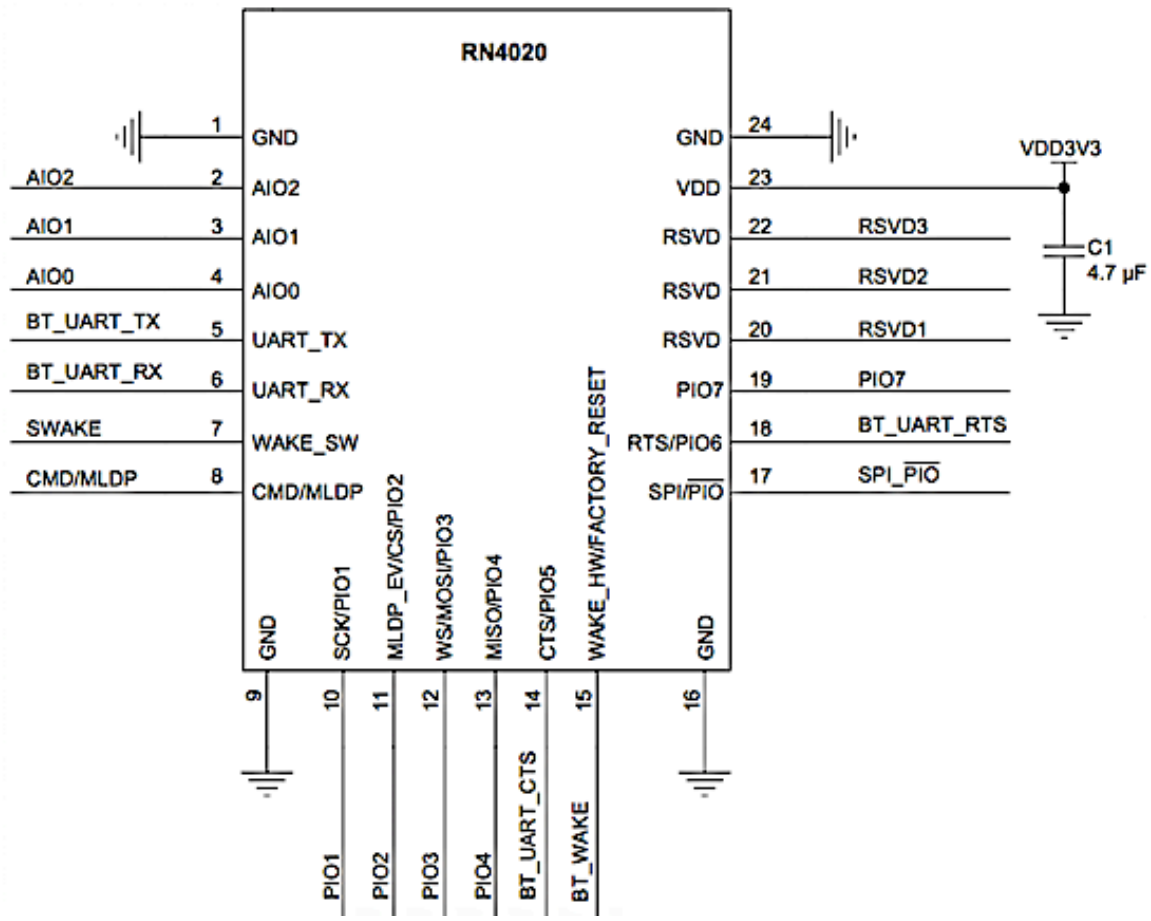


Figure 3.2.4.2 - RN4020 Pin Diagram, reprinted with permission from Microchip

WAKE_SW – Deep Sleep Wake; active-high to wake module from Deep Sleep. Function: Input; weak pull down
CTS PIO [5] - Reserved for CTS if hardware flow control is on the UART. Function: CTS (input)
WAKE_HW - Hardware wake from dormant state. Function: Active-high; internal pull down.

Figure 3.4.2.3 illustrates the RN4020 pins that will be used. Unused pins will be left in a default configuration or grounded per the module specification. The rationale for not utilizing all the available pins is due to unneeded advanced hardware debug functions and manufacturer firmware update modes that will not be used during the lifecycle of this project.

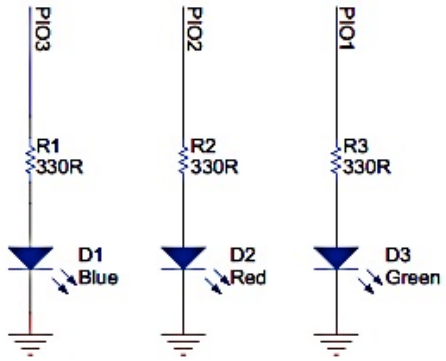


Figure 3.2.4.3 - Status LEDs, reprinted with permission from Microchip

3.2.4.5.2 Software Requirements

In this section, we expanded on how the pins will be used and for what reasons.

Status LED Pins

We have three status LED pins available to us. We decided for what purposes we may need to use LEDs. We wanted to show one LED to the user. Then, we needed to have a power LED that indicates that the device is powered. And then, we need to have some sort of network LED that indicates that the Bluetooth-active connection is going on.

Three status pins that can be set as LEDs or for other purposes:

1) CONNECTION LED (Green LED)/ PIO1/ SCK pin:

This pin can have three configurations that are defined by software. It can be used for general purpose, diagnostics or as a connection LED. For connection LED, default state is output: active-high indicates the module is connected to a remote device. Active-high indicates a disconnected state. For general purpose, the pint can be configured as PIO1 via software command. The pin should be configured as SCK or diagnostics and factory calibration if pin 17 is asserted. In our case, we may choose to use this pin as a connection LED.

2) MLDP_EV (Red LED)/ PIO2/ CS

The pin can be used for general purpose, diagnostics or as the LED indicating MLDP data event. For MLDP_EV, default function is output used for MLDP data event indicator (Red LED). Active-high indicates MLDP data received or UART console data-pending. Low level indicates no events. Event only triggered in CMD mode, when CMD/MLDP (pin 8) is high. For general purpose, the pint can be configured as PIO2 via “|>” and “|<” commands. The

pin should be configured as CS for diagnostics and factory calibration if pin 17 is asserted.

3) WS (Blue LED)/ PIO3/ MOSI

The pin can be used for general purpose, diagnostics or as the LED indicating activity. For LED, default function is an output used for activity indicator. High level indicates module is awake and active. Low level indicates module is in a Sleep state. For general purpose, the pint can be configured as PIO3 via “|>” and “|<” commands. The pin should be configured as MOSI for diagnostics and factory calibration if pin 17 is asserted.

So, the Bluetooth Module gave us three options. The connection LED was our first option. It will be useful when the device is connected to a remote device. This will toggle between high and low, depending, if the connections are active or not. The second pin MLDP_EV gives us an event. Any time the data is received over UART, which means the device sends data to the Bluetooth, it blinks or toggles high and low. It will be useful during the development stage because it will show us that there is a device connected. The third LED is an activity indicator, and is really only used for engineering purposes. We won’t need to use it.

Using LEDs during the development stage would have helped us visually confirm what our hardware is doing. For this reason, we need to have some visible LED or LEDs that will show that there is some sort of connection or activity going on in the network. It may be a combination of green PIO1 and red PIO2 LEDs since the first LED is simply shows when the module is connected. We may have wanted to have had some LED blinking when there are things happening. The first LED is not going to blink because it is going to stay on all the time showing us that there is something connected.

None of these LEDs were used, however, in the final design due to board constraints.

Data Transfer Pins

CTS/ PIO5 pin – reserved for CTS (clear to send) if hardware flow control is on the UART. The pin can be configured as CTS (input) or PIO5.

PIO6 – reserved for RTS (request to send) if hardware flow control on UART. Configurable as PIO6 if hardware flow control disable. The pin can be configured as RTS (output) or PIO6.

There are two data transfer pins CTS (input) and RTS (output) that are used to control the data flow on hardware. These pins allow two devices to talk to each other and control when the data should be sent and at what rate. It’s a nice plus

to have these pins if we will decide to do something like that. Realistically, the RTS and CTS pins are used in situations when the receiver and transmitter need to communicate without the risk of losing data under specific conditions. Conditions such as system scheduling, timing, and high transfer rates can cause data loss. UART Flow Control makes use of the RTS and CTS signals to allow devices to communicate under these conditions. Even if an immediate need for flow control is not needed, it is a good practice to create a design margin for future applications.

Control Pins

WAKE_HW pin allows the RN4020 module to be signaled to exit a dormant state.

WAKE_SW pin allows the RN4020 module to be signaled to wake from a Deep Sleep state. The use of these pins allows the RN4020 module's state to be controlled by a software implementation.

3.2.4.6 RN4020 PCB Layout

Dimensions

Figures 3.2.4.4 and 3.2.4.5 illustrate the RN4020 Bluetooth Module dimensions. It is important to account for these dimensions into the overall Main Board layout and care design.

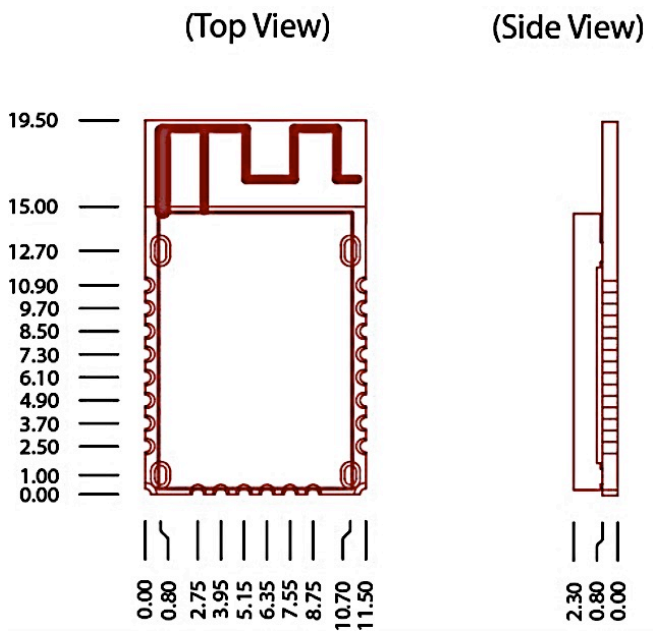


Figure 3.2.4.4 – Top View and Side View of Dimensions, reprinted with permission from Microchip

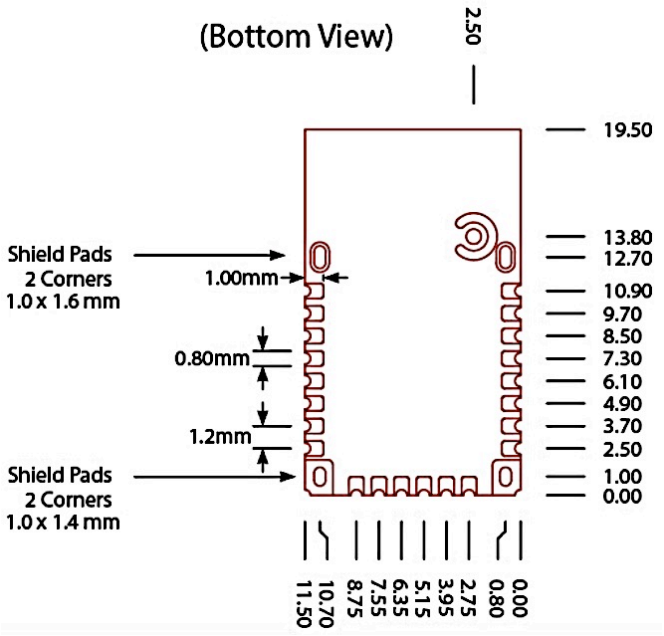


Figure 3.2.4.5 – Bottom View of Dimensions, reprinted with permission from Microchip

Mounting

Figure 3.2.4.6 shows the recommended mounting details. For optimal radio performance, the RN4020 module's antenna end should protrude at least 31 mm beyond any metal enclosure. The PCB antenna is fabricated on the top copper layer and covered in solder mask. The layers below the antenna do not have copper trace. It is recommended for module to be mounted on the edge of the host PCB. It is permitted for PCB material to be below the antenna structure of the module as long as no copper traces or planes are on the host PCB in that area.

Figure 3.2.4.7 shows example of good, bad, and acceptable positioning of the RN4020 on the host PCB. When laying out the carrier board for the RN4020 module, the areas under the antenna, RF text point (semi-circular pad) and shielding connections should not have surface traces or ground planes.

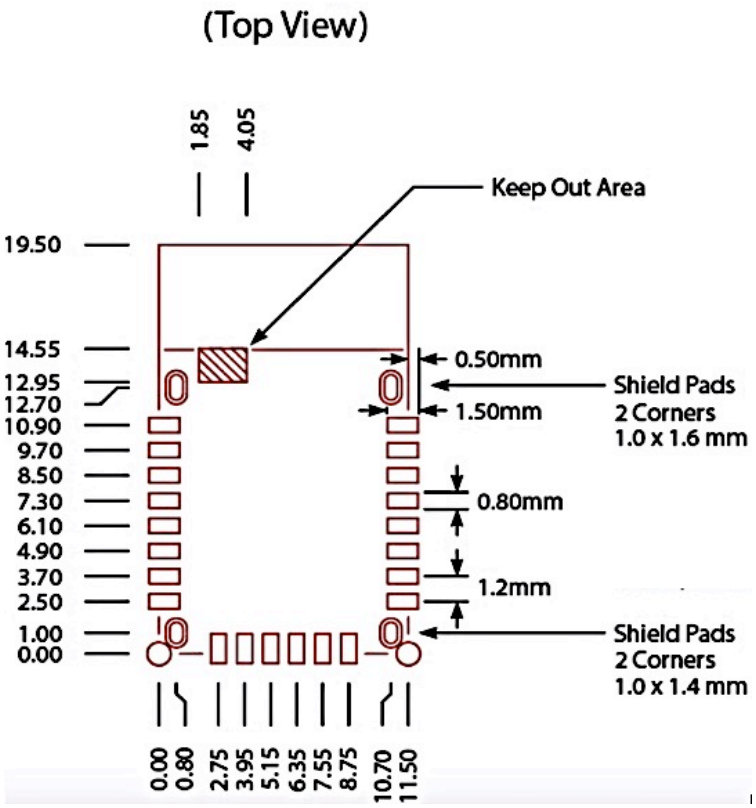


Figure 3.2.4.6 – Recommended PCB Footprint, reprinted with permission from Microchip

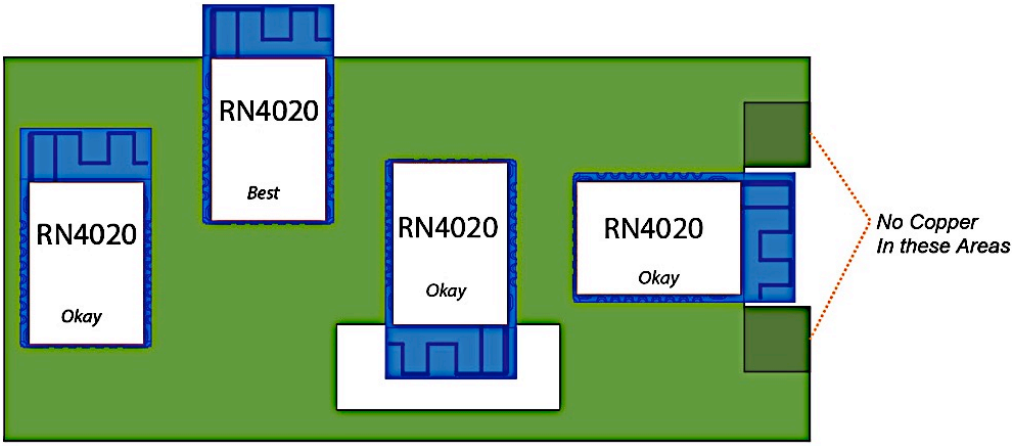


Figure 3.2.4.7 – RN4020 Host PCB Example Layout, reprinted with permission from Microchip

Soldering

The RN4020 wireless module was assembled using standard lead-free reflow profile IPC/JEDEC J-STD- 020. The module can be soldered to the host PCB using standard leaded and lead-free solder reflow profiles.

To avoid damaging the module, the following recommendations are given:

- Microchip Technology Application Note: “AN233 Solder Reflow Recommendation” (DS00233) provides solder reflow recommendations
- Do not exceed peak temperature (Tp) of 250 C
- Refer to the solder paste data sheet for specific reflow profile recommendations
- Use no-clean flux solder paste
- Do not wash as moisture can be trapped under the shield
- Use only one flow. If the PCB requires multiple flows, apply the module on the final flow

Complications

Unfortunately, the chip chosen was a single-mode chip and did not support any non-LE Bluetooth devices. As a result, we were forced to relegate it to only providing serial access to the console and used a USB Bluetooth dongle for the controller instead.

3.2.5 LEDs

During operation of the FBC, it is ideal for a form of a power status indicator light to be available to the user for feedback on the remaining battery life. Considering the need for a visual representation to be compartmentalized for a hand-held, portable device, the use of light emitting diodes (LEDs) are a sufficient choice to indicate the battery charge status. LEDs lend themselves to low power consumption, color representation versatility, and ideal surface-space minimization. The FBC offers two LED-based battery status indicators, one which directly indicates the battery charge status with an RGB LED, and the other which will utilize surface mounted miniature LEDs to indicate a more precise measure of remaining battery life.

3.2.5.1 LED Light Color Properties

The LED is to always be considered as a current-powered pn-junction diode, with an individually identified voltage contribution when illuminated (in the ON status). The current flowing through the LED, the forward current, determines the amount of light, or brightness, emitted, with the maximum forward current distinguishing the limit of current that can pass through the diode without catastrophic failure. Additionally, the LED contains a forward voltage to be considered in relation to the power supply. Maximum forward voltage and current values are specified for the LED used, with common value ranges expected within certain colored LEDs,

such as red or green diodes, to be lower than that of blue LEDs, which require higher voltages. We noticed that the red LED, which has a forward voltage of 2V, has a much lower tolerance of current in excess of its forward rating. The blue LED, meanwhile, can withstand values higher than its forward current rating, failing around 3.8V. However, even though the blue LED can function past its forward current rating, doing so can damage the diode and shorten its performance life significantly.

It is always important to not overload the LED with too much current that would potentially burn out the diode. A simple solution to restrict current flow would be to design a two-part voltage regulator, consisting of a current-limiting resistor in series with a Zener diode and the LED. The resistor value will be chosen to ensure that the current flowing through the diode will not exceed the maximum forward current value, and the Zener diode, with contribution from the LED forward voltage, will limit the voltage from the power supply across the resistor. This series circuit is ideal for its simplicity and effectiveness. A disadvantage is that it lacks efficiency, as the resistor releases heat as it limits current. However, due to the LED circuit reading directly from the DC battery power source, at a low maximum voltage of 4.2 volts, the resistor/Zener series regulator will be sufficient.

3.2.5.2 Red, Green, Blue (RGB) LEDs

The RGB LED serves as three separate colored LEDs in one ‘bulb’ display. Within the device are three separate diodes, one each for the red, green, and blue LED. The RGB LED consists of four pins, one anode, or negative, pin for each of the three diodes, and a cathode, or positive, pin commonly shared by all three diodes. Even though the RGB LED joins three separately colored LEDs under one bulb, each one behaves as a single LED, and follows the forward voltage and current restrictions unique to that particular LED. Likewise, the same voltage regulator circuit design can be applied to control each of the three LED colors separately, and in combination to generate many various color outputs.

The RGB LED is ideal for color combinations and sequencing illumination signals, with a wide range of combinations available for output via incorporating the three different LED colors together. Additionally, forward current increase or reduction can dim or brighten the LED for a desired dominant color, and can be used to transition from one diode in the RGB LED turning off to the other turning on, assuming the change in current is not largely immediate in value extremes. Figure 3.2.5.2 below demonstrates the color spectrum wavelengths achieved for maximum intensity, with overlapping defining the capability to combine two separate colors for a third spectrum option. In the FBC application, each of the three available diodes in the RGB LED will be used for a specific status, however, and the transition from each diode within the RGB LED will be the focus.

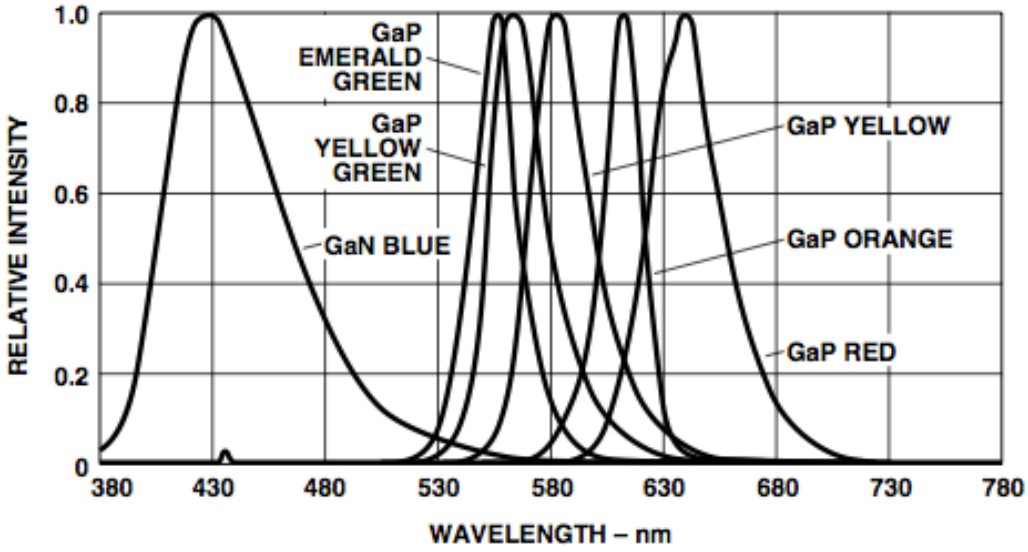


Figure 3.2.5.2 - RGB LED Wavelength Spectrum, reprinted with permission from Wikipedia

3.2.5.3 Surface Mount LED (SMD LED)

Surface mounted LEDs (SMD LEDs) are, by comparison to single LEDs, much shorter in height from the surface board, with the average SMD measuring 1.6 millimeters tall, compared to a standard green LED that measures 8.6 millimeters tall. In design, SMDs are designated to be soldered directly to the surface, such that the anode and cathode regions are not evident with pins, but are instead represented as a mounted platform at opposite ends of the SMD. This height reduction makes the SMD ideal for designs with limited spacing constraints, as is the case with a handheld portable device as the FBC. With a square, flat design, SMDs also boasts a significantly increased viewing angle, which is the angle of brightness away from the viewing center of the LED. The SMD viewing angle is typically 100 to 140 degrees, compared to the 30 to 60 degrees viewing angle of a single green standard LED, making the SMD ideal for mounted displays that can give off a wider range of light across a surface. Figure 3.2.5.3 below shows the viewing angle range standard for LED displays.

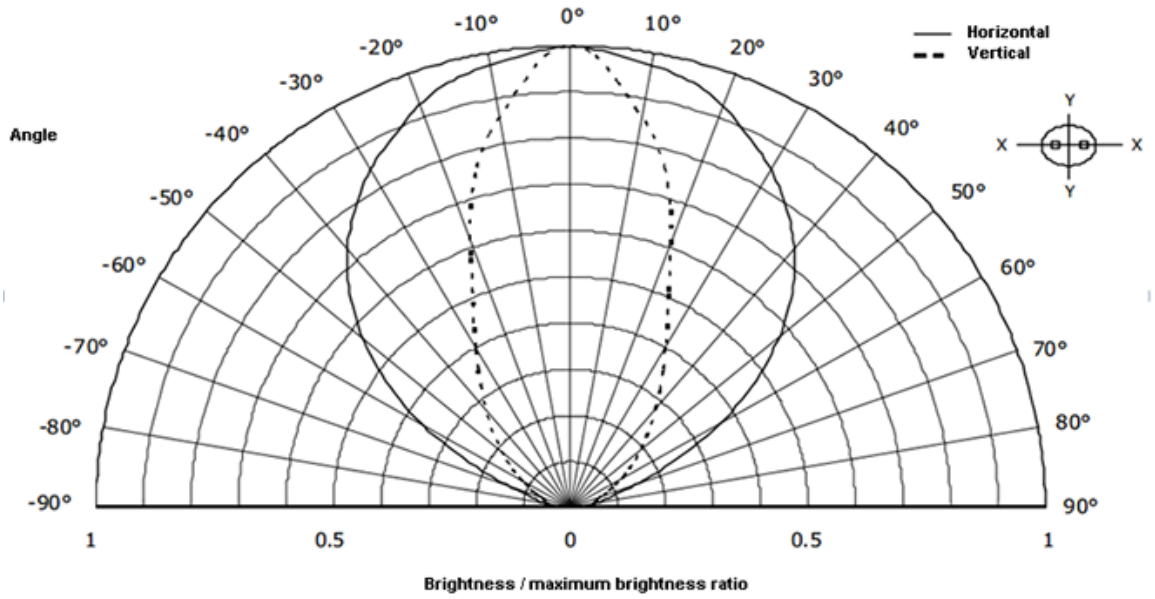


Figure 3.2.5.3 - Viewing Angle Spectrum for LED, reprinted with permission from Wikipedia

Selecting the ideal SMD LED for the indicator circuit revolves around taking in to consideration the acceptable forward current and LED-Zener voltage summation contribution. The standard forward current for LEDs is 20 mA, with a lower current simply reducing the luminosity of the LED, and a higher current potentially shortening the operational life of the diode, and even destroying it. Wanting to reduce the current draw from the power source while still attaining measurable current through the microcontroller, we must consider the voltage contribution that will attribute the current along the current-limiting resistor. We were looking for a SMD LED with a lower forward voltage to factor into the Zener contribution, while meeting the ideal forward current and viewing angle advantages found in SMD LEDs. Also, the size of the SMD LED will be considered for space availability of the FBC design layout. Below, in Table 3.2.5.1, are three comparable green SMD LEDs for consideration of the battery power indicator circuit. We chose a green LED indication, as green lighting has been a universally common indicator of sufficient status for most electronics.

Model	Forward Current	Forward Voltage	Viewing Angle	Size Dimensions
LG L29K	20 mA	1.7 V	160°	1.3 mm x 0.8 mm
APA2106MGC	20 mA	2.1 V	120°	2.1 mm x 0.6 mm
LG R971	25 mA	2.2 V	160°	2.1 mm x 1.35 mm

Table 3.2.5.1 SMD LED Model Comparison

Looking at the three green SMD LED models, we first compared the forward current. The LG R971 is the only one that breaks the standard of 20 mA, having a higher tolerance of 25 mA. The advantage to this is that the LED can withstand a higher current draw, allowing for more flexibility in terms of current response from the power system. However, the higher forward current means that the LG R971 requires higher than normal current to achieve maximum brightness, and we wanted to be mindful of the allocation of current throughout the device for battery supply purposes.

Looking at forward voltage, the LG L29K has a much lower than average rating of 1.7 V. This can allow for lower Zener diode voltage contributions in relation to the current-limiting resistor, and better manage the allowable forward current through the LED. When considering viewing angle, the APA2106MGC is the least practical, as that it has an angle of 120 °, much lower than the typical 160°. Since improved viewing angle is, in nearly every sense, preferred, we eliminated the APA2106MGC from consideration for our design. With size constraints, the LG R971 width, by box design, takes up much more space than other LED models. However, with only 3 SMD LEDs being employed in relation to their side visibility of the case design, this constraint is flexible to overcome.

With all considerations, we chose the LG R971 model over the LG L29K. This decision was primarily based on the LG R971's higher current tolerance, which, for SMD LEDs, is of the highest importance for both turning on the LED while ensuring it withstanding potential current-overdraw. Furthermore, the LG R971 does not require maximum brightness, and lends itself to more flexibility with acceptable current to adequately illuminate for battery status indication. Figure 3.2.5.4 displays the dimensions of the LG R971, both in millimeters and inches, to showcase its desired minimal surface area for design implications.

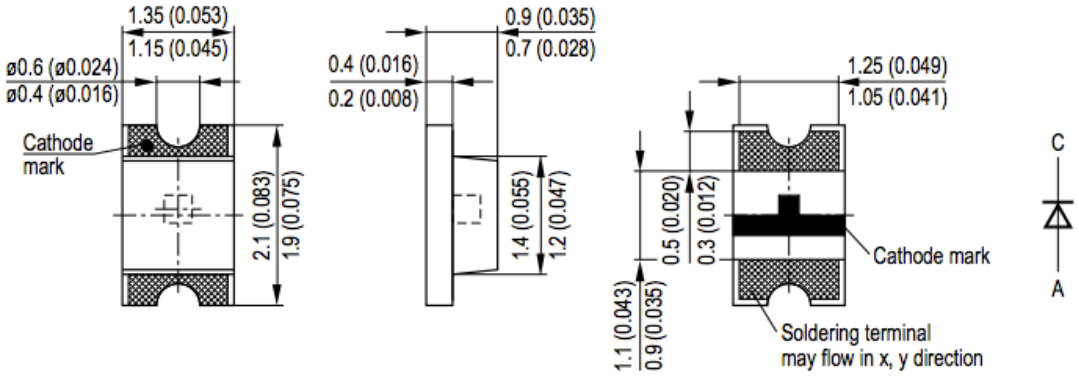


Figure 3.2.5.4 - LG R971 Dimensions, reprinted with permission from OSRAM

3.2.5.4 LED Implications

The most significant restraint to most LED technology is the forwarding current through the circuit. Since LEDs are under the diode family, they are operated at specified current levels, with a maximum forwarding current defining their limit. At maximum rated current, the LED will be at its peak luminosity, but will also be prone to quick component degradation, and a shortened functional life span. Current exceeding the forward current, past a maximum value, can destroy the diode, and permanently burn out the LED, ruining it for further operation. While LEDs can operate below their forwarding current value, the luminosity will be lessened, and the output can be dim. One of the considerations for any LED circuit is being able to supply an acceptable forward current through the LED. Unfortunately, the standard for forwarding current is 20 mA, which can be proportionally small compared to the current output throughout the device. Realistically, we can implement current-limiting resistors at the LED inputs, which can appropriate current. Although economically speaking, LEDs and resistors are not a financial concern in numbers, size constraints for the FBC limit the amount of additional components added to regulate current.

Another concern for working with LEDs, and SMD LEDs, in particular, is the small workable surface factor. The SMD LEDs we are working with are only 2.1 mm long and 1.35mm wide. For actual implementation on the designated work board, these size constraints require specialized small-scale tools to solder and test the components. This is a necessary constraint, however, as the FBC is meant to be a limited-sized handheld device. For building the SMD LED battery indicator circuit, investment and knowledge in small-scale soldering is to be desired.

3.2.6 Solar Paneling

A specification for the design included a means to recharge the power supply battery via exterior solar paneling that effectively extends the power supply while meeting the constraints of the power output. While means to charge battery power supplies via solar cells is simple, panel dimensions, quantity, and charge characteristics must be considered. Additionally, the output voltage from the solar module contributions must not overcharge the initial power source, to which voltage regulation application must be applied. In effect, the solar panel charging contribution design was factored by the necessary standards of available solar modules that meet the constraints of the hardware design. When applying additional charge to the power supply battery via solar paneling contribution, the effectiveness of the resulting solar output were considered. Solar cell efficiency is most commonly measured in energy conversion efficiency, which yields the percentage of solar photons converted into actual contributing electrical power, and is largely considered for application.

3.2.6.1 Efficiency Versus Cost

The energy conversion efficiency rating of the solar module is an important value to consider when applying a solar-fueled charging contribution, but a higher rating product does not mean that it is commercially realistic, nor the most feasible for the project. The highest recorded efficiency for a solar cell has been 44.7%, with similarly rated cell efficiencies existing, but these cells are not practical in the consumer market, and are often constrained to laboratory research, due to being made from more costly multi-junction sub-cells that require sunlight magnifications. More realistically, crystalline silicon photovoltaic cells are the prevalent product for the solar power market, with monocrystalline, polycrystalline, and thin film silicon panels being the dominating technology. The efficiency ratings of these three materials vary, as does their cost per cell/panel.

Monocrystalline Cells

Monocrystalline silicon solar cells are comprised of single-crystal silicon material with an average efficiency rating of 20%. The appeal to monocrystalline cells is that they are the most commercially efficient panels in circulation, and are capable of performing better in indirect sunlight, such as overcast weather conditions, compared to the polycrystalline and thin film counterparts. The drawback to monocrystalline solar cells is the cost in exchange for better efficiency, and the fragility of the panels themselves.

Polycrystalline Cells

Polycrystalline solar cells are the most commonly, commercially produced solar cells, with a correspondingly lower price and efficiency than monocrystalline. The average efficiency rating for polycrystalline cells is 15%, a value in-step with most widely available solar paneling products. Polycrystalline cells are ideally preferred for small-scale projects with a limited budget, but, like monocrystalline cells, they are fragile in application, and the lower efficiency make them a factor for usefulness in the power contribution.

Thin Film Panels

Thin film solar panels boast the lowest cost per watt in terms of all three materials, but also record the lowest efficiency rating, varying on the specific material used. Thin film panels are commonly made from three types of material. Amorphous Silicon panels have a 8% efficiency rating and have a low manufacturing cost, making it a competitive product. It also can be produced in specified surface dimensions, which is better for design layout. Cadmium Telluride (CdTe) panels are significant in that the efficiency ratings can be as high as 15%, matching the efficiency of crystalline silicon, while maintaining a significantly lower production cost. However, most commercial efficiency ratings for CdTe are closer to 10%, and a primary concern for development is that

cadmium is extremely toxic, and CdTe film panels can potentially be an environmental concern. Copper Indium Gallium DiSelenide (CIGS) film panels are the next growing material for thin film solar panels, with experimental efficiencies reaching as high as 20%, while most commercial ratings hover around 11%. CIGS panels use considerably less cadmium levels, and have greater heat resistances, but struggle to be price competitive compared to amorphous silicon and CdTe films.

3.2.6.2 Solar Cell Selection

Effectively for FBC, the solar paneling design serves primarily as a means to recharge the power source battery, or, alternatively, extend the available power time to the device while in play. Therefore, the solar panel contribution is not specifically designed as the primary source of battery charge, as assumed by the external power charge plug-in, but rather as the auxiliary contribution to an extended alternative. With this in consideration, for supplying additional charge to the Lithium Polymer battery, we looked at four separate models of solar cell technology, two monocrystalline cells, one polycrystalline cell, and one amorphous silicon thin film, as shown in Table 3.2.6.1.

Model	Output Current	Efficiency	Dimensions	Cost (single quantity)
IXYS SLMD481H08L	200 mA	22%	89 x 55 mm	$31.91
IXYS SLMD121H8L	50 mA	22%	86 x 14 mm	$10.23
P-MAXX-Series Polycrystalline	400 mA	14.8%	80.43 x 19 mm	$1.99
Panasonic – BSG AM-1417CA	13.5 µA	Varies	35 x 13.9 mm	$2.40

Table 3.2.6.1 – Solar Panel Comparisons

By comparison, the monocrystalline cells yielded substantially higher efficiency ratings, and significantly higher costs. The thin-film Panasonic-BSG output a marginally lower current, not suitable for charging the FBC lithium polymer battery. The P-MAXX polycrystalline cell supplied the largest output current, which is ideal for the time taken to charge the source battery to full capacity, and costs considerably less. However, its limited efficiency raised concerns for implementation on successfully charging the battery in a limited forecast environment, making it unsuitable for an effective handheld design.

Between the two monocrystalline panels, the case size factored into the importance given to the solar cell dimensions. Based on the design constraints, the FBC is designated to have an exterior case area range similar to that of the internal Raspberry Pi2 and the LCD Composite screen of 85 x 56 millimeters (mm), giving approximately the equal amount of space available for the solar cells to be paneled on the back of the case. The SLMD481H08L has a dimension that would closely match the surface area of the case, allowing for the need of only one cell module, with a favorable output current of 200 mA. Likewise, the SLMD121H8L monocrystalline solar cell can match the surface area and 200mA current by paneling four cells lengthwise, and connecting them in parallel, which would sum of the four 50 mA to the near same output current of the single SLMD481H08L.

The cost discrepancy was that four of the SLMD121H8L would be significantly more expensive, but the tradeoff was the benefit of replaceable panels. Should one of the SLMD121H8L get damaged, it can be replaced, while the other three remain functional and can be kept. With the larger, single cell SLMD481H08L, if the panel were to be damaged, the entire solar contribution would need to be replaced. Additionally, the four separate SLMD121H8L panels give way for more maneuverability with the positioning on the device, a flexible attribute to consider.

After reviewing the variety of solar paneling options, we concluded that the monocrystalline design would best serve as the choice technology for the FBC, given its higher efficiency rating in relation to the contribution to extending the power charge of the source lithium polymer battery. Although a lower efficiency rating was more feasible, a larger surface area would have been needed to make up the same electrical charging energy, and for a small, handheld device, such as the FBC, that was not a practical option. In terms of comparing cost and size, we concluded that the IXYS SLMD121H8L solar cell would be the best option for the case design, as well as meeting the specifications for sufficiently charging the device. Below, in Figure 3.2.6.1, is the model part SLMD121H8L that we used.

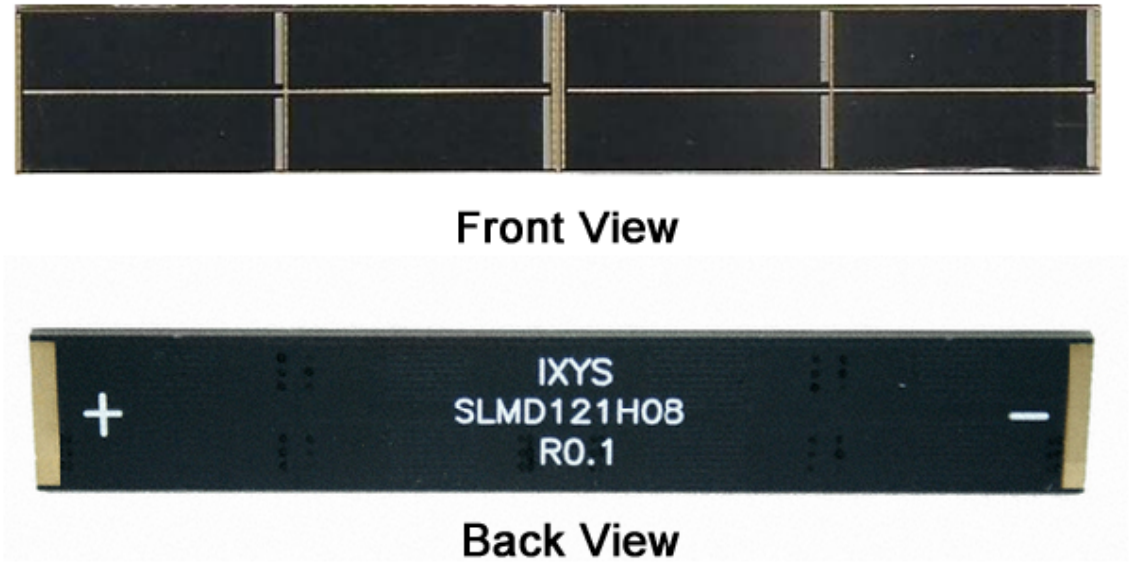


Figure 3.2.6.1 - SLMD121H8L Solar Cell

Additionally, in Figure 3.2.6.2, we have the solar cell size dimensions for perspective of exterior case design.

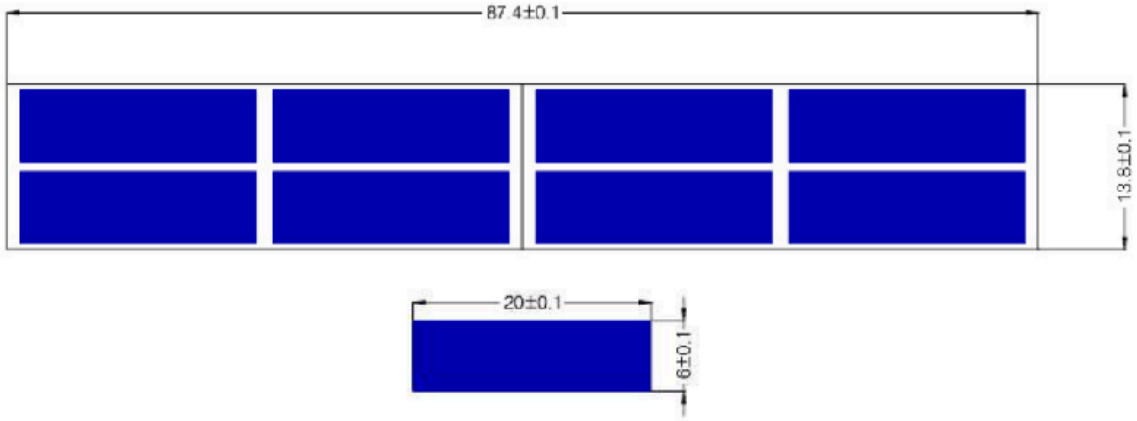


Figure 3.2.6.2 – SLMD121H8L Solar Cell Dimensions

3.2.6.3 Solar Overcharge Protection

One concern addressed with the addition of the solar panel circuit to the battery power source was to regulate the voltage discrepancies and avoid current leakage. When the solar panel charger is not being utilized, or in direct sunlight, we do not want reverse current contribution from the battery to flow back into the solar cells. The solar circuit essentially acts as a secondary charger to the FBC, and will use a similar charge protection IC for charging the battery. Additionally, we needed to monitor the solar cell's input voltage contribution to manage supplied charge current, otherwise the solar charger's voltage will collapse when it drops from maximum open-circuit levels. Another concern was that charging our lithium polymer source battery required constant current and constant voltage from the charger, to avoid battery damage. The solar panel has widely variable voltage and current supply, and a charging IC was needed. For consideration, we considered three charging IC models, both designated for lithium battery charging, and ideal by means of solar energy.

LT3652

The LT3652 is a 12-pin lithium battery-charging controller, with charge switch protection embedded in it. The charge controller can take a minimum charge voltage of 4.92V and a maximum of 32V, although this is unnecessarily high, given our low power system. The LT3652 produces constant voltage and current to the charging destination, and has a built-in output charge detection to terminate input voltage when charging is complete. This charge controller is ideal for the very use of charging a lithium battery via solar cells, but is intended for a much larger contribution scale.

bq24210

The bq24210 is a 10-pin charge controller, with an input charge voltage range of 3.5V to 18V. Similarly, it allows for a constant voltage and current to be supplied to the charging battery, and specifically caters to lithium ion battery charging circuits. The bq24210 also offers battery charge level detections to signal the controller's status, thus indicating if the battery currently needs to be charged at all, if already at maximum voltage ratings. This model, as with the LT3652, is specifically designed for solar circuits, being ideal for ensuring protection by limiting leakage current through the input pins.

SPV1040

The SPV1040 is an 8-pin, low power charge controller, with input voltage ranging from 0.3V to 5.5V. It provides constant voltage and current to the charging battery, and includes protection from discharge at low voltage levels. One drawback is that this controller is low-powered, and is designed for smaller

battery supply contributions, creating concern for conflicting shutdown conditions while charging.

3.2.6.4 Solar Technology Constraints

One of the significantly contributing constraints to renewable energy technology, especially solar energy, is efficiency. Even higher-grade commercial monocrystalline silicon solar cells have typically an efficiency rating of approximately only 20%. While efficiency ratings can certainly reach much higher, up to about 44%, such values are only reasonable in carefully controlled environments, typically in research laboratories. However, the means to achieve such ratings also include much more costly multi-lens technology for solar magnification, and are not yet practical for public manufacturing. Although lower efficiency ratings are acceptable, and much more cost-efficient, the trade-off is the time required to make up for such energy loses. A 22% efficiency solar cell will take twice as long to produce the same amount of usable electrical energy as would a 44% solar cell. Thus, even cheaper and less efficient polycrystalline cells will take even longer. The constraint is factoring in how long it can take to produce the desired electrical energy to meet product specifications.

One solution was to simply apply more solar cells in the paneling circuit, with connections in parallel or series designed as needed for achievable voltage or current levels. However, cost and space were debilitating factors. Depending on the application, surface area for solar paneling can be limited. In the case of the FBC, being a portable handheld device, the surface space for additionally solar cells was extremely limited. Thin film solar cells, which can wrap around the device and are more flexible to design, are a realistic solution. However, this technology is the most limited in output efficiency, and can also be potentially harmful to the environment, pending on the material used. Additionally, designing a panel with more solar cells can be costly, with the marginal benefit of added power production needing to outweigh the marginal cost of purchasing more cells. Such cost considerations were factored into choosing the SLMD121H8L cells for the auxiliary charging circuit.

3.2.7 Audio

The cornerstone attribute of the FBC was to recapture retro video games in a modern sense, and a hallmark trait of the Super Nintendo Entertainment System (SNES) was the vintage gaming music. In original hardware production, gaming systems, such as the SNES, used audio sound chips that were separate from the main system, and relied on five audio wave channels (Pulse Wave1, Pulse Wave2, Triangular, Noise, and Delta Modulated Samples) to accomplish the precise tempo, pitch, and other effects for the soundtrack composition. Given that FBC will be supporting SNES games, it is important to compare the original SNES audio to the FBC's Emulation Station for accessing the audio sample codes from the game ROM. The SNES audio system was the Nintendo S-SMP, which operated at 2.048 MHz and performed from an 8-bit CPU core, the Sony SPC700. The S-DSP is credited for mixing and creating the actual sounds and audio, yielding the unique and iconic music samples based off of all five audio channels. By comparison, the FBC software, Emulation Station, accesses the same audio samples from the game ROM, and transmits them via the 3.5mm audio jack to the system stereo speakers. These emulated files arguably lacked the distinct modulated waves and noise compositions achieved by the S-DSP, as well as prove to have an audio speed discrepancy from the emulated SPC700 on Emulation Station. However, efforts to incorporate the original S-SMP sound chip to the FBC's microcontroller proved excessively challenging, and overstepped the allotted size constraints of the casing. Therefore, it was decided to work past the potential audio shortcomings of the FBC emulation in favor of reduced size and power.

3.2.7.1 Stereo Output

The primary choice for audio output from the FBC was decided between monophonic or stereophonic speaker design. The Raspberry Pi 2 core audio output lends itself to two audio channel pins, allowing the potential for either speaker design. Monophonic audio is generated through a single channel output, and only needs one audio speaker to transmit sound, a design classic with original handheld consoles, such as the Nintendo Gameboy Color. Using both audio inputs for two separate speakers, stereophonic output can be achieved. Stereophonic sound allows more depth and surround-sound output, generating a more perspective approach to the system user. Therefore, the stereophonic two-speaker design was used.

Amplifiers

Standard audio output speaker sizes in portable handheld consoles range 22 mm to 29 mm in diameter, and have an output impedance of 8 ohms. Given this output impedance, the speakers needed an amplifier circuit to make them functional with the Raspberry Pi 2's line level high impedance. The TDA2822M 8-pin amplifier offered dual-speaker stereo capabilities while limiting current drawn

from the device and keeping a power voltage within the 5volt supply. Comparatively, TS4984 amplifier offered a 16-pin multi-stereo option, and came with a much larger supply current. LM4880, on the other hand, was another 8-pin stereo capable amplifier, but with lower required current draw than the TS4984. In Table 3.2.7.1, we compared each of the three audio amplifier models for consideration.

Model	Supply Current	Supply Voltage	Power Output
TDA2822M	6 mA	1.8 V to 15 V	300 mW
TS4984	7.4 mA	2.2 V to 5.5 V	1 W
LM4880	3.6 mA	2.7 V to 5.5 V	250 mW

Table 3.2.7.1 – Amplifier Comparison

Given the desire for a low current draw from the power supply contribution, we chose the LM4880 model for our audio output amplifier. The LM4880 used the minimum 8 pins to use two magnetic speakers for the stereo output, while handling the 8-ohm impedance load. The supply voltage also allowed for direct power input from the system power supply. Additionally, we chose the LM4880 based on compatibility review with multiple controller platforms, including the core Raspberry Pi 2.
Later on in development, we elected a design that designated the LM4880 to supply the audio output for the audio port alone, and opted for each speaker to be managed by a LM4861 audio amplifier. This design lent itself for to a more controlled output from the Raspberry Pi 2, since the LM4880 could take on the left and right audio signals outputted to the audio jack, and each LM4861 handled the separate “left” and “right” audio signals for the left and right speakers.

3.2.7.2 Volume Control

Audio control levels needed to be established for user application in selecting the desired volume output of the device, or to completely mute the audio all together. The most common method for device volume control was through the use of a voltage-dividing, resistive-setting analog potentiometer. When the user slides the potentiometer bar or wheel, the level of resistance was set to drive the system’s voltage to ground for muted audio, or to the maximum rated voltage for allowable amplitude levels.

3.2.7.2.1 Linear Versus Logarithmic Control

Setting the correct resistance for the desired audio levels is achieved by moving the analog potentiometer bar or knob in the direction indicated of higher, or lower resistance. However, the concept of changing audio at acceptable rates factors in the amplitude level change as detected in decibels by the human ear. The two most common potentiometers for volume control are linear and logarithmic rated

potentiometers. Linear potentiometers change the output audio response on a linear scale, with the change of resistance proportional to the extent of which the potentiometer has been moved. Logarithmic potentiometers change output audio response on a logarithmic scale, with an initially steady change in volume levels increasing at a faster rate near the approaching power limit for maximum value.

For user consideration, the logarithmic potentiometer was the preferred design based on the human ear reception. The human ear is sensitive to amplitude changes on the logarithmic scale, and audio signals are better responded to gradual changes, instead of linear levels. However, many available potentiometers, especially models common in handheld devices, were defaulted as linearly changing controllers. The easiest way around this was the addition of a series resistor to divide the rate of voltage change. Figure 3.2.7.1 below compares the linear and logarithmic potentiometer levels, as well as the presence of the series resistor to toggle the output rate.

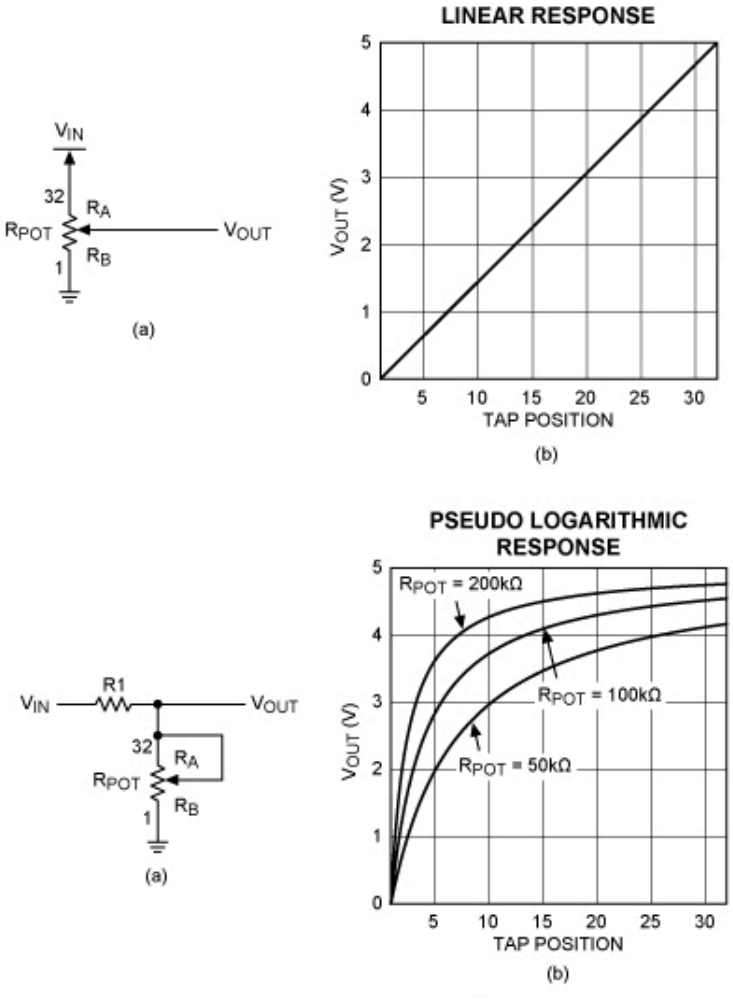


Figure 3.2.7.1 - Linear and Logarithmic Potentiometer Responses, reprinted with permission from Wikipedia

3.2.7.2.2 Analog Potentiometers

The most common, and simpler, potentiometer design found in popular handheld gaming devices was the analog models. Analog potentiometers are three-pin electro-mechanical devices that can adjust the output amplitude signals by increasing or decreasing their internal resistance to permit anywhere between maximum allowable voltage to zero voltage output. This change in resistance was directly commanded by the user, and was usually executed by means of an external slide bar, a thumbwheel, or a rotary knob. Typically, analog potentiometers alone function as linear audio output devices, and need an added resistor voltage divider in series to produce a more logarithmic change in volume, as discussed above. The clearest advantage for analog potentiometers is that they, unlike digital, require no additionally voltage source to operate; they simply regulate the output voltage to the speakers at the user's settings. Additionally, analog models are useful in that the resistance set by the user is maintained, even when the device is powered down, and then powered back on again. However, analog potentiometers are limited in precision, and over larger mechanical aspects to factor into case design restraints.

3.2.7.2.3 Digital Potentiometers

As opposed to analog potentiometers, which are directly adjusted by user interface, digital potentiometers can be used in an integrated circuit for better precision. Digital potentiometers are programmable microcontroller-interfaced components that feature an internal mechanical potentiometer that can be adjusted by input pin setting signals, such as a push-button command. Using multi-resistor ladder integrated circuits, as shown in Figure 3.2.7.2, the digital potentiometer uses a wiper switch connection to corresponding resistance levels to control the output current to the stereo system. The user push-button controls act as the mechanical turn knob or wheel, with each button input sending a status signal to the next available wiper register. When the wiper register is set to the corresponding "close" signal, the switch to the matching resistor closes, increasing the resistance that the potentiometer give out.

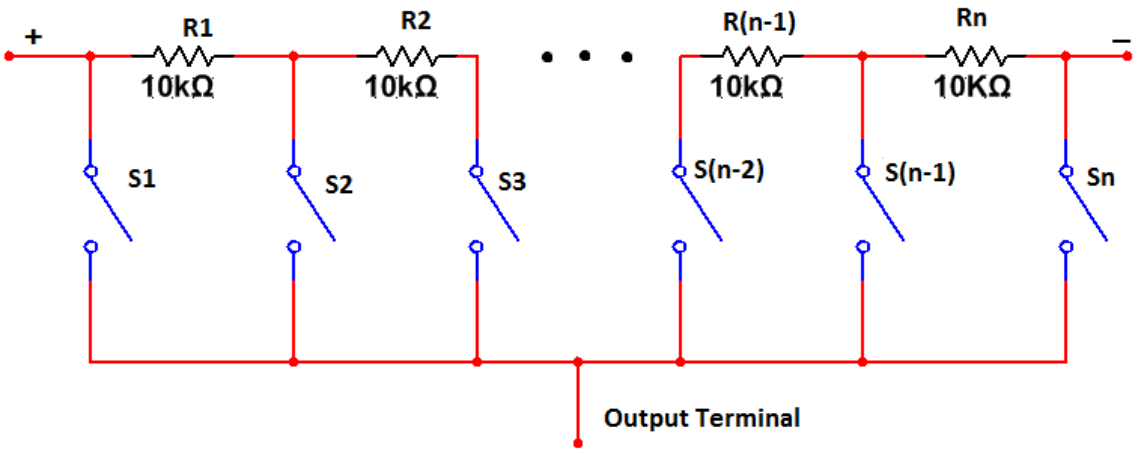


Figure 3.2.7.2 - Resistor Ladder Digital Potentiometer Circuit, reprinted with permission from Wikipedia

Initially, this ladder resistance stacking only offered a linear response, which, as discussed above, was undesirable. However, many recent digital potentiometers, such as the Microchip AN1080, could be programmed to have a logarithmic characteristic by simultaneously closing multiple wipers in the ladder circuit, which changed the audio output for a more gradual response. This created a digital to analog converter (DAC) feature that smoothed out the audio output. This is demonstrated in Figure 3.2.7.3, where we observed that as the slider bar is moved from lowest position (maximum resistance) to highest position (minimum resistance), the output voltage increases on a linear rate. However, the decibel level of audio output has a logarithmic curve at the same slide bar directions. Digital potentiometers can offer better precision and can be programmed to scale in correspondence to the desired change of volume output. One challenge with the digital versions, however, was that when the system was powered down, the potentiometer did not save the last input resistance value on it, and usually defaulted to a median resistance. Additionally, the digital models typically required an input voltage to operate, and likely a DC-to-DC converter for the output voltage from the connecting amplifier circuit.

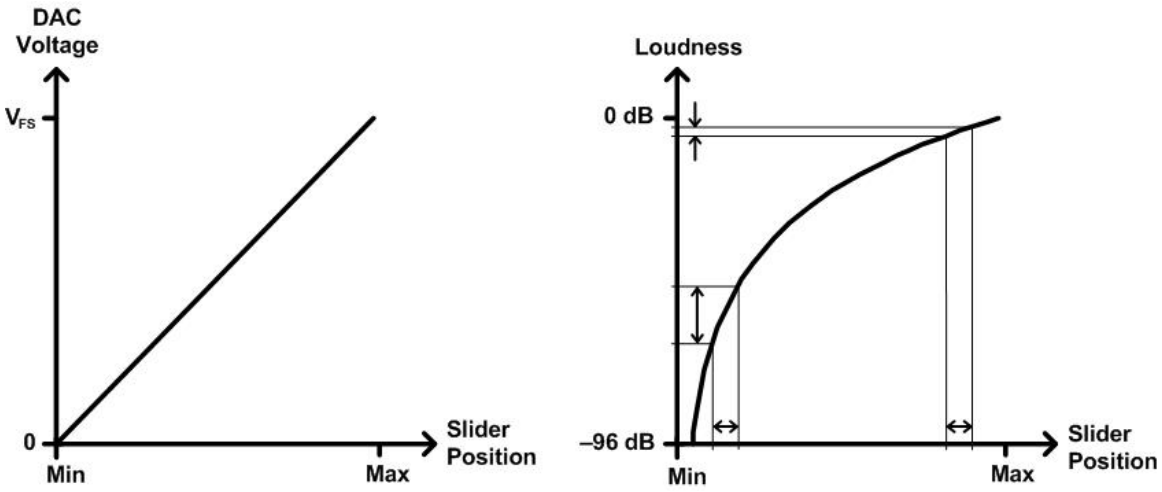


Figure 3.2.7.3 - Digital Potentiometer Using DAC to Create Logarithmic Output, reprinted with permission from Wikipedia

3.2.7.2.4 Potentiometer Model Selection

Potentiometer model selection came down to deciding between linear or logarithmic, analog or digital, and finally the model designs available. Clearly, the logarithmic design was to be used for the FBC, as linear volume control would have too harsh of an effect on users, and would significantly lower the gaming experience quality. Both analog and digital potentiometer designs were initially set to linear controls, with the analog potentiometer acting as a logarithmic through the use of a series resistor, and the digital model being digitally configured to adjust resistance intervals in a logarithmic simulation.

Analog and digital potentiometers could have both been appropriately functional for the FBC, with the advantages and disadvantages considered within the design constraints. The analog design could be accomplished by direct user interface, and could maintain the designated volume setting, even through power phases. Additionally, with the analog mechanical volume control used, the user could visibly see the potentiometer setting and know what output volume to expect. Digital potentiometers offered better audio precision, and could be logarithmically programmed to change volume at a custom ideal rate. The lack of significant mechanical components also made the digital design a more likely candidate for size-restricted projects. Both designs also had drawbacks, with the analog taking up significant space, and the digital being power dependent. When deciding between the two, we considered the power consumption and size availability factors of the FBC. As with many handheld, portable gaming devices, audio level precision is not a significant concern, as long as the output transitions on a logarithmic scale. For those considerations, we chose the more traditional analog potentiometer design.

The three most commonly used mechanical potentiometer designs are the slide bar, thumbwheel, and rotary models. The slide bar design adjusts the applied resistance by the user sliding an externally exposed bar linearly up and down a track. Visually, the user can use the position of the slide bar in relation to the maximum and minimum ranges to expect the current volume output. The thumbwheel model functions via a semi-exposed disk that can be rotated at an angle generally between 270° and 300°, and is generally numbered from “0” through “10” on the outer perimeter. Each number represents the volume level of the device, with “0” equating to a ‘muted’ output, and “10” meaning maximum volume at the highest output voltage allowed. Despite the linear increase numerically, the number rating represents sound levels on the logarithmic scale. The rotary potentiometer adjusts volume via a protruding knob that, like the thumbwheel, can be rotated along a 270°-300° angle. The rotary design is discounted due to its functionality requiring a significant knob protrusion. The volume control mechanism to the FBC was specified to be operated with a single finger from the user, and the turn-knob design of a rotary potentiometer required more effort, making it the more inconvenient model.

Between the slide bar and thumbwheel designs, we chose the thumbwheel. The slide bar covers more exterior surface area due to its slide track, and could be prone to more unintended motion by the user when handling the device. Additionally, the slide bar could very easily go from minimum, muted output to maximum volume in a single swipe, which could be detrimental if accidentally moved. The thumbwheel, on the other hand, could be more carefully adjusted, was less prone to significant unintended volume change, and required less linear spacing for operation. The standard impedance rating for potentiometers in low-voltage small devices is typically 10 Kilo-ohms, and the ideal thumbwheel diameter for a handheld design is approximately 9-12 mm. Variations between company models did not significantly alter the intended functionality for the audio caption, and based on current availability, we initially chose the Bourns 3352T-103LF-ND thumbwheel potentiometer. The model and dimensions are shown here, in Figure 3.2.7.4, as reference. Included in the diagram is also a demonstration of the rotation of the thumbwheel in relation to the internal resistance wiper. Starting with the maximum 10 Kilo-ohm resistance, at the thumbwheel positioned at the furthest counterclockwise angle, the volume is “muted”. As the thumbwheel is turned in the clockwise direction, the wiper resistance is decreased as angle rotation increases. When at the highest possible clockwise setting, the wiper resistance is zero, and maximum voltage is outputted through the audio speaker or jack systems.

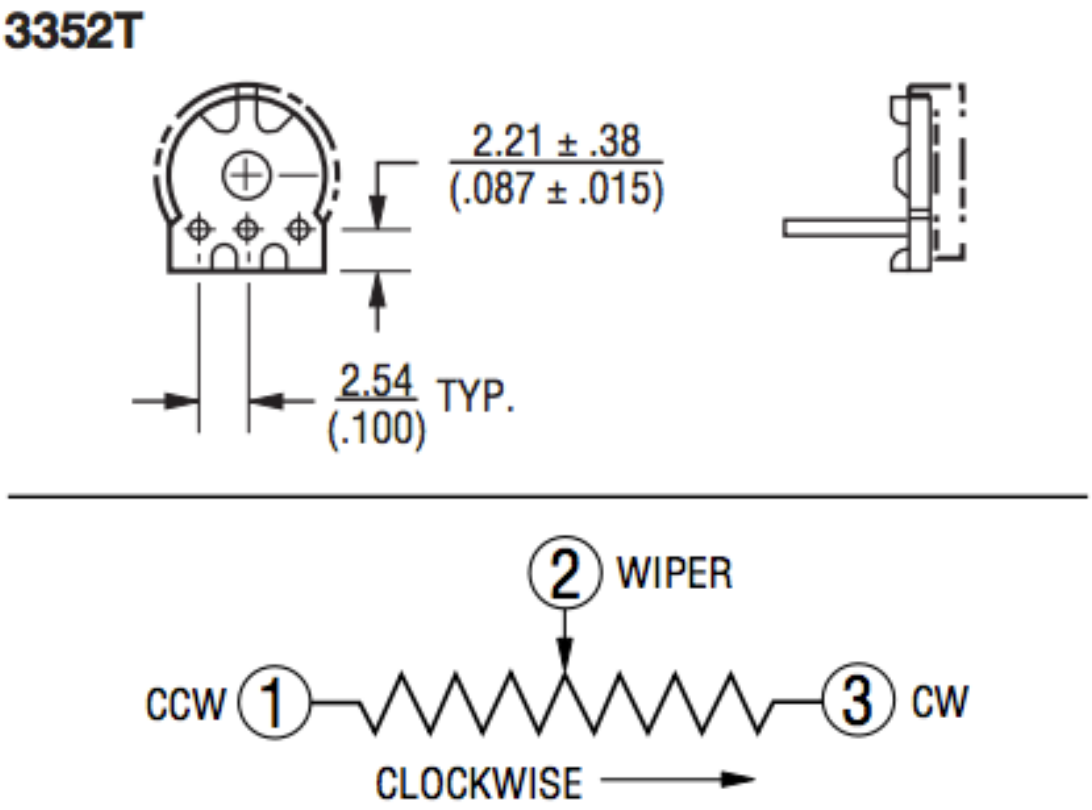


Figure 3.2.7.4 - 3352T Potentiometer Diagram, reprinted with permission from Bourns

A later reevaluation of the design revealed that a 3-pin potentiometer would not meet the specifications required for a stereo audio system. 3-pin potentiometers utilize pin1 as the input audio circuit, pin3 as the output, after variable resistance applied, and pin2 serving as ground. The Raspberry Pi 2 output two separate audio signals, a left and right signal. Such a design would call for two 3-pin thumbwheel applications, which we found to be cumbersome and unpractical. For that reason, we instead implemented the RadioShack 271-001 10K-Ohm Wheel Potentiometer. This potentiometer boasted a 5-pin function, which allowed for pin3 and pin4 to handle left audio output, and simultaneously allowed pin2 and pin5 to handle right audio output. Pin1 was designated ground. When the thumbwheel was adjusted, the four pins allowed for left and right signals to be applied simultaneously.

3.2.8 Power System

Our power system, shown in Figure 3.2.8.1, is one of the most important parts of our console. The power system needed to adequately apply power to the different components, while also supporting prolonged device usage away from a wall outlet. One of our requirements was that the battery in our system would be able to charge from a standard USB wall adapter or computer outlet. The 5 volts from the USB needed to be put through a charging circuit specific to our battery that would ensure our battery safely charged. The battery also is able to receive a small amount of charge via the solar panels attached to the case. The workhorse of our system is the Raspberry Pi 2 which runs off of 5 volts through USB. That means our power subsystem needed to output 5 volts. Since none of the common types of batteries would produce a constant 5-volt output we needed to regulate the output. The output of the battery was put through a DC-to-DC conversion circuit and regulated to the 5 volts needed by the Raspberry Pi 2. The Raspberry Pi 2 also can output the regulated 5 volts from its power supply and a regulated 3.3 volt output built in. These outputs were used to power the various components of the mainboard that will interact with the Raspberry Pi 2. The first thing we needed to do was choose a battery to determine how we could charge it and what kind of DC-to-DC conversion circuit we needed to make.

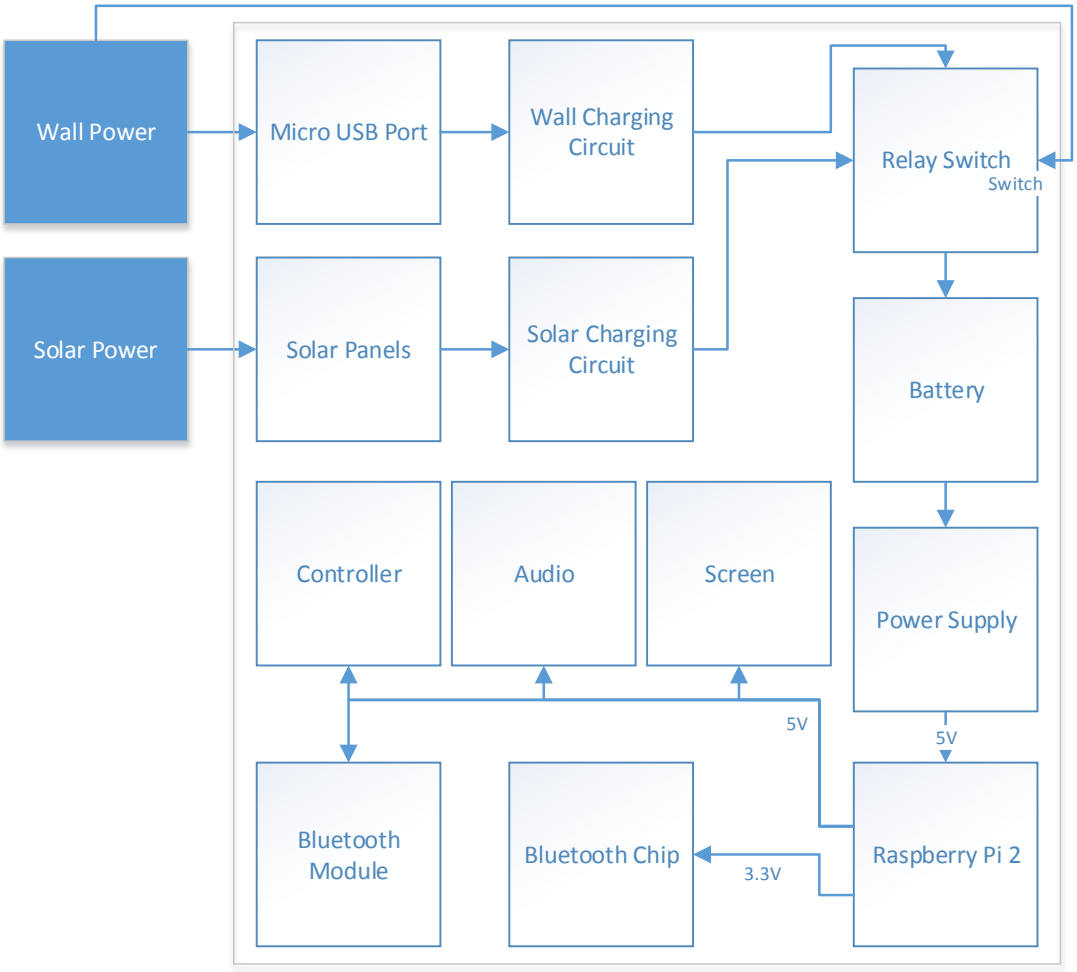


Figure 3.2.8.1: Power Subsystem

3.2.8.1 Battery Selection

Due to our system being a handheld game console, we determined that power to our system would be supplied by a battery in order to make the system portable. Choosing an appropriate battery for a portable system was very important. We compared the positives and negatives of five different types of batteries before settling on the type of battery we were going to use. The five types of batteries we considered were standard alkaline batteries, nickel-cadmium (NiCd) batteries, nickel metal hydride (NiMH) batteries, lithium-ion (Li-ion) batteries, and lithium polymer (LiPo) batteries. We compared the batteries focusing mainly on size, weight, capacity, and longevity to try and keep the system small and running for extended periods of time, and to have the battery last for a lot of charge cycles. Other battery attributes that factored into our decision were output voltage, charging methods, safety, and environmental impact.

Alkaline

We decided against using alkaline batteries pretty early on so not a lot of research was done for them. During discussion we determined that the cost of constantly replacing alkaline batteries was prohibitive. Another factor that played into our decision not to use alkaline batteries is that they take up more space than other batteries while having a lower capacity and output voltage than what we were looking for. Ultimately we decided that alkaline batteries were not the appropriate battery for our device.

Nickel-Cadmium (NiCd)

Nickel-cadmium batteries were one of the first types of rechargeable batteries. The term nickel-cadmium comes from the elements that make up NiCd batteries, nickel oxide hydroxide (NiOOH) and cadmium (Cd). While they were very widely used in the past they have seen a drastic decrease in use in recent years due to the emergence of lithium-ion and nickel metal hydride batteries. We decided NiCd batteries were worth looking into as they are cheap and still used in some devices and are very heavily used in the RC community.

First we took a look at the primary factors of comparison. NiCd batteries are available in standard sizes as well as battery packs with multiple battery cells. NiCd batteries are also heavier than other batteries. Ideally we wanted a smaller battery, but this was not enough of a deterrent for us not to take a closer look at NiCd batteries. The largest capacity AA sized NiCd battery I could find was 1000 mAh. This is significantly lower than some of the other battery options that were considered. We would have needed five AA NiCd batteries to come close to reach the capacity of a 5000 mAh lithium-ion battery (which is about the size of two AA batteries) or lithium polymer battery. NiCd batteries last for quite a few charge cycles. While this would normally be a good thing, NiCd batteries also suffer from something called a memory effect. This means that NiCd batteries will hold less of a charge over time if not completely discharged each time. This was a huge negative for us due to the fact that we did not want our game system to have to die before it could be charged, and also because we have a solar power unit that is constantly charging the battery.

The nominal output voltage of a single NiCd battery cell is 1.2 volts. The actual voltage can range anywhere from 1.35 volts to 1.1 volts depending on where the battery is in the discharge process. NiCd batteries have a decently flat discharge curve so the vast majority of the time they operate at around 1.2 volts. While this is certainly useful in many situations, our battery output voltage is fed through a dc-to-dc converter and regulated to supply the needed voltage for our various components. Figure 3.2.8.2 shows the discharge curve of a single NiCd battery cell. The figure shows that between 90% and 5% battery remaining there is only a 100 millivolt change in voltage.

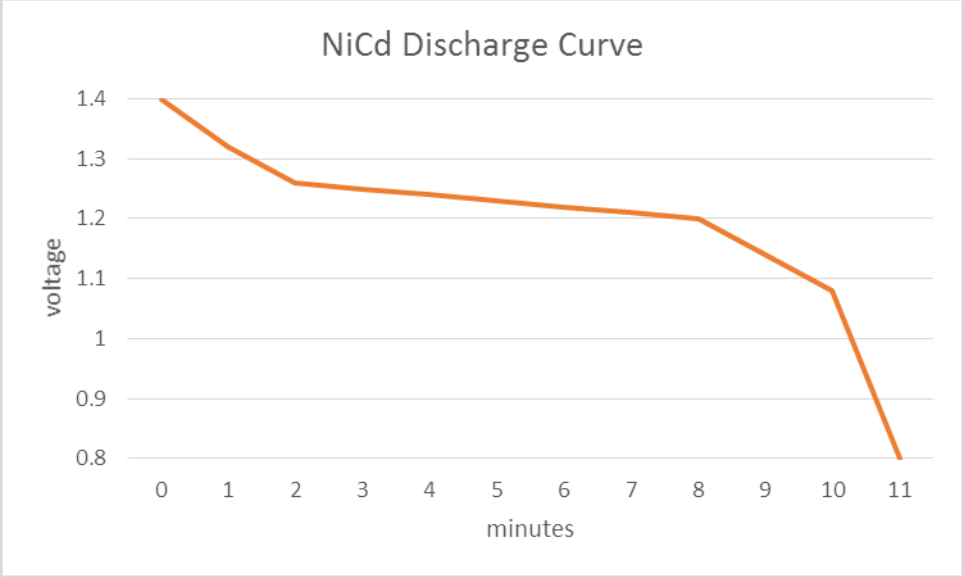


Figure 3.2.8.2: Discharge Curve of a Normal Nickel-Cadmium Battery

Charging a NiCd battery consists of supplying it with a steady current of 10% of its capacity for fourteen to sixteen hours. The voltage supplied by the charger varies with temperature, but not by much. Charging efficiency is never 100% and batteries tend to have a higher capacity than listed so charging longer than ten hours is required. Overcharging is a possible issue with NiCd batteries because they do not change in voltage by much, so a charger will have a harder time determining when a NiCd battery has reached full charge based on the battery's voltage. Another potential downside to NiCd batteries is the self-discharge rate. NiCd batteries will discharge 10-20% per month when not under any load. While not a massive detriment to us, we wanted to be able to pick up the console after not using it for a few months and still have some charge remaining in the battery.

NiCd batteries are both safe and durable. They can be fully discharged safely unlike other battery types. NiCd batteries do contain cadmium, though, which is a toxic metal. NiCd batteries require special disposal and have a negative impact on the environment if not disposed of properly. While we do not worry about having to change out the battery anytime in the near future, we prefered to have a battery in our device that did not have a material that is hazardous to the environment.

Nickel Metal Hydride (NiMH)

Nickel metal hydride batteries are significantly newer than NiCd batteries and have been improved upon significantly in relatively recent years. Like NiCd batteries they contain nickel oxide hydroxide (NiOOH), but in place of cadmium they have an alloy that joins with a hydrogen atom during the charging process to form a metal hydride (MH). NiMH batteries have replaced NiCd batteries in many applications. We decided to look into NiMH batteries because they are very similar to NiCd batteries, but they tend to have more charge capacity while being just as cheap if not cheaper.

Like NiCd batteries, NiMH batteries are available in standard sizes and battery packs with multiple cells. NiMH batteries are lighter than their NiCd counterparts while having a larger capacity. The largest capacity AA sized NiMH battery we found was 2600 mAh. This was a significant improvement over the capacity of the NiCd batteries we saw. We would only need two of those batteries to reach the same 5000 mAh threshold we set for NiCd batteries which makes it roughly similar in size to lithium-ion batteries. Both of those attributes were huge positives towards the efforts to make our console very portable. There are downsides to using multiple NiMH batteries simultaneously, though. The different cells may discharge at different rates, so charging and discharging them can become more complex. Testing each cell individually is a pretty big hassle. The amount of charge cycles that a NiMH battery lasts seems to fluctuate quite a bit based on the current drawn. They seem to last for several hundred charge cycles with normal use, which suits our needs. NiMH batteries also do not suffer from the memory affect that plagues NiCd batteries.

Again, like NiCd batteries the nominal output voltage of a single NiMH battery cell is 1.2 volts. The actual voltage can range from around 1.4 volts to 1 volt depending on where the battery is in the discharge process. The discharge curve of NiMH batteries is very similar to NiCd batteries. This means that the vast majority of the time NiMH cells operate at around 1.2 volts. The same positives and negatives apply here as they did for the NiCd battery. The flat discharge curve is a detriment to our battery level indicator and the near constant voltage is unnecessary for our device components. Figure 3.2.8.3 shows both the charge and discharge curve of a single NiMH battery cell. The curve is incredibly similar to the discharge curve of a NiCd battery. Many of the websites I visited while gathering information said the discharge curves of NiCd and NiMH batteries were basically interchangeable.

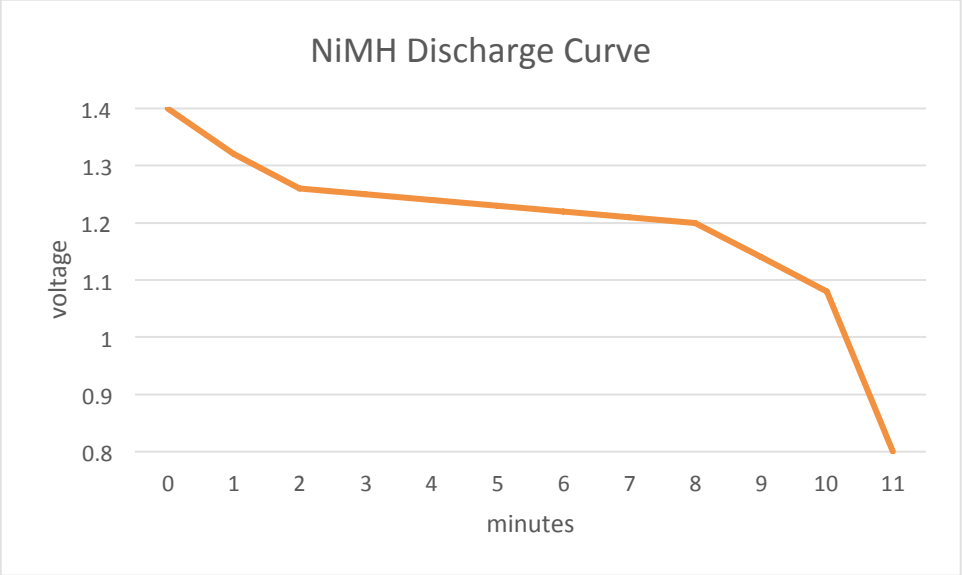


Figure 3.2.8.3: Discharge Curve of a Nickel Metal Hydride Battery

Charging a NiMH battery is often similar to charging a NiCd battery. The same 10% of its capacity for around fourteen hours is supplied to the battery. The voltage supplied is between 1.4 and 1.6 volts. Similarly to NiCd batteries, NiMH batteries need to worry about overcharging because of the constant current supplied to the battery by the charger. NiMH batteries have a very large self-discharge rate in comparison to other batteries. NiMH batteries self-discharge at about 30% a month when not under any load. This by itself is not terrible, but what makes it particularly bad for our implementation is that the self-discharge is not linear. The battery can self-discharge up to 20% of its capacity in the first day alone. This is not ideal for a portable console that aims to be taken on long drives and flights.

NiMH batteries are also safe and durable. They are used as batteries for many power tools much in the same manner as NiCd batteries. NiMH batteries are also very environmentally friendly. They do not contain the cadmium that makes NiCd batteries so toxic. For this reason and a few others nickel metal hydride batteries are a solid choice. If we had to choose between NiCd batteries or NiMH batteries we would have chosen NiMH, but we still considered two other types of batteries.

Lithium-ion (Li-ion)

Lithium-ion batteries did not see commercial use until the 1990s. They are some of the newest batteries available and they are more expensive than the previously discussed types of batteries. Li-ion batteries get their name from the lithium ions that move from the anode to the cathode while the battery is discharging and from the cathode to the anode when the battery is charging. The advent of Li-ion batteries has had a huge effect on portable electronics. Li-ion

batteries are used widely in consumer electronics and are smaller than both NiCd and NiMH batteries. Most modern phones and portable devices use Li-ion batteries.

Li-ion batteries are available in all the standard sizes, but also come in different sizes and shapes. The most notable shapes are cylinders and flat/rectangular like a cell phone battery. They are lighter than both NiCd and NiMH batteries, and have a similar capacity to NiMH batteries. The largest capacity I could find in AA size was 800 mAh, but we would be using a slightly larger sized Li-ion battery that can hold up to a 3400 mAh charge on a single cell. The lightweight and high capacity properties of the li-ion batteries were a huge selling point for us. The amount of charge cycles that a li-ion battery lasts is similar to a NiMH battery, generally in the range of 300 full cycles. Li-ion cells have no memory effect whatsoever.

The nominal output voltage of a single Li-ion cell is 3.7 volts. The actual voltage output of a Li-ion battery ranges from around 4.2 volts when charging should be stopped down to 2.5 volts when discharge should be absolutely stopped. Ideally you should stop discharge around 3 volts. A Li-ion battery should never be discharged below a certain voltage. When Li-ion batteries drop below or raise above certain voltage thresholds irreversible chemical reactions take place that ruin the battery and can cause fires and explosions. The discharge curve of li-ion batteries is different from the nearly flat curve of NiCd and NiMH batteries. The voltage is regulated so the fluctuations in voltage from the Li-ion battery were a non-issue. Figure 3.2.8.4 shows the discharge curve for a single Li-ion cell at a constant current of 20% of its charge capacity and the discharge curve of a single NiCd or NiMH cell at 20% of its charge capacity. Clearly the voltage in the Li-ion discharge curve fluctuates far more than the voltage in the nickel oxide hydroxide based batteries we have discussed.

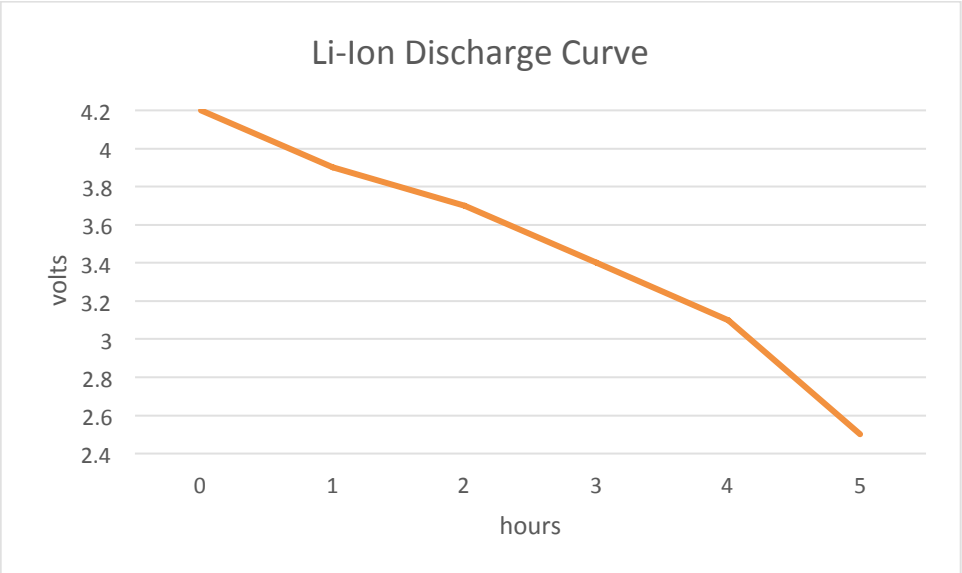


Figure 3.2.8.4: Discharge Curve of a Li-ion Cell

Charging a Li-ion battery is more complex than charging a NiCd or NiMH battery. Instead of just supplying a constant current the whole time, a constant voltage is also applied towards the end of the charging process. A constant current is supplied to the Li-ion battery based on the Li-ion battery and the charger that is used. The voltage output of the charger will increase as the charge in the cell increases and the current remains constant. When the maximum charge voltage (generally around 4.2 volts) is reached, a constant voltage equal to the maximum charge voltage is applied to the Li-ion battery. The current supplied by the charger will decrease until reaching a set value when the charger will stop charging the battery. This process is faster than the “trickle charging” method of the nickel batteries. As stated before, overcharging a Li-ion battery is dangerous and can cause explosions, so strictly following the maximum and minimum voltage values and the maximum current of a Li-ion battery when charging was very important. Li-ion batteries, unlike their nickel based counterparts, have a very low self-discharge rate. Generally Li-ion batteries only self-discharge at a rate of around 2% a month. Such a small self-discharge rate was ideal for a console that you might forget about for a few months and then want to play immediately. A Li-ion battery should also not be allowed to self-discharge below a safe voltage.

Li-ion batteries are less safe and durable then NiCd and NiMH batteries. While they are used in a lot of consumer electronics, they are not generally used in heavy duty applications. While safety is a concern with Li-ion batteries, when handled properly it is easy to use Li-ion batteries safely. Some Li-ion battery cells come with a circuit to shut off the battery when it approaches being overcharged or over-discharged. These batteries are known as protected batteries. On top of that Li-ion chargers are made with both constant voltages and constant currents that will detect when to switch from constant current to constant voltage and when to stop supplying the constant voltage. A lot of Li-ion chargers actually allow you to set the constant voltage supplied by the charger for when you are using multiple cells to supply a higher voltage. Like NiMH batteries, Li-ion batteries are negligibly toxic. While NiMH batteries are a solid choice for a lot of applications, we ultimately agreed that the faster charging, lighter weight, and more fluctuation in voltage of a Li-ion battery better suited our needs. Li-ion was the current front-runner but there was still one more type of battery to consider in lithium polymer.

Lithium Polymer (LiPo)

Lithium polymer batteries are very similar to Li-ion batteries, but they come in a soft pouch instead of the hard cylinder or rectangle shape of a standard Li-ion battery. The reason they are able to be held in a soft pouch is because instead of using the liquid electrolyte that a standard Li-ion battery uses, they instead use a

solid polymer electrolyte. These batteries are commonly referred to as lithium polymer batteries because of the lithium ions and the polymer electrolyte.

LiPo batteries are available in various different pouch sizes. They are lighter than their Li-ion counterparts, but in turn they suffer from a worse energy density. The lighter weight of LiPo batteries make them perfect for use in radio controlled models, but at the cost of a firm structure. LiPo batteries are in danger of having pressure put on the pouch that increases capacity retention. The difference in weight will be barely noticeable in a handheld gaming console. Having to make sure that the LiPo battery does not have any pressure put on it could make designing the interior layout of the case more difficult.

The voltage characteristics of a LiPo battery are the same as a Li-ion battery, and the batteries are also charged in the same manner. They also have the same amount of charge cycles as a Li-ion battery. They are, in general, more expensive than a Li-ion battery of equal charge capacity, but the difference in cost is not a deal breaker.

The LiPo battery is another solid choice, and one that potentially suits our needs. While we really like how lightweight LiPo batteries are, we do not think that such a minor difference in weight will have a huge impact on the portability of our system, yet it is still a benefit when designing a handheld device. We do, however, think that being required to compensate for a sensitive battery pack that cannot withstand pressure will make determining the interior layout of the case significantly harder, but at the same time the wide variety of sizes and shapes that LiPo pouches come in could make case layout easier. LiPo batteries can be as thin as a credit card which is a huge selling point. When it comes down to a direct comparison between Li-ion and LiPo the choice is still not clear, so both of these types of batteries were compared when choosing a specific battery.

Choosing a Battery

To pick a specific battery we first had to decide how much voltage we would need to supply to the circuit. In order to keep our cost and battery size lower we decided that the standard 3.7 volts provided by a Li-ion or LiPo battery cell was fine, and that we would increase the voltage to whatever we needed it to be with a DC to DC converter. From there it could just be regulated down to whatever voltage different components in the circuit need.

After we determined that 3.7 volts would suffice, we had to figure out what charge capacity we would need for our device to run for a fair amount of time. The Raspberry Pi 2 will draw anywhere from 300 mA to 500 mA of current, but we can safely assume that for our case the Raspberry Pi 2 will draw no more than 300 mA on average. The 4.7-inch screen that we selected says that it will draw around 150 mA. To be safe we assumed that it will draw 200 mA. The other components of the device will not add up to anywhere over 200 mA, so assuming

that 700 mA of current will be drawn on average is a fair estimation, if not too high. This means for a battery life of 3 hours, not including the charge provided by the solar panels, we needed a battery with a capacity of 2100 mAh. Our selections were limited to batteries at or above 2100 mAh.

The next thing to check when choosing a battery is physical size, weight, and shape. Upon browsing through many different batteries we came to an important choice between two Li-ion batteries and one LiPo battery. Table 3.2.8.1 shows a comparison of the specifications between the two different batteries. The difference in physical size of the two Tenergy Li-ion batteries is simply that the 5200 mAh battery is the same size as two of the 2200 batteries put next to each other with a wrapper around them. The LiPo battery is wider than the Li-ion batteries, but it is also less than half as thick. The LiPo battery is also the lightest battery, though the 2200 mAh Li-ion battery is very similar in weight. The 5200 weighs about twice as much as the other two batteries. All three batteries contain a protection circuit, which is ideal as additional protection against overcharging and overdischarging. The 2200 mAh Li-ion battery is the only cylindrical battery, the others being rectangular. We determined that a rectangular battery was more ideal because the screen and Raspberry Pi 2 are both rectangular so the battery could just be placed under those components. The price difference is less than ten dollars between the three batteries.

	Tenergy Li-Ion 18650 Battery Module 5200	**Tenergy Li-Ion 18650 Battery Module 2200**	**Adafruit Lithium Ion Polymer Battery**
Capacity (mAh)	5200	2200	2500
Size (mm)	66 x 37 x 19	69 x 19	65 x 51 x 8
Weight (g)	96	54	52
Protection Circuit	Yes	Yes	Yes
Shape	Rectangular	Cylindrical	Rectangular
Price	$19.99	$10.99	$14.95

Table 3.2.8.1: Comparison of Battery Choices

The LiPo battery fit our needs the best. It has the rectangular shape that we determined was a better fit than a cylindrical shape. Even though it is wider than the other batteries it is still not as wide as the screen or Raspberry Pi 2. It is also lighter than the other batteries and right between them in terms of cost. It has a capacity of 2500 mAh which was enough for our needs. While it would have been nice to have a battery with a large capacity like the 5200 mAh battery, it was decided that the thin and lightweight features of the LiPo battery made it the best fit for the FunBox Classic.

3.2.8.2 Charger

Due to the selection of a LiPo battery, we needed to choose a charging IC chip to match our needs. There were a large amount of things to compare between the different chips. Even though different chips have many different features there are a few features that mattered more to us than others. We needed the chip to make sure the battery safely charges without overcharging. The charging circuit needed to take in 5 volts from a standard USB connection, either to a wall or a computer, and charge the battery using the constant current followed by constant voltage method. The constant current needed to be 500 mA and the constant voltage needed to be 4.2 volts. There were some additional peripherals that it would be nice for the chip to have but they were not necessary. These peripherals were mostly just additional safety features. There are quite a few different LiPo charging ICs, so choosing the one that best fit the FBC proved to be challenging. After choosing a chip we needed to design a charging circuit using the IC to take in a voltage input and charge the battery. We also wanted to include LEDs to show when the battery is charging and when it is fully charged.

Charging IC Selection

After comparing many Li-ion charger chips based on the specifications we set, we narrowed our selection down to three different ICs. The ICs that we chose from were the LTC1734, LTC4056, and the MCP73831. We will now examine the specific chips in more detail.

The LTC1734 in a sample 300mA constant current circuit, has a constant current anywhere from 200mA to 700mA programmable by attaching a resistor to the PROG pin. It is available in both a 4.1 and 4.2-volt model, the latter being the relevant one to our project. The IC enters sleep mode when no power is connected to it and draws negligible current from the battery. The PROG pin also has a constant 1.5-volt output during the constant current portion of charging, which then drops down to very low voltage levels as charging nears completion and the current through the resistor reaches the cutoff level. The chip also has a built in temperature sensor that protects the circuit from getting too hot, and limits the output current to prevent damaging the battery or IC. The LTC1734 is 1 mm thick and has 6 pins.

The LTC4056 is made by the same company as the LTC1734 and shares some similarities. Per modern Li-ion standards the constant voltage output is 4.2 volts. The constant current can reach up to 1400 mA using a resistor attached to the PROG pin on the IC. The constant current is equal to the current through the PROG resistor multiplied by nine hundred fifteen. The PROG pin outputs a reference voltage of 1 volt for resistor selection. The current through the PROG resistor can be tested in a similar fashion to the LTC1734 to shut down the circuit if desired. The CHRG and TIMER/SHDN pins are used to program a shutdown timer for the circuit to protect against overcharging during the constant voltage

step of the charging process. The LTC4056 has the same temperature and current protection as the LTC1734.

The MCP73831, shown in a sample 500 mA charging circuit in Figure 3.2.8.5, has only 5 pins, which is less than the number of pins in both of the LTC charging ICs. The charging current is anywhere from 15 to 500 mA. The output current is also decided by the resistor attached to the PROG pin. The MCP73831, like the other ICs, has current and temperature protection. The V_{DD} pin takes a voltage, V_{in}, anywhere from 3.75 to 6 volts. V_{DD} needs to be attached to at least a 4.7 microfarad bypass capacitor. V_{BAT} connects to the battery and outputs the constant current and voltage needed by the battery. It also needs to be connected to at least a 4.7 microfarad bypass capacitor. The STAT pin is an output that connects to a LED to show the status of the battery or to a resistor to connect to a microcontroller. The V_{SS} pin connects to ground. The charge cycle ends if the current drops below 5 percent of the charge current.

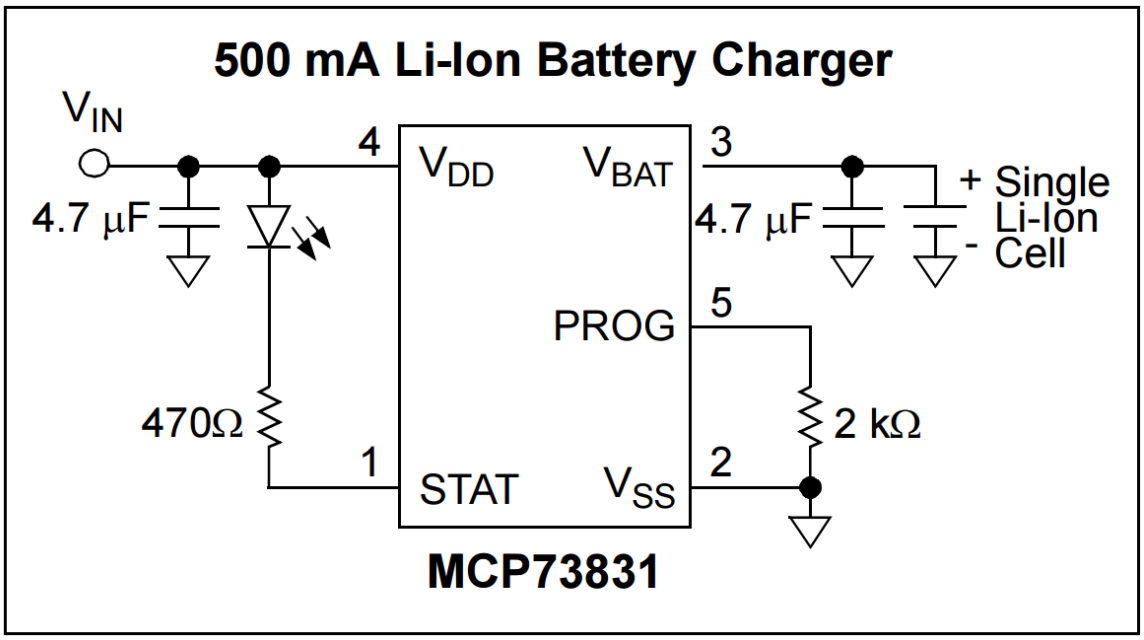


Figure 3.2.8.5: Sample 500 mA MCP73831 Circuit, reprinted with permission from Microchip

Comparing the datasheets of the three different chips made choosing the MCP73831 a pretty clear choice. The MCP73831 offers the most out of the chips compared to the complexity of including it in a circuit. The timer feature on the LTC4056 was deemed unnecessary. The MCP73831 will also allow us to hook up an LED to show when the battery is charging and fully charged. The max charging current of 500 mA is perfect for us. Ultimately the MCP73831 charger IC offers everything we need and will be the easiest to implement in our charger circuit. At 56 cents per unit the MCP73831 is also well within our budget.

3.2.8.3 DC-to-DC Converter and Regulator

Now that we had a circuit to charge the battery we needed to make a circuit to power our device using the battery. The output of the battery ranges from 3 to 4.2 volts and the battery is able to output up to 2500 mA of current, which is far more than our device will draw. Since we want to turn 3 – 4.2 volts into a regulated 5 volts we need to find a Step-Up (also sometimes called Boost) DC-to-DC converter chip. Just like with the charging IC there are a multitude of Step-UP DC-to-DC converter chips available. Thankfully we had a few requirements for our converter chip that helped narrow down the selection. The chip needed to be able to output 5 volts. Whether it only output 5 volts or had a variable voltage output did not make a huge difference to us, but a variable voltage source would allow us to make the voltage slightly over 5 volts if we needed to, which we ended up doing to account for voltage drops at higher current. The converter also needed to be able to output enough current to power our system. While our system will probably run under 700 mA, without having been able to test the actual current draw of the system we wanted to be safe and only looked at converters that support close to or more than 1 amp of current output. We also wanted to limit our search to synchronous converters due to their smaller size and higher efficiency than their nonsynchronous counterparts. Removing the need for an external power diode is also nice. Another thing we needed the converter to have was a dedicated enable or shutdown pin. This pin connects to the battery and ground through a simple switch. This switch acts as the ON/OFF switch of the device. A power efficiency of over 90% at 1 amp was also desired. A lot of the converters we came across the power efficiency seemed to fall off significantly around 1 amp. The two DC-to-DC converters we compared that were most suitable to our device were the PAM2401 and the TPS61030

The PAM2401, shown in Figure 3.2.8.8 in a sample 5 volt out circuit, can take an input voltage anywhere from 0.9 volts to 4.75 volts. Our LiPo battery will always be between these ranges when operating safely. The PAM2401 supports currents up to 3 amps which is well above our 1-amp requirement. The chip also has a dedicated enable pin. The output voltage can range anywhere from 2.5 volts to 5 volts. While we technically only needed 5 volts we did end up going with about 5.15 volts output instead to account for any voltage loss at higher currents. The power efficiency of the system, shown in Figure 3.2.8.9, drops to around 90% for our operating voltage range. This fits our requirements. The PAM2401 is definitely an okay choice, but does not leave any room for future changes to circuits.

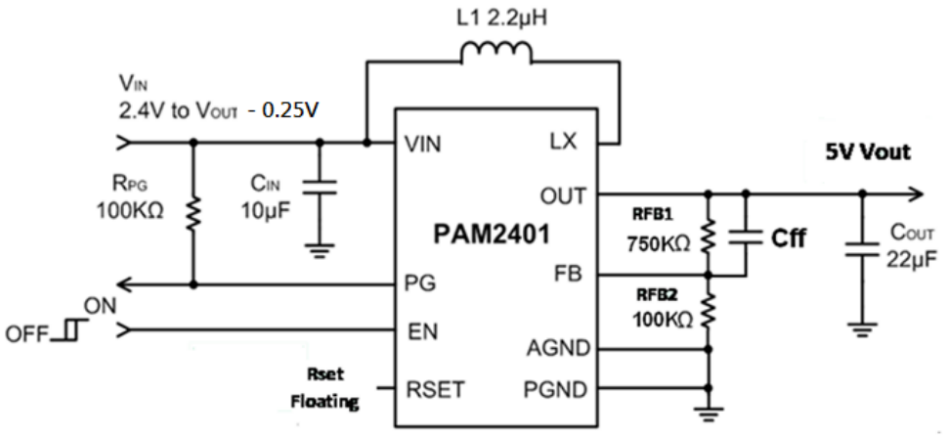


Figure 3.2.8.8: PAM2401 5 Volt Output Circuit, Courtesy of Diodes Incorporated

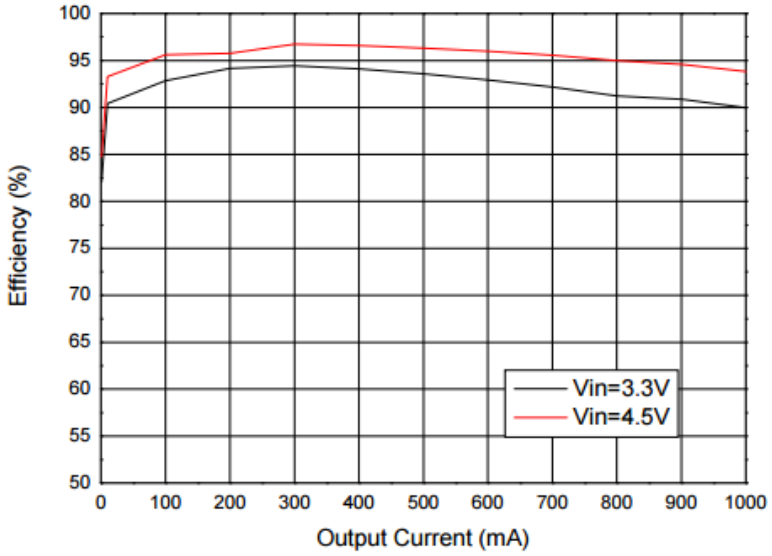


Figure 3.2.8.9: PAM2401 Efficiency Curve, Courtesy of Diodes Incorporated

The TPS61030, shown in Figure 3.2.8.10 in a sample 5 volt out circuit, can take an input voltage anywhere from 1.8 to 5.5 volts. The LiPo battery will always be well within this range. The TPS61030 outputs currents up to 1 amp at 5 volts. This perfectly matches our needs. Like the previous IC, this chip also has a dedicated enable pin. The output voltage of the chip can go up to 5.5 volts. This gives us a little headroom in case we need to increase the voltage a bit to compensate for changes in the circuit. The power efficiency of the system, shown in Figure 3.2.8.11, is about 95% at 3 volts input voltage and 1-amp output current. This efficiency will always meet our requirement of above 90% because our battery will normally be operating at a higher input voltage with a lower output current which will only increase the efficiency even further. The TPS61030 is an excellent choice. It fits all of our requirements and has good efficiency which will lead to longer battery life.

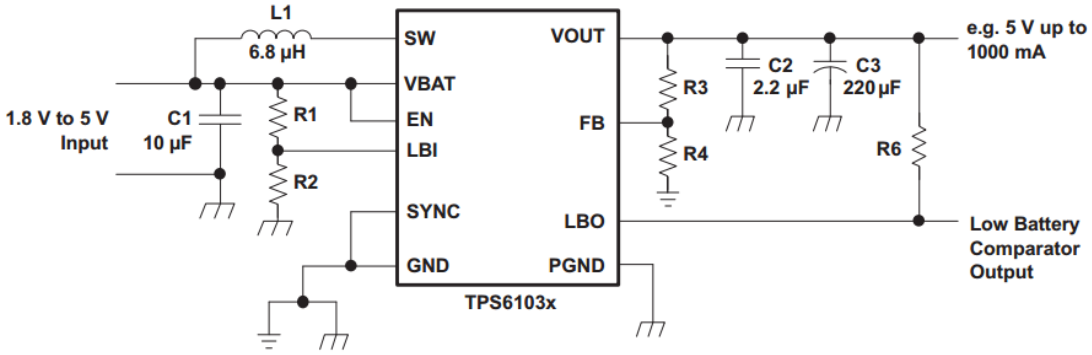


Figure 3.2.8.10: TPS61030 5 Volt Output Circuit, Courtesy of Texas Instruments

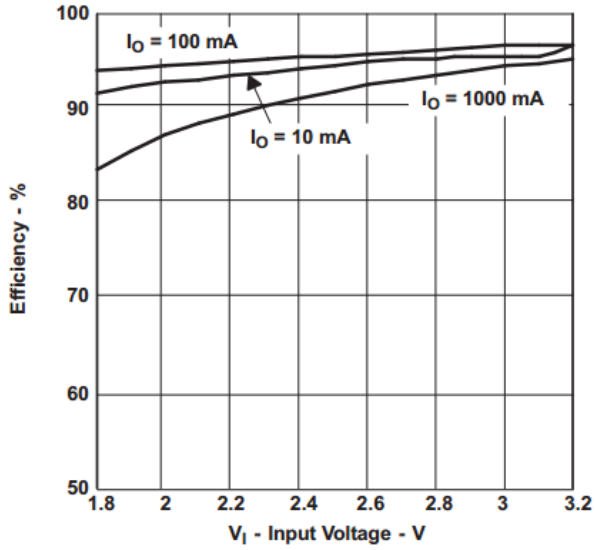


Figure 3.2.8.11: TPS61030 Efficiency Curve, Courtesy of Texas Instruments

Both the PAM2401 and the TPS61030 fit our specifications, but the TPS61030 definitely matched what we needed more closely. The 3-amp max output current of the PAM2401 is unnecessary for our applications and the efficiency is not as good as the TPS61030. The slightly over 5 volt maximum output that the TPS61030 was seen as potentially useful and was eventually utilized, whereas we would have been stuck with 5 volts maximum using the PAM2401. The TPS61030 meets our needs perfectly while giving us just enough headroom. It is also perfect for our portable system because the power efficiency is so high. The LBO (low battery comparator output) pin allowed us to have an LED indicate when the device has low battery. The cost of the chip is only $3.15 which was definitely an acceptable amount.

3.2.9 Case Design

The inspiration for the case design for our gaming console came mostly from case designs made by Nintendo Company. This professional company, a leader in the gaming industry has many great designs that are based on years of research and testing to insure the best user-experience. We looked at both Nintendo DS and Game Boy lines.

3.2.9.1 Comparing Nintendo Lines

We mostly looked at Nintendo DS and Game Boy lines. Nintendo DS line offers the consoles with dual displays: LCD and touchscreen. Two displays are convenient in a way that two players can play multiplayer using only one console. However, this causes a problem that one player can see the other player's screen. Game Boy line introduces a single display consoles. We thought that dual display consoles looked a little bulky and would add a lot of extra weight to our console. So, the case was decided to be with a single display.

Next we had to decide what shape the console should have. A clamshell design looked very tempting. We implemented solar batteries design in our console that had to be attached to the backside of the console. The clamshell design would be perfect to get the most of solar battery since the sunlight would be continuously charging it. We considered using the SolidWorks software to implement the case design, and then 3D print it at UCF Innovations lab. A clamshell design was causing many complications with designing and printing it on 3D printer. We were not sure if we would be able to develop in Solidworks the proper design of clamshell case since it had two separate parts that had to be attached. A unibody shape of the console was complicated enough, and it was decided to work with that design alone.

For the control buttons, we wanted to reuse the existing circuit boards from Nintendo DS console or Super Nintendo controller. Nintendo DS consoles have the following controlling functionalities: D-pad, circle pad, C-stick, A/B/X/Y, L/R, ZL/ZR, and START/SELECT buttons, home button, and touchscreen. Whereas, Super Nintendo controller has more basic controlling buttons: C-stick, A/B/X/Y, L/R, ZL/ZR, and START/SELECT buttons. Super Nintendo controller seemed to have a cleaner easier buttons layout, which was suitable for our design.

The first console in Figure 3.2.9.2 has a general rectangular shape. This shape does not look very convenient to use. If we decide to use it, we would like to modify and add some elongation to sides. It would be more comfortable for a user to hold this device while playing the games. The console on Figure 3.2.9.3 has a clamshell design similar to Nintendo DS.

3.2.9.3 Research on the Case Design

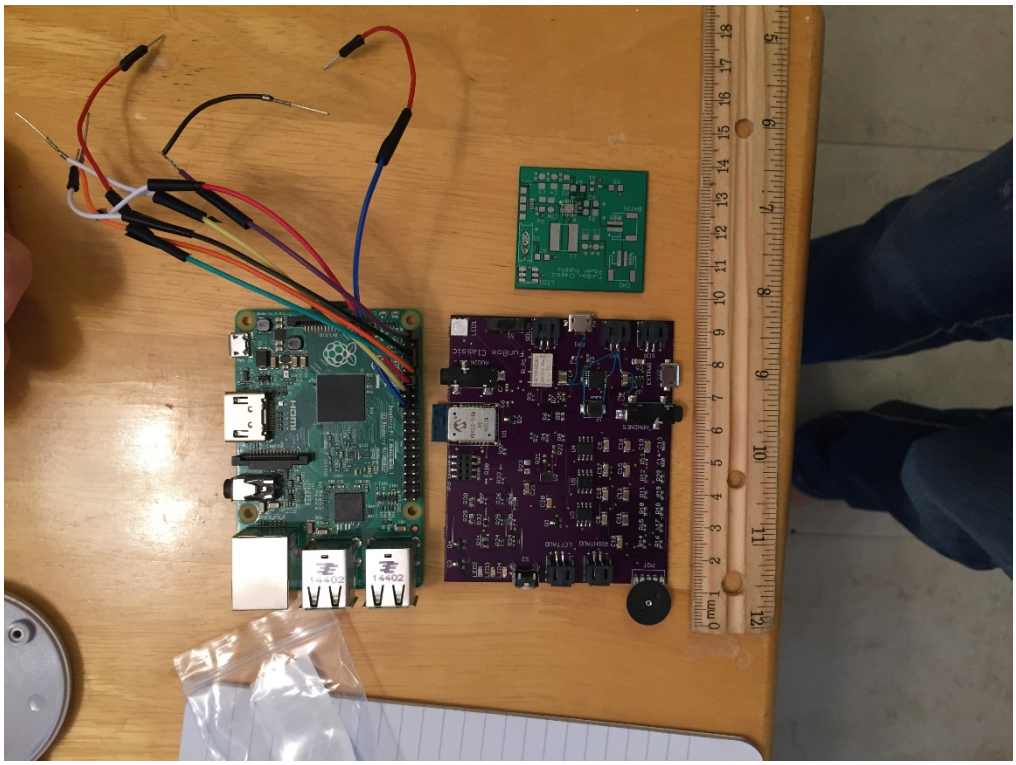
The case design for the console depended on such characteristics as shape, dual displays layout versus single, location of the buttons, and sizes of all components that had to be placed inside the console.

Dual versus Single Display

Dual-display consoles looked very sophisticated and more appealing toward a great user-experience. It would be great to go with that design, but it would also mean that we had to have a more involved functioning of other parts that go inside the console. We thought that out system was involving enough, and didn't want to create an extra complication to it. The parts that we put inside the console did not have perfect design. The Raspberry Pi was very bulky; two circuit boards instead of one took a lot of extra space etc. As students, we had limited professional engineering and manufacturing skills, which greatly affected the console's size.

Clamshell versus Rectangular Design

The rectangular design looked less complicated to manufacture, but was more challenging to design the layout of its inside components. We had circuit boards, speakers, battery and other components that had to be placed inside one box instead of two. The parts had to be placed inside in a way that they don't touch and don't short-circuit.



It was decided to install solar panels on the back of the console as an additional source of charging the battery. In the clamshell design, we could locate solar panels on the backside of the folding top. A user would be charging the battery using solar light continuously and keeping the battery last for many hours. In rectangular design, solar panels would have to be placed on a backside as well but it would make solar batteries less useful. Every time the user would want to use solar battery, he/she would have to keep the device vertically or at an angle. However, a user could also take a break from the game and leave the device out on the sun charging for a while. Solar panels were relatively big in size and took a lot of space on the backside of the console. We were faced with the challenge to design a shape of the case in a way that it didn't look bulky and had enough area to place solar panels. We thought that we would have to take a lot of risk if we decide on pursuing the clamshell design. The risks included: not being able to attach two separate halves, properly attach the wires and ended up redesigning the case. So, to be on the safe side, we decided to choose a rectangular shape for the device with few modifications. We wanted our design to look similar to the design shown in Figure 3.2.9.3. This model has very clean look.

Figure 3.2.9.3 - Retro Bit Portable Handheld Console V2.0
Reprinted with the permission of Retro Bit Games

3.2.9.4 Designing the Front-Facing Buttons

A lean design technique was implemented for the control buttons. When the user's attention is shifted from one location to another, there is a cost associate with time or effort. If buttons are not easily acceptable, the user may feel frustrated and even loose interest in playing on the console with such buttons. The design of the buttons should minimize this inconvenience by providing the buttons located to the nearest possible position.

We wanted to design our console with minimum amount of buttons, but without reducing the user-experience. For front-facing buttons we need to have a start, select and game controlling buttons. Usually, Nintendo consoles have the following buttons: The D-pad, an analog stick, and start, select and four A/B/X/Y buttons. We decided not to use an analog stick on our console.

Front-facing buttons that will be used:

- D-pad
- 4 A/B/X/Y buttons
- Start button
- Select button

These can be seen in Figure 3.2.9.4 below.

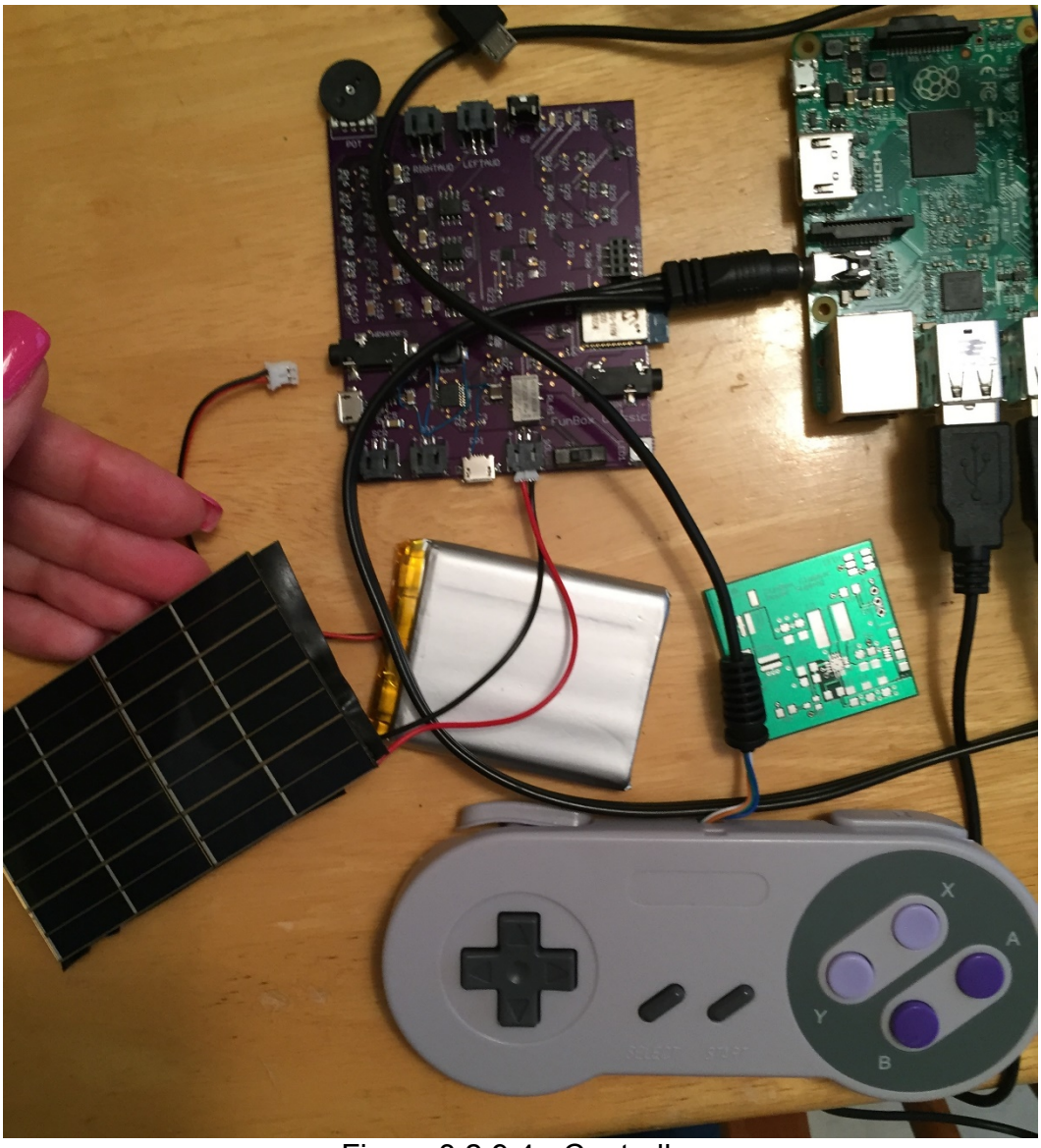


Figure 3.2.9.4 - Controller

3.2.9.5 Basic Design Philosophy

The mechanical design of the Fun Box Classic portable gaming console stemmed from two basic requirements:

- Create a cost-effective device that meets all applicable environmental requirements.
- Utilize board's outlines and interconnections of all the parts in order to fit them inside the case.

Research into recent designs of the portable consoles led us to select the mechanical design philosophy of a Retro Bit portable handheld console shown in Figure 3.2.9.3.

Figure 3.2.9.5 represents the rough design of Fun Box Classic console. The button assignments are given in Table 3.2.9.1.

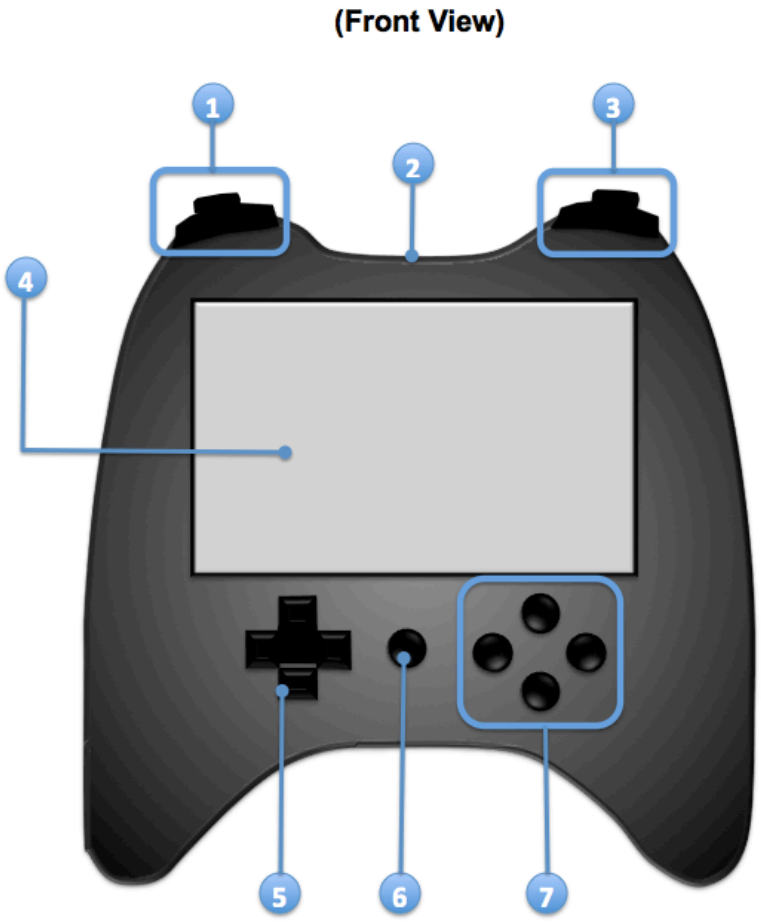


Figure 3.2.9.5 – Case Design of Fun Box Classic Console

Number	Button Name
1	L & ZL Buttons
2	USB Port
3	R & ZR Buttons
4	LCD Display
5	Control D-Pad
6	Power Button
7	A/B/X/Y buttons

Table 3.2.9.1 Front View System Components

Advantages include:

- The opportunity to use highly cost-effective castings common across the range for several of the major components, such as the front panel, back pane and two shoulder buttons.
- Well proven structural integrity
- Effective space utilization

3.2.9.6 Case Components

To make this type of case, we first have to measure all the parts to find out the width and height of them. Then, we will stack all the parts and find the depth of the console.

We will measure all our parts in mm units since these are the most common units used in specifications for the parts that we bought.

3.2.9.6.1 Front Panel

The width and height of the display we thought would be about 105 x 65 mm. The width and height of the circuit board with the front buttons were thought to be 127 x 50.8 mm. Then we considered to have elongated sides of the console similar to the design of Nintendo Wii U Pro Controller. First sketch of the front panel is shown in the Figure 3.2.9.6.

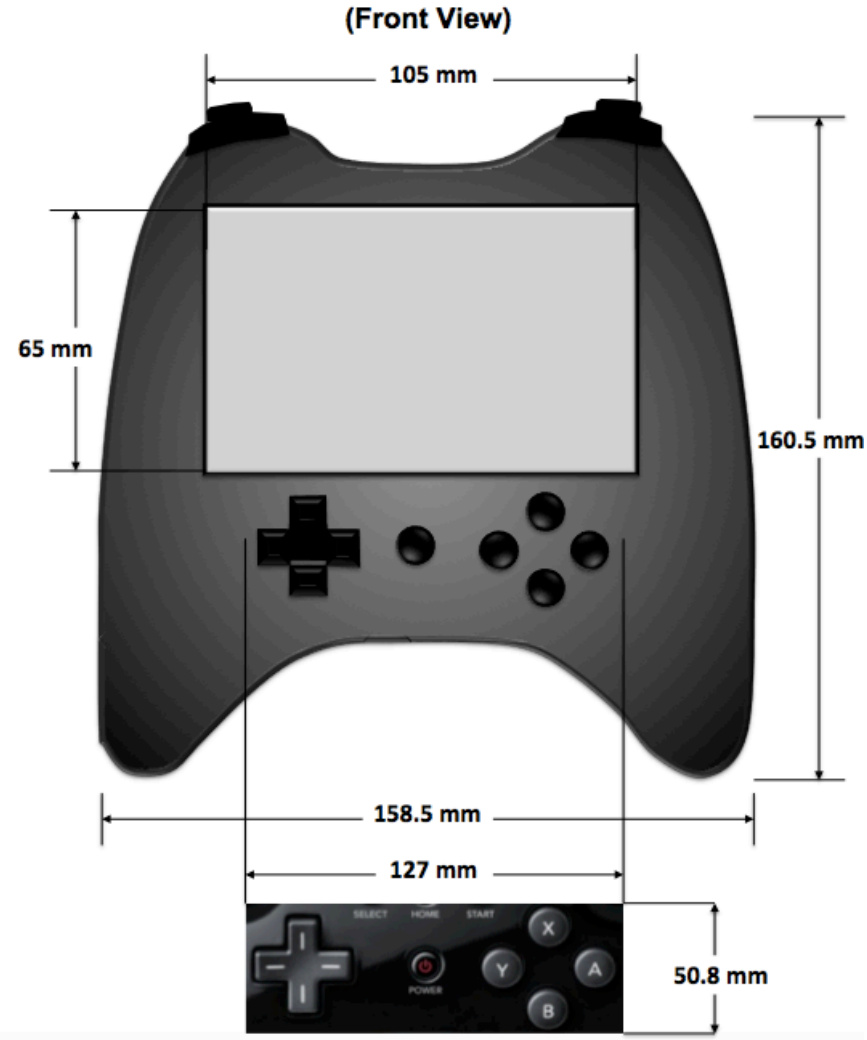


Figure 3.2.9.6 - Front Panel Sketch #1

Later, the design of the front part of the case was comprehended. The second better version of the case design is shown below in Figure 3.2.9.7.

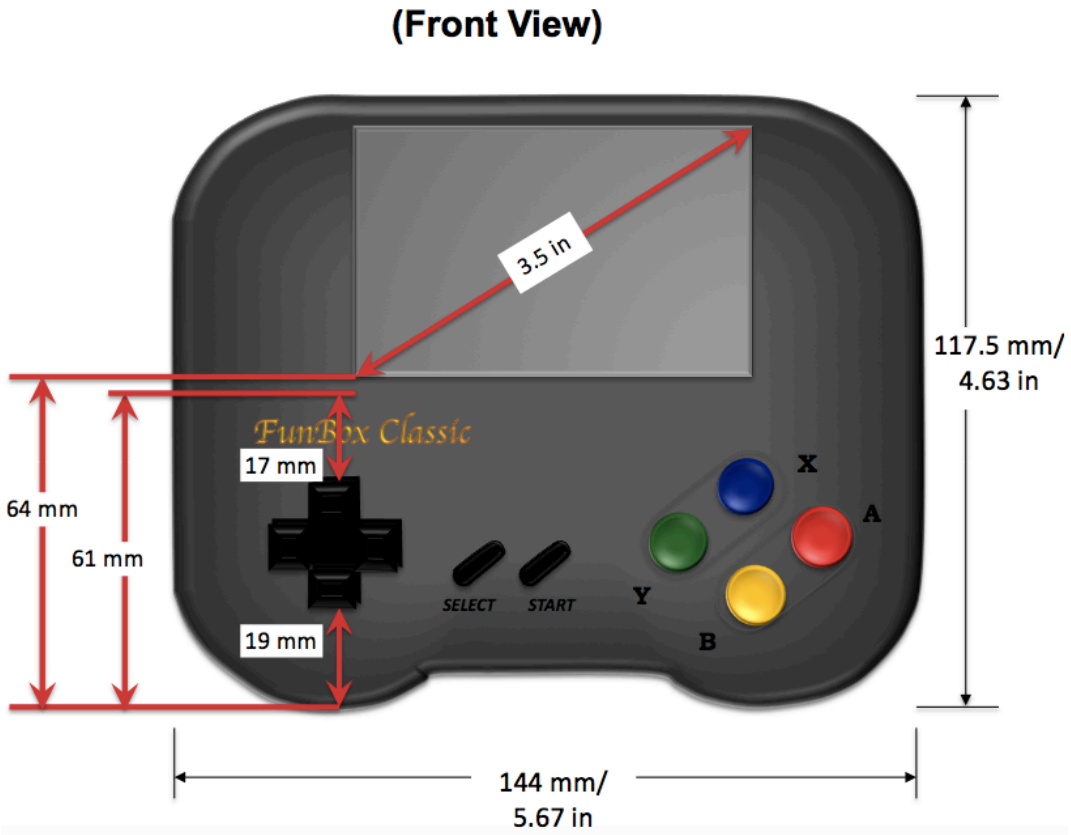


Figure 3.2.9.7 - Front Panel Sketch #2

3.2.9.6.2 Back Panel

A physical characteristic of the backside of the case is to allow the users to remove the battery through an accessible lid that can be unscrewed. We used rechargeable lithium ion polymer battery that has 65 x 51 mm in width x height. Analyzing the lid sizes of existing consoles and considering the size of the lithium ion battery, we were thinking to design the lid with dimensions about 65 x 127 mm. There also had to be a place for two or four solar panels. The size of each solar battery is 86 x 14 mm in width x height. The approximate design of the back panel is shown in the Figure 3.2.9.8.

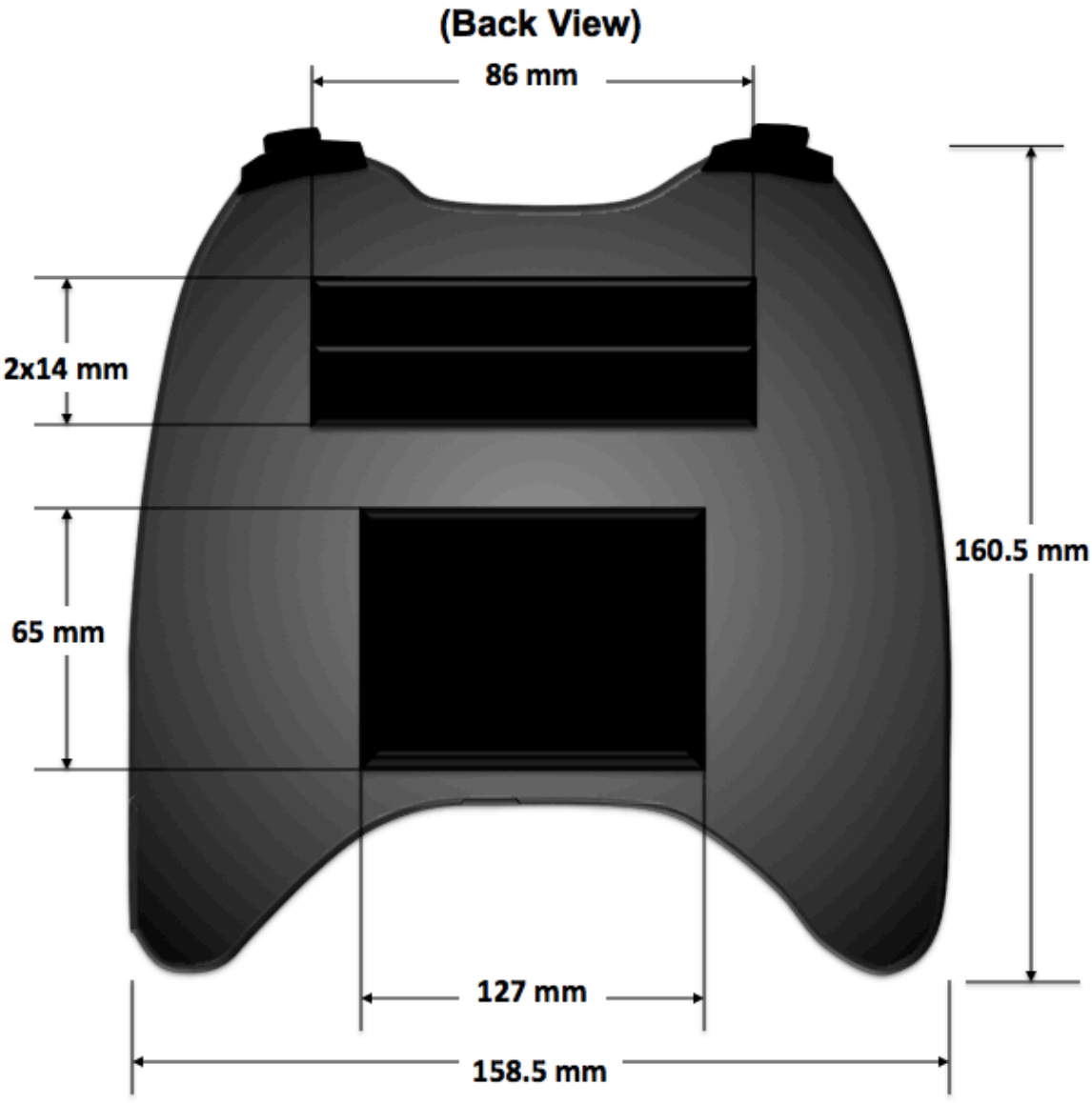


Figure 3.2.9.8 - Back Panel Sketch #1

This design was farther researched and changed to the design shown in Figure 3.2.9.9 below.

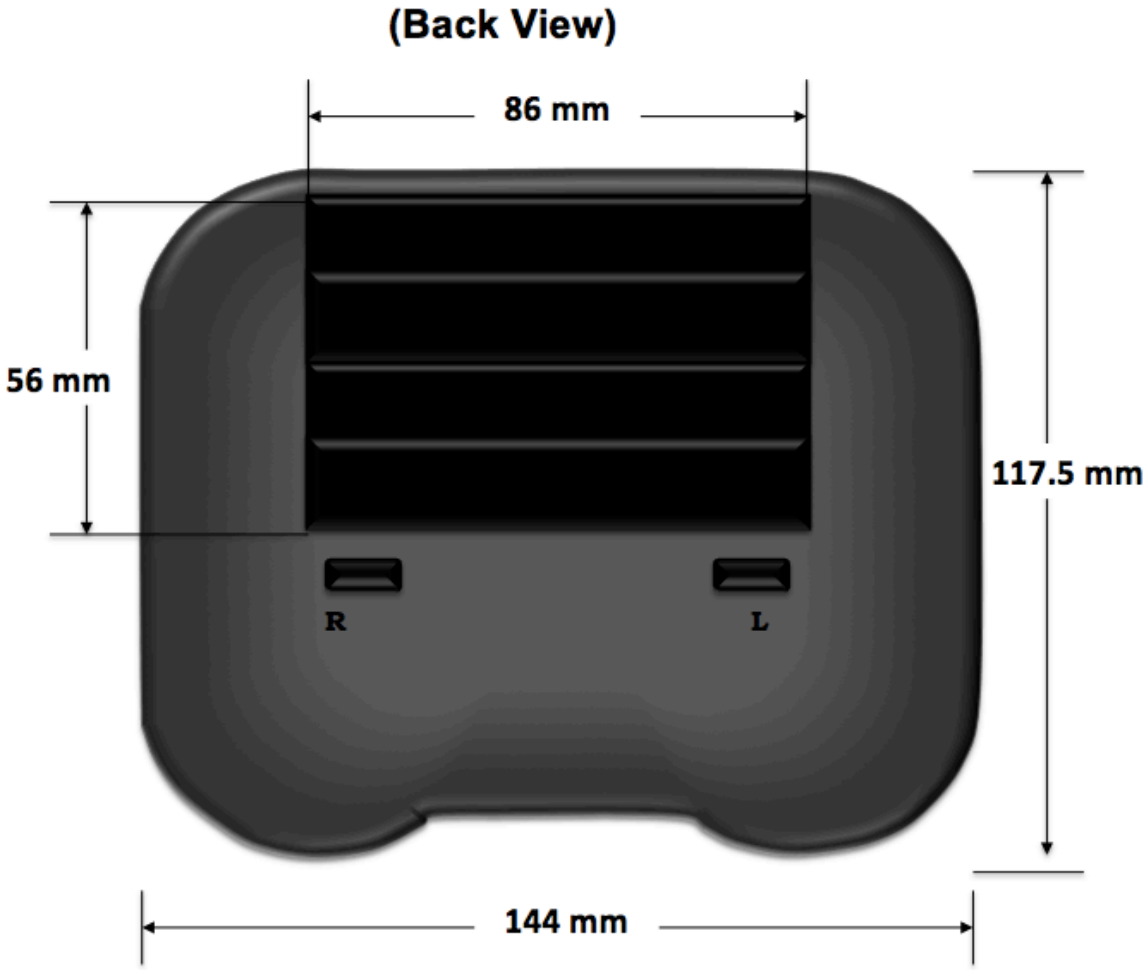


Figure 3.2.9.9 – Back Panel Sketch #2

3.2.9.6.3 Side View

The Table 3.2.9.2 has an approximate estimation of the thickness of the future console. This analysis was based on the specifications of some big parts that were placed inside the console and also the specifications of existing products, which were used for comparing purposes. Below figure 3.2.9.10 represents the idea of what we thought the upper part of the console would look like.

Part	Thickness (mm)	Weight (g)
Solar Panel	2	5
Battery	8	52
Display	15	132
Raspberry Pi	3	50
Other Components	57	240
Total	**85**	**479**

Table 3.2.9.2 - Estimate Thicknesses of the Console

Figure 3.2.9.10 - Side View of the Future Console

3.3 Software Research

This section details the research into a base operating system for our device, a software frontend GUI for users to interact with, a software backend to run the games, and potential modifications to the operating system.

3.3.1 Base Operating System

Initially, we considered using a FPGA system and designing from the very lowest level a custom operating system, built from a custom kernel geared towards the FPGA. The advantages were obvious. We would have been able to maximize power efficiency, since no unnecessary OS functions would have been required that would have drained more power, like a task manager. We would have been able to cut down on the disk space used by the OS as, again, no unnecessary space wasters, like advanced GUI elements, would be required. Finally, we would have been able to make sure the OS used all components of the hardware, such as the processor and memory, most optimally. This would have ensured the maximum possible amount of resources was available to the emulators, for maximum performance for each game.

However, the main disadvantages were too great to overcome. Learning to build an operating system from scratch, including the BIOS, the kernel, libraries, drivers, the GUI, and the user ring, would have taken an inordinate amount of time. From memory management to file system permissions, there was simply too much to do in too little time. In addition, we would have had to port all the emulators to our custom operating system, requiring more time. The operating system or emulator ports alone could have filled up a Computer Science Senior Design project, and thus we opted to abandon our overly ambitious goal. We can see how complex a standard operating system structure is by the flowchart in Figure 3.3.1.1 below.

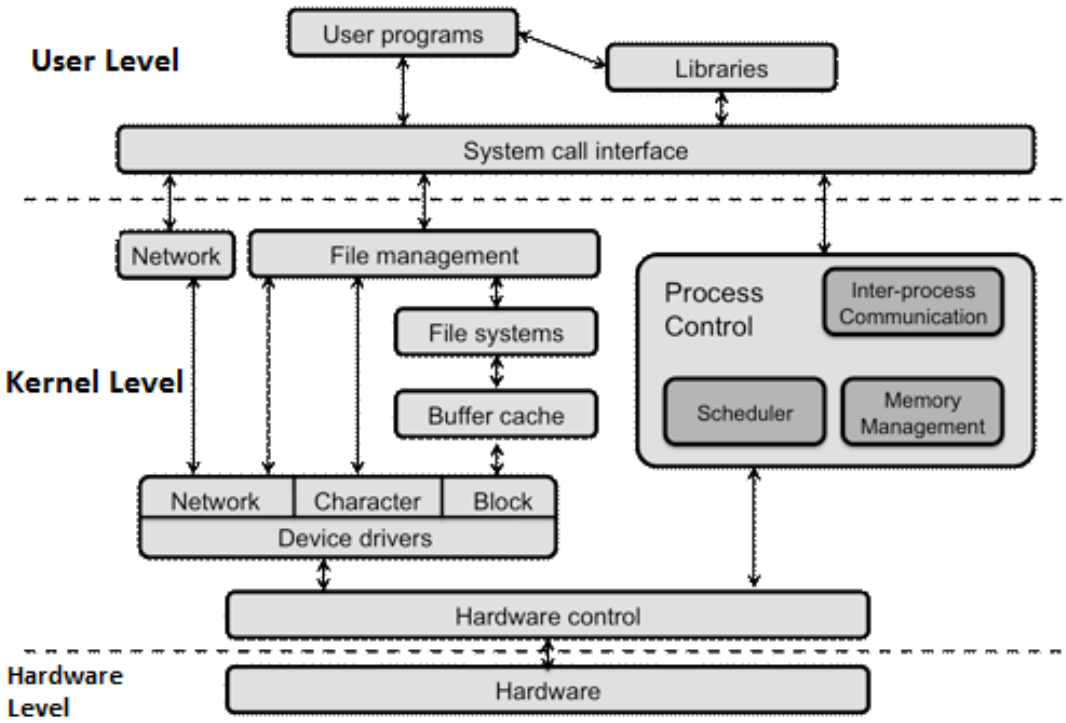


Figure 3.3.1.1 – Full Operating System Flowchart, reprinted with permission from Wikipedia

We decided to go with a Linux Kernel, due to its open-source, and therefore freely available, nature as well as the easily modifiable kernel. We thought, initially, about using something easy to use, like Ubuntu, but realized we should probably switch to a lighter distro that would more easily run on a micro-computer, like Raspberry Pi or BeagleBone Black. Looking at commercial derivatives, such as Fedora, and fan-proclaimed "pure" distributions such as Arch Linux, we opted to go with a midline Linux distro, Debian. Specifically, we used the most supported version of Debian with the Raspberry Pi – Raspbian, made by the developers of the Raspberry Pi to work best with their system. A more detailed comparison of Linux distros is shown in Table 3.3.1.1.

Distro	Cost	Default FS	DE	arm support	GUI Installer	Rpi Support	ES Support
Arch-Linux	Free	None	None	Yes - Unofficial	No	Unofficial	Non-native
Debian	Free	ext4	GNOME, etc.	Yes - 32-bit	Yes	Yes	Native Pi
Fedora	Free	ext4	GNOME	Yes - 32-bit	Yes	2nd Party	No
Ubuntu	Free	ext4	Unity on GNOME	Yes	Yes	2nd Party	Non-native

Table 3.3.1.1 – Linux Distro Comparison

As can be seen in the table above, Debian met all of our system requirements perfectly, and thus became the obvious choice.

3.3.2 Software Frontend

We used a frontend called EmulationStation, which is built on top of the Raspbian variation of the Debian distro, specifically designed for Raspberry Pi. This will allow us to focus more on the hardware and not be concerned with the already functional software components. In addition to performing all necessary frontend functions, the EmulationStation software is freely available and encourages people to use it in whatever projects they have. The GUI shown to the user is displayed in Figure 3.3.2.1 below.

Figure 3.3.2.1 – EmulationStation GUI

We looked into other more fragmented solutions, some using RetroArch like RetroPie does. Each of these solutions, however, would require the user to browse a standard desktop environment like GNOME. This, given the size of the screen and the lack of internal keyboard and mouse controls, was a non-ideal solution. EmulationStation is the official frontend of a combination solution called RetroPie, which allows us to have all emulators in a central directory, with games, emulators, and settings easily controllable with only a standard game controller. Certain options do require the use of a keyboard to configure, but these will be preconfigured before the final release, making that level of user input unnecessary.
As we have decided to support only the maximum native resolution of our screen, which is 640x480, we will configured the EmulationStation to support only this maximum resolution. This reduced the needed resources from the

Raspberry Pi 2, which will prevent low resource issues, such as blank screens and freezing. Additionally, we only enabled support for the Nintendo Entertainment System (NES), the Super Nintendo Entertainment System (SNES), the Game Boy (GB), the Game Boy Color (GBC), and the Game Boy Advance (GBA). These limitations helped to cut down on required resources as well. The BIOSs required to emulate each system were extracted directly from the physical system, thereby sticking to legal use of the copied material.

Additionally, we configured EmulationStation to accept not just the internal controller, but our external Bluetooth controller as well. Thanks to a built-in configuration utility, this proved to be very easy.

3.3.3 Software Backend

ROMs of the test games were extracted from our own physical copies of each game, using already available flash chips. These were saved in their appropriate directories on the Micro SD card. To put ROMs on the card, it was necessary to use a direct USB connection.

All emulator tests were performed using much larger sets of conditions, which we have consolidated to save space in the diagram. For each emulator, we performed a barrage of 47 to 159 tests, depending on the system being emulated. These are tests which the speed-running community uses to evaluate emulators. Since these players are obsessed with shaving off even one more millisecond of time from their playthrough of any given game, they know that they need perfect emulation. As a result, we can be assured that the tests are comprehensive and accurate.

For the NES, we decided between three emulators: Jnes, FCEUX, and NesterJ. Jnes was a very accurate and powerful emulator, but required too many system resources for accurate emulation. NesterJ was a solid emulator, that had been proven to work on portable systems, such as when it was ported to the Nintendo DS through homebrew applications, but ultimately did not suit our needs due to emulation inaccuracy and having not been updated in quite some time. We opted to go with FCEUmm, a port of FCEUX with better mapper support, which provided the best balance of updates, performance, and system requirements.

The emulators below are the most accurate ones that were precompiled for the Raspberry Pi. The emulators puNES(closed-source) and Nestopia (open-source), when compiled for the Raspberry Pi, might provide better accuracy and performance, and so might be considered as the project progresses for maximum enjoyment. The test results are shown in Table 3.3.3.1.

Test	Jnes	nesterJ	FCEUX
APU (/40)	8	8	18
CPU (/55)	21	23	38
Mapper (/13)	0	1	7
PPU (/42)	6	10	21
Misc(/5)	3	4	5
Demo (/3)	0	0	0
Total (/158)	38	46	89
Grade (%)	24.05%	29.11%	56.33%

Table 3.3.3.1 – NES Emulator Accuracy Comparison

For the SNES, we decided between three emulators as well: ZSNES, a variation of SNES9x called PiSNES, and higan (formerly BSNES). Higan is, bar none, the most accurate emulator on the market. The creator mapped every single pathway of every single chip on the SNES and even expansion chips on the cartridges. For this effort, he was rewarded with 100% emulation accuracy. However, emulating an entire system perfectly requires far more resource than our Raspberry Pi 2 can support, and thus we sadly had to get rid of this option. ZSNES is an excellent emulator, being very accurate and also considerate of resources. Unfortunately, the port for Linux systems was not optimized well, and thus we were forced to remove it from consideration. We ended up going with a port of the popular SNES9x emulator specifically for Raspberry Pi. The test results are shown in Table 3.3.3.2.

As we can see, PiSNES reaches nearly 90% accuracy, without the massive performance drops seen by the higan emulator. As a result, it is the clear choice.

Test	ZSNES	PiSNES	higan
Blargg Tests (/9)	2	4	9
Official Tests (/30)	20	29	30
Cx4 Tests (/8)	8	8	8
SPC7110 Tests (/12)	12	12	12
Total (/59)	42	53	59
Grade (%)	71.19%	89.83%	100.00%

Table 3.3.3.2 – SNES Emulator Accuracy Comparison

For the GB and GBC, we chose between no$gbm, Visual Boy Advance, and Gambatte. No$gbm was relatively clunky, experienced slowdown, and has an appalling level of accuracy. Visual Boy Advance supports Game Boy, Game Boy Color, and Game Boy Advance games, making it a great choice to cut down on needed cores for emulation. However, when playing around with it on the portable system, there were some aspects of the user interface we felt did not mesh properly with the system as a whole. In addition, the main team stopped updating the emulator in 2004, and the new team has made some feature additions which we felt were not worth the additional resources required. Finally, its emulation accuracy is still poor. Gambatte, on the other hand, is pre-built with support for the backend system of RetroArch, making it ideal for our idea of a unified system set. It does not support GBA games, but we felt this lacking was made up for by constant updates and integration with the backend. The test results are shown in Table 3.3.3.3.

Test	nos$gmb	VBA	Gambatte
CPU (/12)	9	12	12
Sound (/24)	1	1	24
MEM (/3)	0	2	3
OAM (/8)	2	3	3
Total (/47)	12	18	42
Grade (%)	25.53%	38.30%	89.36%

Table 3.3.3.3 – Game Boy and Game Boy Color Emulator Accuracy

Additionally, we can see that Gambatte achieves nearly 90% accuracy, far more than either of the other tested options. With minimal performance effect and significantly better emulation accuracy, we can safely say that Gambatte is the clear choice.

Finally, for the GBA, we decided between Visual Boy Advance and gpSP. Visual Boy Advance was discarded for the reasons stated above. GpSP, while being originally for the PSP, received a native Raspberry Pi port and seems to work flawlessly on it. For this reason of ease of use, we chose gpSP. As these were the only two options available and VBA had already been discounted, we felt that testing was superfluous at this point.

3.3.4 Operating System Modifications

Even using a premade operating system, there were several modifications we had to make to maximize effectiveness on our platform.

First and foremost, we made sure to maximize battery life. To this end, we disabled unnecessary features of the OS, such as the SAMBA share for the emulators, as we will have no network capabilities. Further, we disabled the LAN

chip itself, giving us a savings of 40 mA. These changes nearly double the battery life of the system, as the total current drawn when fully stressed will be 260 mA and it will idle at 200 mA. More exact measurements of power savings are shown in Table 3.3.4.1.

100% Load Cores	0	1	2	3	4
Pi2	230	280	320	380	420
Pi2 w/ OS Changes	200	215	230	245	260

Table 3.3.4.1 – Power Saved Due to Ethernet Removal

Secondly, as we tried to minimize user complexity, auto-USB synchronization was setup. By this, we mean that upon plugging in a USB drive to the system, it copied the directory structure and contents of the ROM folder onto the USB. From then on, any changes made to the USB, such as adding or removing a ROM, will also be made on the system once the USB is plugged back in. In this way, the user does not have to navigate the Linux filesystem and worry about messing something up. We disabled most setup options, so the user does not accidentally, say, delete the core emulators.

Thirdly, we considered overclocking the BCM2836 chip, as this made Nintendo 64 games playable. However, as we decided to not add an analog stick and as most games had large compatibility issues with the conversion to the ARM architecture, we dropped Nintendo 64 support. As a result, the performance benefits of overclocking were no longer necessary, and we were only left with a much larger power footprint. The idea of overclocking the system was then scrapped, leaving us with a more power efficient chip that serves performance purposes.

Finally, we locked the software volume at 100%, leaving all volume control up to the hardware potentiometer. This will eliminate the potential of a user forgetting what they set the software volume at, and thus minimize user error in that area.

4. Hardware Design

It goes without saying that the meat of a Senior Design project is, in fact, the design. This is the most important part of the first half of Senior Design. In this section, we will lay out, in detail, the design of the various hardware components that make up the FunBox Classic. Properly laid out, well researched, and well documented design ensured the least amount of wasted time, effort, and money when it comes time to actually build the project.

4.1 Screen Setup

Our first step will be to take apart the screen and strip the component connectors, making sure not to damage the delicate ribbon cable in the process. Once properly disassembled and stripped, we will move onto the Raspberry Pi. We will first remove the existing composite video/stereo audio hybrid connector, as it is tall and does not fit our needs. This will also leave the audio connections open for our custom audio processing, to output it to headphones or speakers on a switch. We will connect the composite cable to the solder point PP24, which is the Composite Signal Input. The ground will be soldered to solder point PP6, which is a ground point.

Next, we prepare the external screen to accept a more reasonable (for our purposes, at least) 5V input as opposed to the 12 V it currently accepts (due to it being a car monitor, this makes sense as cigarette lighters output 12V). This is accomplished with relative ease. If we remove the linear chip, the circuit automatically accepts the desired 5V again. We then connect the 5V input and the ground to the unused USB header marked 2.

Finally, we de-solder the switches below 2 and link them to the backlight controller. By sending timed pulses, we are able to then control the backlight capabilities of the monitor.

By performing these three relatively simple steps, we have a natively supported screen, with the resolution and quality we need, with full backlight (and even contrast and saturation if needed) control. This also avoids any messy complications due to driver conflicts and any loss in quality due to analog to digital conversion.

However, we ended up not doing that at all, scrapping the backlight controller and soldering a wire directly to pads past the regulator.

As the original brightness control switches for the screen would add unnecessary bulk (and complication, due to the menu system) to the design of our system, we have opted for manual control of the brightness. Two options are potentially available to us.

First, the method that would be guaranteed to work, we could have pulses sent to the areas where the switches used to be, in pre-programmed ways, to control the brightness. This method has the benefit of already being known to work, as it's just substituting wired pulses from a microcontroller for the original switches. The downside, of course, is that the onscreen menu overlay would display the volume, negating any software control of that interface. Additionally, it might be slower, as navigating a menu is, by its nature, slower than direct control.

Second, the method that we are currently testing, we could bypass the microcontroller and send whatever pulses it uses to control brightness to the LEDs directly. This method has the benefit of allowing us to use our own GUI for brightness level displays, as well as being faster due to bypassing the onscreen menu overlay. The disadvantage to this method is, of course, that it might not be possible or, more specifically, it might not be possible for us.

Whichever method ends up being the correct one, we plan on using the ATtiny13 from Atmel to control the backlight. This tiny, and cheap, chip is able to do both of the things we might require: either sending pre-programmed pulses by listening for specific input (the user changing brightness) or using PWM to control the brightness directly, also listening for the user's input (if the screen accepts this method). Additionally, with the use of a photoresistor and a switch that the user would control, we can set the brightness to automatically dim or brighten based on the current level of light in the room. This would, naturally, have to be a system the user could disable at will, as these systems can provide an inadequate (or overlarge) level of light at times.

A basic schematic for the backlight controller is shown in Figure 4.1.1.1.

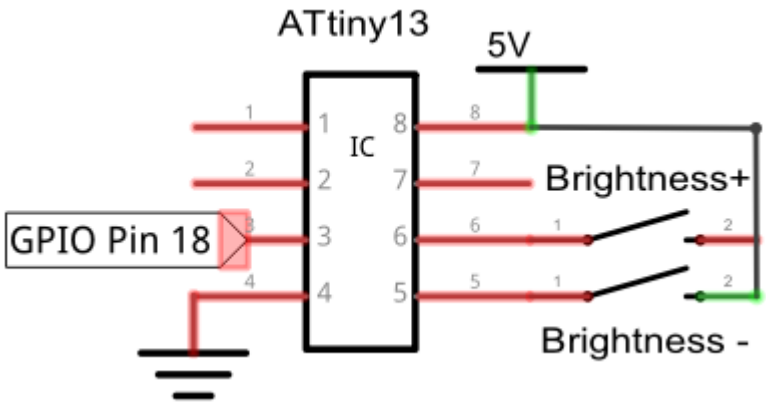


Figure 4.1.1.1 – Basic Backlight Controller Schematic, reprinted with permission from Wikipedia

However, we ended up not implementing the backlight controller.

4.2 Audio

The FBC offered two designated means to output audio from the software: two external stereo speakers that export sound to the surrounding area of operation, and also via an audio jack port that could be paired with external headphones to provide a closed audio system designated only for the headphone operator. A specification for the FBC design was to externally output the device audio via the stereo system speakers by default, but to only supply audio through the audio jack port when a device is plugged to it, thus muting the stereo speakers until the auxiliary listening device had been removed.

4.2.1 Speakers

We used two external speakers in the FBC audio stereo system, each positioned on either side of the device to maximize the audio dimension output to the user. When choosing our device speakers, we referenced previous handheld gaming models as reference to determine what is an acceptable means of output in terms of frequency and power rating. As previously mentioned, the standard for speaker impedance in handheld devices is 8 ohms. Frequency ranges for the SNES games can rate up to 8 to 12 Kilohertz, so we wanted our speakers to be able to attain that maximum frequency output. Power consumption was a main concern, with minimal current draw from the power source being desired, especially given the use of dual-stereo speaker components. Additionally, speaker size in relation to the case design was considered. We were looking for a traditional round speaker design, with a minimum diameter of 22mm, which is the speaker diameter for the classic Gameboy Color, and a maximum diameter of 30 mm. Below, in Table 4.2.1.1, we compared available small-scale output speakers for consideration.

Model	Frequency Range	Power Input	Diameter
102-2502-ND	448 Hz – 7 KHz	0.3 W	20 mm
668-1231-ND	500 Hz – 20 KHz	1 W	28 mm
102-1554-ND	530 Hz – 20 KHz	0.1 W	27 mm

Table 4.2.1.1 - Stereo Speaker Model Specs

Comparatively looking at the selected models, we first considered the frequency range. The 102-2502-ND can attain the lowest available frequency of 448 Hz, but also only can reach 7 KHz. The other two models can reach up to 20 KHz, well within the maximum frequency output range desired. For power consideration, the 668-1231-ND takes the most power, at 1 Watt, much more than the other models, and more than ideal for power consumption. For diameter dimensions, the 102-2502-ND is the most efficient in size, which can be ideal for extreme case design constraints. However, considering all fields together, we chose the 102-1554-ND model. This model required the smallest input power at 0.1 W, and

was in the ideal frequency output range. Factoring in that the FBC will be using two stereo speakers for audio output, this model fulfilled more of the desired requirements for the sound system.

4.2.2 Audio Jack Output

The secondary source of audio output was from the implementation of an exterior audio headphone jack. When an auxiliary device, such as a headphone plug, is inserted into the audio jack, a connection is made that sends the audio output, from the amplifier, to the headphone output. Additionally, when the plug connector of the auxiliary device is inserted into the jack, an internal switch is flipped, breaking the connection to the dual external stereo speakers, and only providing audio output to the plug-in. The FBC featured the audio jack primarily for headphone plug-in use, so we used the standard 3.5-mm jack size for our design. To be noted, the core Raspberry Pi2 for the FBC initially featured a 3.5-mm jack already attached, but we removed that feature from the surface, as it was not needed for our device implementation.

For audio jacks, phone connectors are used as the input to channel audio signals. In particular, stereo headphone jacks comprise of three contacts: the tip, ring, and sleeve (ground). Each of the three connectors directly corresponds with the audio jack when plugged in. There are two types of headphone jacks for device use consideration: open circuit audio jack, and closed circuit audio jack. Open circuit jacks, when unoccupied by a connector, initially serve as a connector between the amplifier and the speakers. When a phone connector is inserted, the tip of the connector also receives audio output, and both the stereo speakers and the headphones output audio. Closed circuit jacks also serve the initial purpose of connection between the amplifier and speakers. However, a moveable internal switch within the jack port keeps this connection by remaining closed. When a headphone connector is inserted, the switch is flipped open, breaking output connection to the speakers. Now, the only audio output is directed to the plug-in headphones. Figure 4.2.2.1 below exemplifies the headphone connector opening the jack switch.

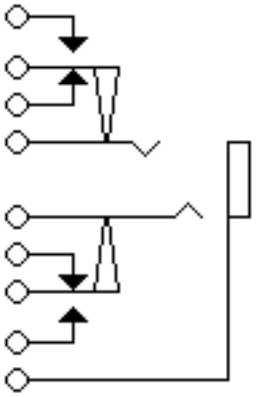


Figure 4.2.2.1 - Closed Circuit Audio I/O

When the auxiliary headphone connector is inserted, from the right side of the diagram, into the audio port, two pin connectors are pushed outward. When pushed, the two connectors move the mechanical dials on either side away from the initial arrow contact to the exterior contacts. This breaks the connection, cutting signal away from the speakers, and only applying audio output to the jack connector. Below, in Figure 4.2.2.2, is the initial audio circuit output in relation to speakers and audio jack, using an NMOS inverter to signal power to the respecting audio outputs. Note, due to schematic limitations in Multisim, only the symbol for a single input, single output audio jack was available. However, we still simulated the stereo system dual-speaker audio jack by placing two single jacks side by side in series to more closely resemble the audio schematic from Figure 4.2.2.1

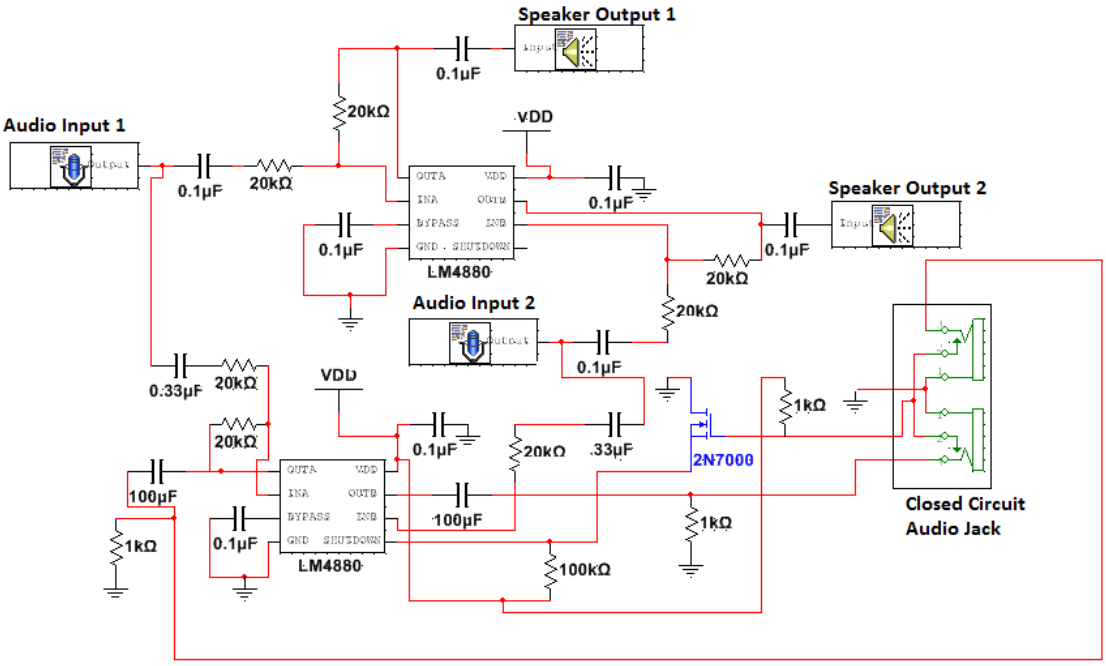


Figure 4.2.2.2 – Initial Closed Circuit Audio Speakers and Audio Jack

Later design analysis revealed discrepancies with the initial audio circuit. The utilization of the LM4880 to drive signal to the left and right speakers was inefficient, compared to driving an external load, such as the audio jack. The LM4861, however, provided a better output for lower power quantities, and was specifically designed for bridged speakers. Additionally, the LM4861 was capable of outputting higher power ratings of typically 1.1W, thus requiring speakers that could take a higher maximum power rating; we chose the CLS0231-L152 magnetic speakers. The final audio circuit can be shown in Figure 4.2.2.3. An automatic switching design is favored, with the use of the Shutdown pins on both the LM4880 and LM4861. An NMOS inverter is used to toggle a supply voltage Vdd to both shutdown pins, which alternate with the connection status of the audio jack.

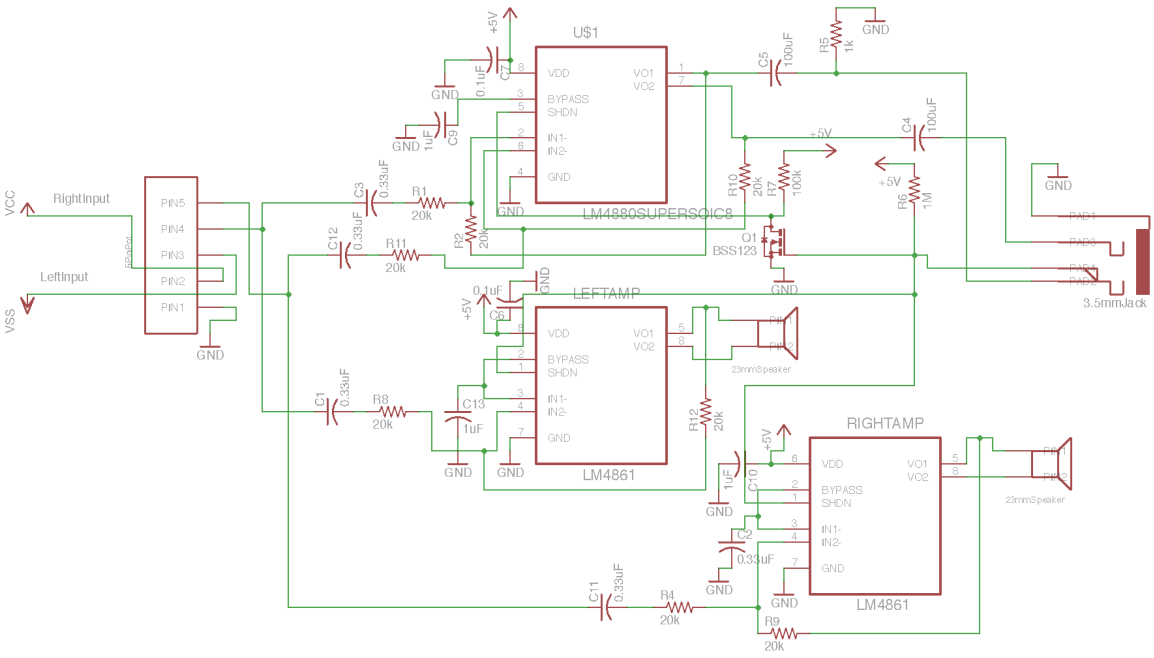


Figure 4.2.2.3 – Final Audio Circuit Design

To implement an effective switching between audio jack and speakers signal, we needed a 4-pin audio jack, one that included an auxiliary pin to indicate the presence of a headphone plug. We chose the SJ-3524-SMT 3.5mm audio jack for the job. The sleeve, pin 1, is designated as ground, while the tip and ring (pin 2 and pin 3 respectively) output left and right audio signals. The fourth pin serves as a connector, which is pushed away into an open circuit design when the headphones are introduced. Figure 4.2.2.4 demonstrates the format of the 4-pin audio jack used.

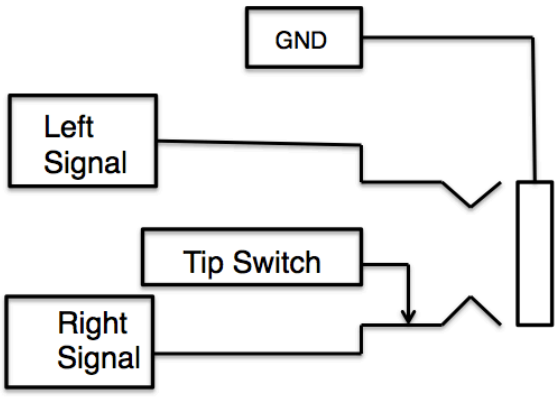


Figure 4.2.2.4 – 4-Pin Audio Jack Diagram

4.3 Power System

The power system design includes the design of all the circuits related to the power subsystem. This consists of the battery wall charging circuit, DC-to-DC converter circuit, 5-volt power supply circuit, solar panel charging circuit, and LED battery indicator circuit. Also included in this section is the design of a relay circuit that will switch from solar charging to wall charging when the wall charger is plugged in.

4.3.1 Wall Charging Circuit Design

Figure 7.3.1.3 showed a sample 500 mA LiPo battery charging circuit using the MCP73831. We wanted to make a circuit very similar to this but with multiple LEDs to show the various states of the battery during charging. According to the datasheet, the STAT pin has three possible states: High when the battery is fully charged, Low when the battery is charging, and High Z when the battery is not connected or the MCP73831 enters its shutdown mode. In Figure 7.3.1.3 the diode will light when the battery is charging because the voltage difference between V_{in} and STAT will be positive and the current through the diode will cause light. When the battery is fully charged the STAT pin will be High and no current will flow through the LED. In order to have an indication of when the battery is fully charged we can add a resistor and LED from STAT to ground, as shown in Figure 4.3.1.1, or we can use a red/green LED and attach a resistor from the STAT pin to ground. We determined using a second LED was better because it would allow a third option for lighting both LEDs simultaneously. Three combinations of LED lighting correspond to the three states of the STAT pin as shown in Table 4.3.1.1. When the STAT pin is in the High state the voltage drop from STAT to ground through the LED resistor will cause a current to flow through the LED lighting it. In the High Z state of the STAT pin both LEDs will light because there is a path from V_{in} to ground through the two LEDs and their resistors which will ignore the high impedance path into the STAT pin. Ultimately, in the final design, we decided to go with a one LED setup for simplicity and the second LED was deemed unnecessary.

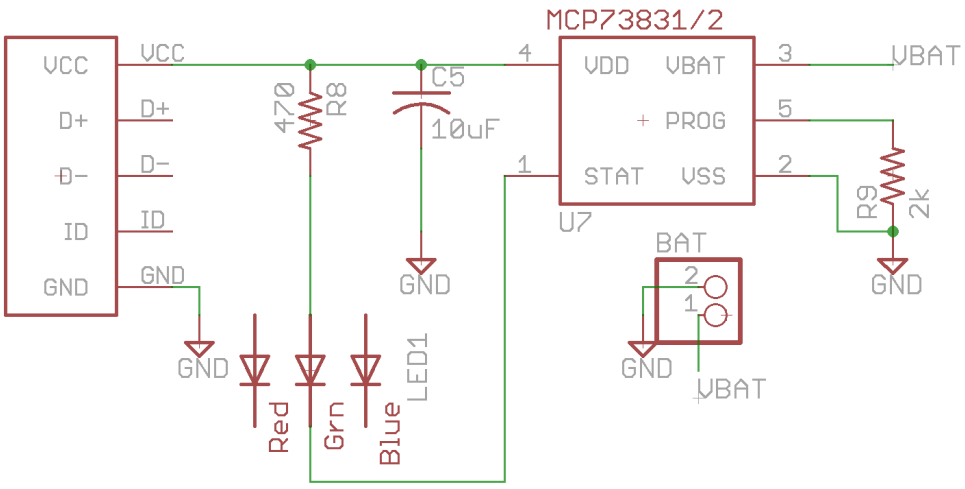


Figure 4.3.1.1 - Schematic of Charging Circuit with Charge State LEDs

Charge State	Orange LED	Green LED
Charging	Yes	No
Finished	No	Yes
Shutdown/No Battery	Yes	Yes

Table 4.3.1.1 - Table of Active LEDs per Charge State

This circuit safely charges the battery using the standard 5 volts provided by USB 2.0 ports plugged into a wall adapter or a computer, and shows the user the current charging state of the battery. The total cost of the circuit is less than $3.00. The circuit also does not have many components, which will help keep the PCB as small as possible. With the additional charge protection circuit built into our battery, we felt very confident that our LiPo battery would be able to charge without any major complications. Now that the battery can be charged we needed to use it to power the device. First the output of the battery needed to be converted to a higher voltage level and then regulated.

4.3.2 DC-to-DC Converter Circuit Design

Figure 3.2.8.10 showed a sample regulated 5-volt output circuit using the TPS61030. We wanted to make a circuit very similar to this circuit, but with an additional switch to connect and disconnect the battery to the enable pin on the TSP61030. This will act as our power switch. Additionally when the device is turned on and working we want an LED to shine. We also want to use the LBO pin to light an LED when the battery is close to 3 volts to indicate that the battery is low and the user should turn off and/or plug in the device as soon.

All references to components in the following circuit design information will be referring to the circuit in Figure 3.2.8.10 until stated otherwise. The output voltage of the device is determined by the resistors R3 and R4 and the voltage at the FB pin. The TPS61030 datasheet says the resistor R4 should be around 200 kΩ and that the FB pin voltage is typically 500 mV. Using R4 = 200kΩ and VFB = 500 mV we calculated that R3 needs to be 1.8 MΩ. The LBO pin is active low when battery voltage drops below the set level and high otherwise. The set battery voltage cutoff is determined by the resistors R1 and R2 and the onboard LBI threshold voltage. The resistor R2 is supposed to be around 500 kΩ and the LBI voltage threshold is 500 mV. Using R2 = 510 kΩ and VLBI-Threshold = 500 mV and VBAT = 3 V we calculated that R1 should be 2.55 MΩ. Using a 2.7 MΩ resistor instead makes the LBO pin go active low when VBAT = 3.15 volts. This was considered suitable to our needs. In the final design, after messing with different values, we decided to change the resistor values to allow around a 5.2 volt output and a 3.25 volt low battery warning instead. The datasheet says that in typical applications, such as ours, an inductor with inductance 6.7 µH is recommended. C1 is recommended to be 10 µF by the datasheet. It also says to put a 100 nF capacitor in parallel with C1 and as close to the chip as possible. The output capacitor is recommended to be 220 µF. A 2.2 µF capacitor at the output will be used as a decoupling capacitor. We also chose in the final design to use two 100 µF capacitors in parallel instead of a 220 µF capacitor. The basic 5-volt output DC-to-DC converter circuit calculated from the datasheet without any additions is shown in Figure 4.3.2.1.

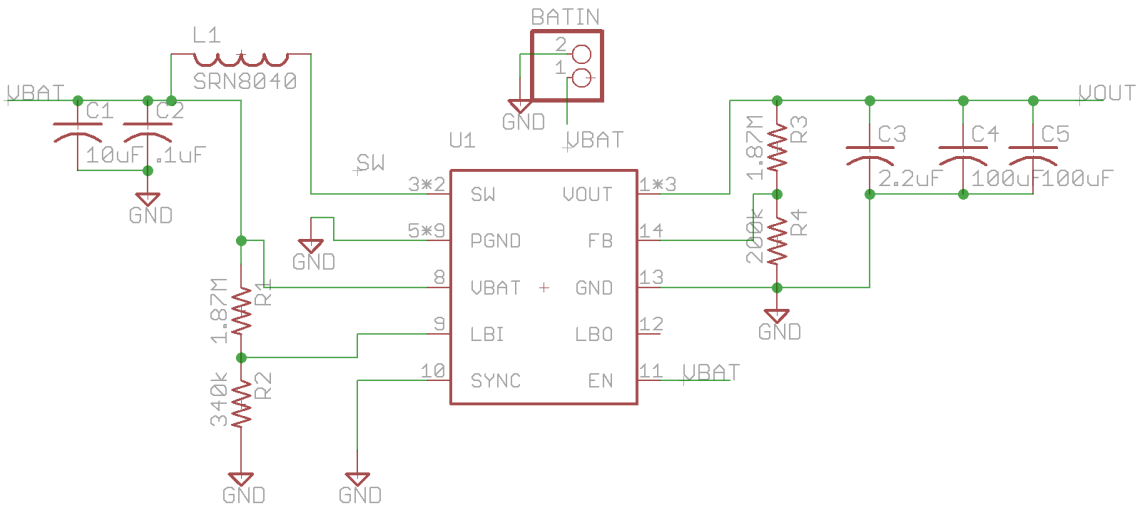


Figure 4.3.2.1 - DC-to-DC Converter and Regulator Circuit

4.3.3 Power Supply Design

Now that the basic circuit design had been handled we could add what we needed to it. The first thing we needed to add is a power switch that will switch the EN pin from the battery to ground. This is demonstrated in Figure 4.3.3.1. Also shown in Figure 4.3.3.1 is a blue LED attached with a resistor from V_{OUT} to ground as a power indicator. When the device is on the LED will be lit. The last major change is the addition of an LED low battery indicator. The LBO pin outputs V_{BAT} when it is High, so a PNP transistor with the emitter connected to V_{BAT}, the base connected to LBO, and the collector connected to a resistor and the LED. When LBO and the emitter are both V_{BAT} the transistor will be off and no current will flow through the LED. When LBO is low the transistor will turn on and current will flow through the LED. Figure 4.3.3.1 shows the power supply circuit that connects the battery to the Raspberry Pi 2 with both a power indicator LED and a low battery indicator LED.

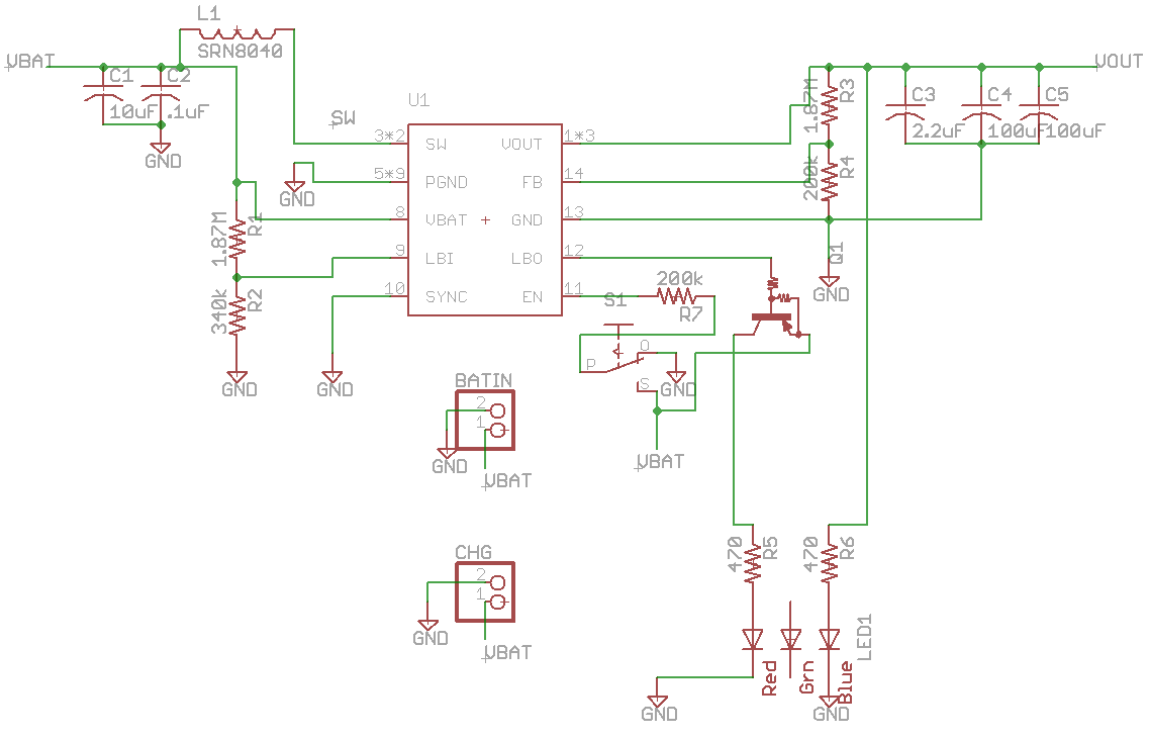


Figure 4.3.3.1 - Power Supply Circuit

4.3.4 Combining the Power Supply and Charge Circuit

The power supply and charge circuit will join at the battery. Some changes to the circuits were needed due to coming in contact with additional components. The charging circuit has the battery in parallel with a 4.7 microfarad capacitor while the power supply circuit has the battery in parallel with a 10 microfarad capacitor and a 0.1 microfarad capacitor. These capacitors make the 4.7 microfarad capacitor unnecessary and it will be removed when joining the circuits. The charger circuit also has a 4.7 microfarad capacitor on the other side of the IC. This capacitor was changed to a 10 microfarad capacitor for symmetry. No other changes were needed to join the circuits. The completed battery, charger, and regulated power supply circuit is shown in Figure 4.3.4.1.

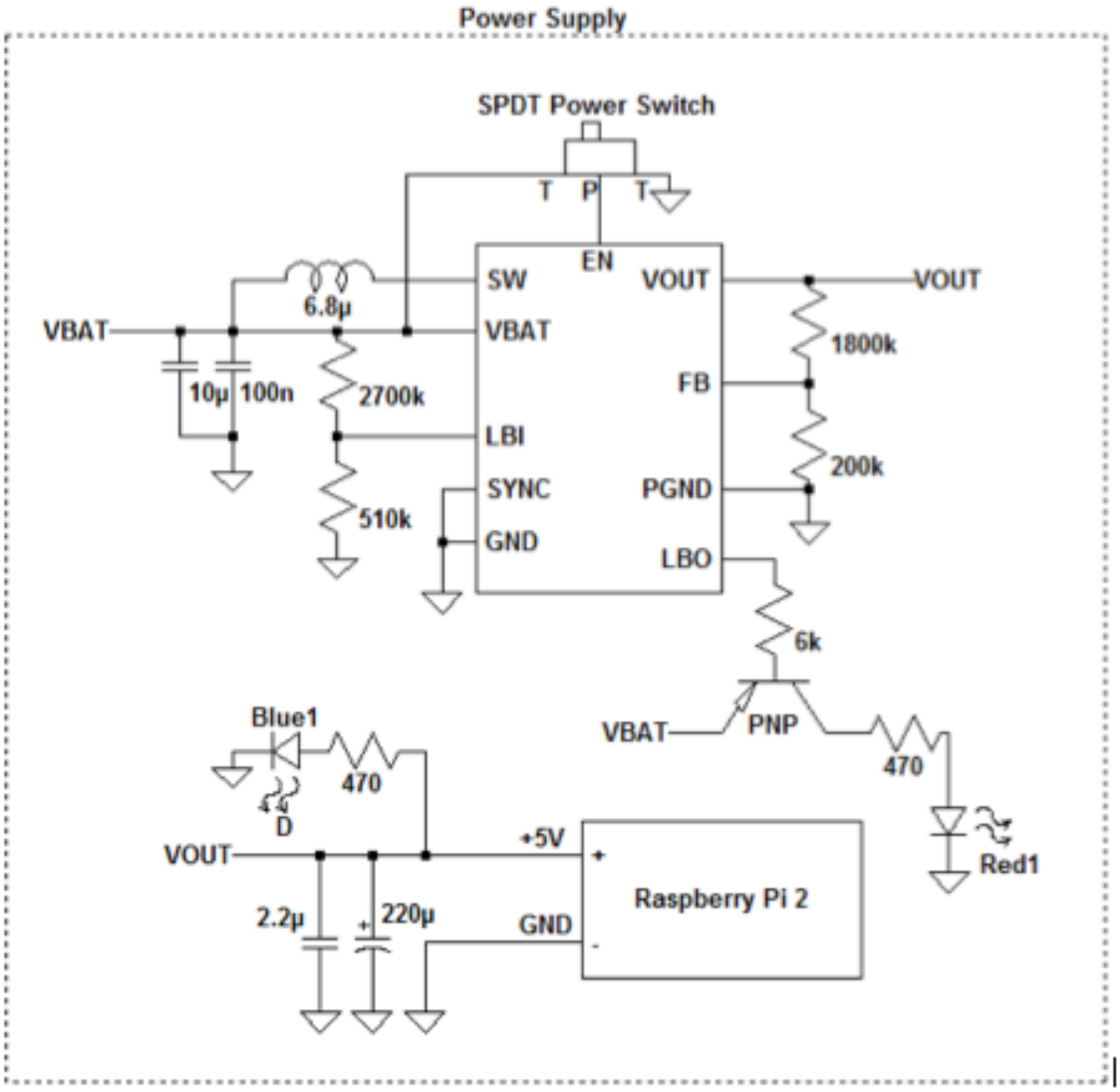


Figure 4.3.4.1 - Complete Power Supply, Charger, and Battery Schematic

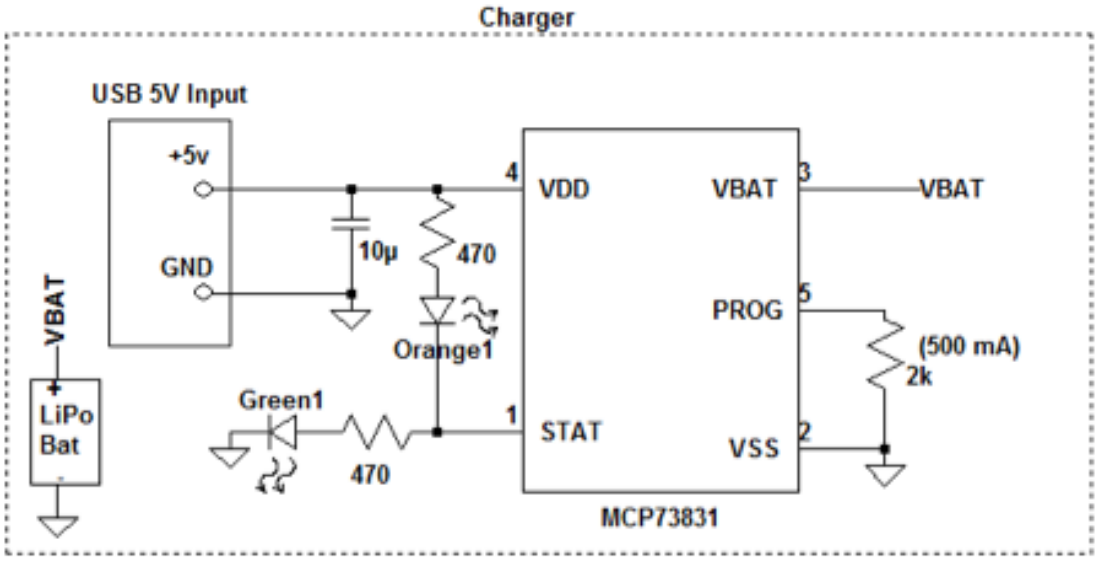


Figure 4.3.4.1 - Complete Power Supply, Charger, and Battery Schematic

4.3.5 Solar Panel Charge Controller Circuit

Comparing all three charge controllers, each one met the initial concern for constant voltage and current supplied to the lithium polymer battery. The LT3652 was a moderate-powered controller that required a minimum input voltage of approximately 5V, which was close to the maximum output of the solar circuit. Additionally, the LT3652 had the largest amount of pins, at 12 pins, that was excessive. The SPV1040, on the opposite spectrum, was targeted for lower power inputs, and raises concern for the compatibility of charging our 4.2V source battery. Thus, we chose the bq24210, which has an ideal input voltage range, and included protection from significant current leakage. Additionally, many sample solar charging lithium battery circuits researched have employed the use of the bq24210, making it an ideal component. Figure 4.3.5.1 below shows the initial solar cell charging circuit, with the bq24210 used in connection with the battery source.

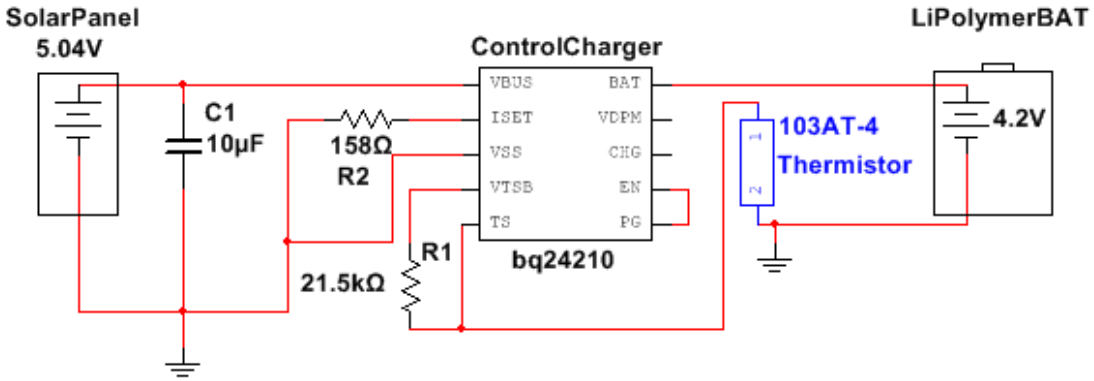


Figure 4.3.5.1 – Initial Battery Control Charger Circuit

Originally, for the bq24210, we added a103AT-4 thermistor close to our charging battery, to take advantage of the thermal protection system. Since the lithium polymer battery does not have a thermistor built in to it, we could add an external one close to the battery. If the battery begins to overheat, the TS pin would trigger the control charger to reduce the voltage and current flow to the battery. Pins VDPM and CHG are designated for charging detection signals, such as an LED connection for battery status. Since we were already using a more detailed battery indicator LED circuit, we chose not be using these pins.

Later revisions of the solar charging circuit led the removal of the thermistor from the circuit, as the lithium polymer battery would not foreseeably overheat at the power draws demanded of the project. Additionally, this resulted in the removal of the 21.5K resistor, as it was not needed. An anticipated maximum current draw of 100mA from the solar panel also resulted in a revision of the ISET resistor to 2kilo-ohms. Figure 4.3.5.2 displays the final solar charging circuit.

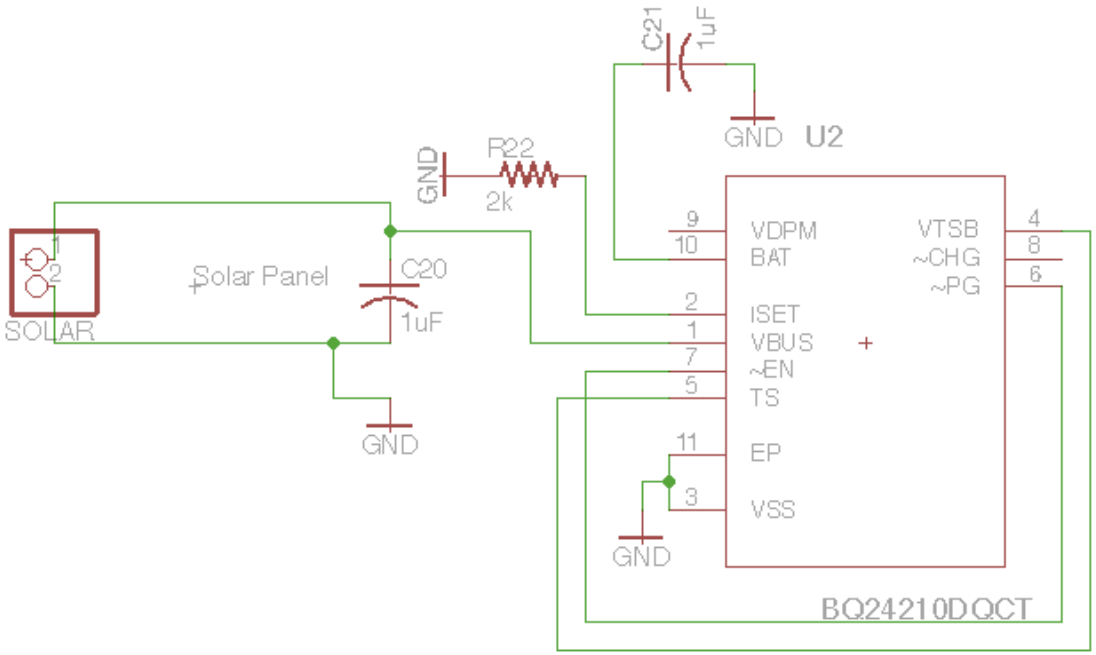


Figure 4.3.5.2 – Final Solar Charging Circuit

4.3.5.1 Solar Panel Design

Original designs designated the solar panel to be comprised of four monocrystalline silicon cells, arranged in parallel connection, to yield a maximum output current of 200mA and maximum output voltage of 5.04V. The idea was given that solar cells add up current in parallel, and voltage in series connections, we would want to charge the source battery fastest with four cells in parallel. However, we did not account for the event of cells on the panel that may be

shaded, covered, or damaged. A parallel connection of all four cells results in a current draw to the shaded cell, significantly reducing the current output available to the charge controller. Bypass diodes would solve that presented problem, but the voltage generated by the diodes would lower the output current from the panel to typical levels around 3.6V, which would not be sufficient to charge the battery at most levels. In order to maximize output, while still implementing the bypass diodes as protection, we opted to create two solar cell branches, each branch containing two cells connected in series. The two branches are then tied in parallel, resulting in a maximum output of 100mA and 10.4V respectively. The implemented bypass diodes across each cell were applied in parallel, avoiding a voltage drop, and allowing optimal current flow, even in the event of a shaded cell. The use of a LM7805C 5VDC voltage regulator limited the output voltage to the charge controller, further protecting from the risk of overcharging the battery. Below, in Figure 4.3.5.1.1, is a display of the solar panel constructed.

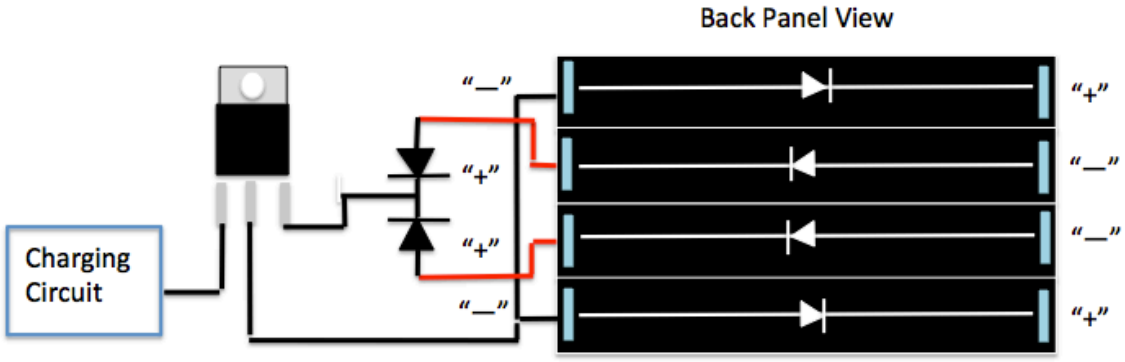


Figure 4.3.5.1.1 – Model of Solar Panel

4.3.6 LED Battery Charge Indicator

A specification for the FBC was to design a light-based indicator of battery supply levels available to the device. Voltage regulated LED circuits enable a test current to be sent from the battery power source to the designated diodes, with the LED output response indicating the charge status of the battery. The FBC has two separate LED battery charge indicators. The first indicator would use a RGB LED close to the user's targeted line of vision while operating the device, next to the upper right corner of the resistive touchscreen. This indicator would utilize each of the red, green, and blue LEDs to indicate the current battery charge status while the device is powered on. Additionally, the LED circuit diagram would be managed to have only one of the three diodes on at one time.

When the FBC is powered on, a current would be generated across each corresponding resistor to the LED. The blue LED would illuminate when the battery charge level reads 100%, indicating that the battery was fully charged. Should the user be charging the FBC's battery while the system is in use, the blue LED of the RGB LED would alert the user that the battery is fully charged, and may be removed from the battery charger. The blue LED would turn off at any battery charge below the maximum 4.2V charge of the lithium-ion battery. When the battery was charged between 100% and 25%, the green LED would illuminate, glowing brightest at the higher battery percentage charge, and dimming as the charge percentage reduces. Once the battery charge level reaches below 25%, the green LED would turn off. Simultaneously, when it had been indicated that the battery charge was below 25%, the red LED would illuminate. This final LED would stay on until the battery shuts down at 3V, in which all three diodes of the RGB LED would be powered down, along with the device.

The secondary charge indicator was designed for the user to more precisely identify the remaining voltage in the source battery, without needing to power on the entire device for a status check. On the bottom side paneling of the FBC, a line of 4 green SMDs would be connected in parallel, with the power supply connection delivered via push-button action, located just left of the SMDs on the hardware. While the button was pushed down, a switch bridging the battery power source to the SMD's would be closed, sending current across the limiting resistors and to the SMD's. At a battery charge reading ranging between 100% and 70%, all three SMD's would be on. Following, at a charged range of less than 70% to 40%, the rightmost SMD, SMD3, would turn off, indicating that the battery is roughly two thirds charged.

4.3.6.1 LED Microcontroller

The push-button battery indicator LED feature was intended to have the SMD LEDs turn on in relation to the charge status of the source battery, and stay illuminated for the specified time of five seconds. Initial designs would accomplish simply using a push-button feature to allow for a current signal to send to the LED circuit for as long as the button remained pressed, and using Zener diodes and current limiting resistors to control the allowable charge flowing through the LEDs. However, this method did not address the specification of keeping the LEDs lit without continuously pressing the push-button, or, in the design case, keeping the LEDs lit for 5 seconds after the push-button has been pressed, signaling the battery status. Therefore, the implementation of a programed microcontroller could be used. Now, with the push-button component directly connecting the power supply battery to the input pin, the corresponding output voltage could be signaled to the three SMD LEDs, and the initial programing would instruct each LED status to remain active for the specified time. In terms of choosing which microcontroller will be suitable to achieve the

battery status indicator, we primarily looked for meeting the required pins needed and acceptable voltage supply to keep the microcontroller on.

The FBC power source was rated at 5 volts, so a microcontroller within that range would be suitable. We determined that 3 SMD LEDs would be needed for the indicator status: 3 LEDs lit for a battery charge range of 70% to 100%, 2 LEDs lit for a battery charge range of 40% to 70%, and 1 LED lit for a battery charge range of 10% to 40%. Thus, 3 pins from the microcontroller were to be utilized, as well as an additional pin each for the turn-on controller voltage, the push-button battery status signal, and ground. So, the minimum pin number we were looking for in our microcontroller is an 8-pin device. We looked at several models to achieve the design circuit specifications. An 8-pin MSP430G2210 offers over 2 KB of flash memory and 4 general-purpose pins. However, like many in its family, it is an ultra-low power controller that would need the voltage source input to be regulated to a lower value. A similar microcontroller to look at is the ATtiny module. Comparatively, the ATtiny 13 and ATtiny 25 both offer 8 pins and a Vcc input of 5 volts. The ATtiny 25 also offers 2K Bytes of programmable flash memory, which is an excessive amount needed for the battery indicator LED circuit, so the 1K Byte ATtiny 13 serves better to avoid resource overhead.

In addition to monitoring acceptable turn-on voltage to the microcontroller, consideration for the battery test current to be read must also be observed. As previously mentioned, flagging the battery status by the remaining source voltage was an ideal method for turning on the corresponding LEDs. However, with our source lithium polymer battery, voltage change is hardly detectable until the battery has nearly discharged; this would result in all 3 LEDs being lit, but quickly dropping from the just 2 lit, and finally 1 LED lit, until the low power LED turns on, in a very short amount of time. A more accurate reading for the lithium polymer battery was via a test current signal, and could be accomplished by current updating microcontrollers. The microcontroller tests the battery current draw against the battery cell capacity, predicting the remaining charge left in the battery. Battery gauge microcontrollers are able to test current, voltage, and temperature status from the source battery, being an ideal candidate for the battery source indicator circuit. In particular, the TI bq27200 gauge series microcontrollers are lithium battery-specific, and can accurately read the remaining battery voltage via a small test current across a designated flag resistor. This model was ideal, in that it, like the ATtiny series, is 8-pins and draws a small amount of current from the battery for continuous operations. The designated status current can be outputted from the microcontroller's specified pin, and be channeled across the Zener-LED series branches to signal which SMD LED to turn on for indication. Below, in Table 4.3.6.1, we compared the three discussed microcontrollers for consideration and comparison.

Model	Supply Voltage	Active-Mode Current	Number of Operation Modes
MSP430G2210	1.8V to 3.6V	220 μA	5
ATtiny13	2.7V to 5.5V	240 μA	2
bq27200	2.6V to 4.5V	< 90 μA	5

Table 4.3.6.1 - Battery Status Controller Comparison

From the three considered parameters, we see that the MSP430G2210 consumes the less voltage needed for controller operation, while the ATtiny13 requires the most, above the readily available 5V pin from the power system. For the supply current needed for the controller to be in active, or turn-on, mode, the bq27200 uses a significantly less amount of current, compared to the MSP430G2210 and ATtiny13. This was desirable for channeling current to the controller without worry of drawing excess current through the rest of the gauge circuit. The number of operation modes was considered for use in application of when the battery status is actually being called upon.

The ATtiny13 has only two modes, active mode, and power down mode, which fulfill the basic “on” and “off” conditions for the controller. However, the MSP430G2210 and bq27200 have 5 modes of operation. In addition to active and power down mode, the bq27200 also features a hibernate and data retention modes, which are ideal for saving battery status data when low input voltage is applied to the controller, but still enough to be in a transient stage without yet being powered down. The fifth option, ship mode, could be ignored, as it only pertains to the controller’s status for manufacturing purposes. The MSP430G2210 also has 5 modes of operation, all being different stages of low power. With each level of input power decreasing, the MSP430G2210 has a mode that systematically shuts down particular features, such as certain timers or CPU operations, that may not be immediately essential for constant operations.

Comparatively, we chose the bq27200 for the FBC battery indicator controller. The operational supply voltage was in the ideal range provided from the internal power source, and the low supply current in active mode is extremely useful. Additionally, the bq27200 features a pin specifically for detecting overheating from the battery via a thermistor, which, when flagged, would decrease power to the controller, or shut it down completely.

The battery indicator circuit would be programmed to read a test current from the source lithium polymer battery when the push-button closed the circuit switch connecting the battery to the input pin. The corresponding output current at the pins connecting the 3 LEDs is 40 mA, so current-dividing resistors would be needed to limit the current down to 20 mA for the maximum forward current allowed by the LED. In this case, 100-ohm SMD 660-SL1TTE101J resistors would be sufficient. Once the test current was read from the battery, and the

corresponding signals turned on the correct LED indicators, the LED(s) should remain illuminated for a 5 second period, after which the controller would reset, and wait for the current reading from the battery when the push-button is pressed again. Figure 4.3.6.1 below demonstrates the SMD LED push-button battery indicator circuit, with current-limiting resistors and voltage-regulating Zener diodes included.

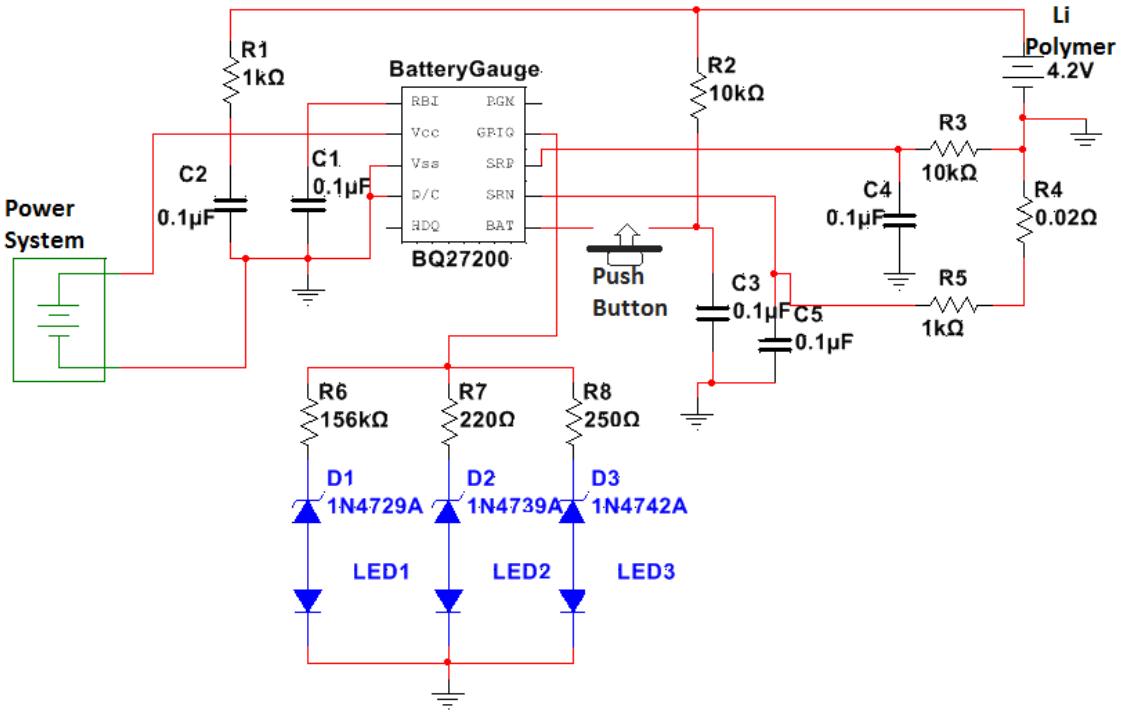


Figure 4.3.6.1 - Battery Status Indicator SMD LED Circuit

4.3.6.2 LED Circuit Revisions and Challenges

Reexamining the LED battery status indicator circuit led us to realize several flaws with the initial design, the largest having to do with the use of the IC. The bq27200 controller primarily functions to indicate the source battery's charge level independently, sending a signal as programmed to alert the user. However, it did not correlate with the designated LED's to visibly indicate a battery operating range. Thus, a simpler design was favored for the battery status indicator circuit, comprising of the three LED's signaled based on voltage dividing transistor circuits. The new design, as displayed in Figure 4.3.6.2, would still implement a push-button to send a test voltage signal directly from the battery to the circuit. LED 3 would always turn on, even at low battery levels, indicating that at most, 30% of the battery charge remained for operation. LED 1 and LED 2 would be turned on as long as a sufficient current turned on the base pin of the NPN transistor. If the voltage dropped below the designated voltage dividing circuit, the transistor would shut off, and the LED would not illuminate. Mistakes

not caught in the design phase of the project led to a PCB designed with a faulty LED battery indicator circuit. Initially, the obvious mistake was the misplacement of the push button, which was not placed before the first transistor circuit, thus resulting in constant voltage flowing from the battery to the circuit. The more serious error was in the values selected in the resistors for the voltage dividing circuit. Even though the resulting current at the transistor was correct, the initial current draw from the first resistors, R1 and R2, was much too high, ending with burnt out traces on the PCB. Given time constraints, and considerable focus on more prioritized components, we elected to cease repairing the battery indicator circuit and abandoned it altogether.

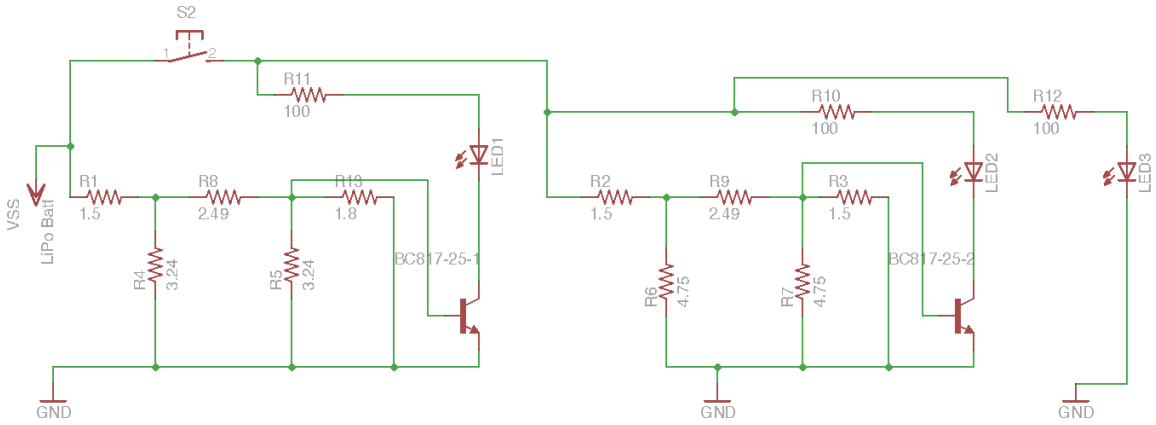


Figure 4.3.6.2 – Finalized LED Battery Charge Indicator Circuit

4.3.7 Switching Battery Chargers

In this design, we did not want the solar cell charger to be charging the source battery at the same time as the wall-charger. In effect, the solar charger was more of a secondary auxiliary charger, and the wall charger was to take priority when introduced to the system. To accomplish this, a relay circuit would be employed to switch from solar charging to wall charging when the USB charger is inserted to the power supply. For this, the KS2E-M-Series double throw relay would accomplish the task, with a switch voltage at the wall charger's 5-volt value. In functionality, the relay would have its power source, or its coil voltage, at the source input for the wall charger. Additionally, the double throw input pins would be set to both the wall charger circuit and the solar circuit, and the output pin to the lithium polymer battery.

Initially, when the wall charger is not in play, the coil voltage is at zero, and the relay circuit will be "open", connecting the solar panel charging circuit to the battery source. When the wall charger is introduced to the system, the relay coil will turn on, and the internal switch will "close", switching from the solar circuit connectivity to a direct connection between the wall-charging circuit and the source battery. Once the wall charger is removed, the relay will power down, and the switch will return to the solar charging circuit. Figure 4.3.7.1 below represents

the two charging circuits connected to the relay for connection to the source battery. Initially, the relay connected the solar charger to the battery, but when the wall charger was introduced, the relay's internal switch flips to break the solar circuit's connection with the battery, and establishes a connection between the wall charger and the battery.

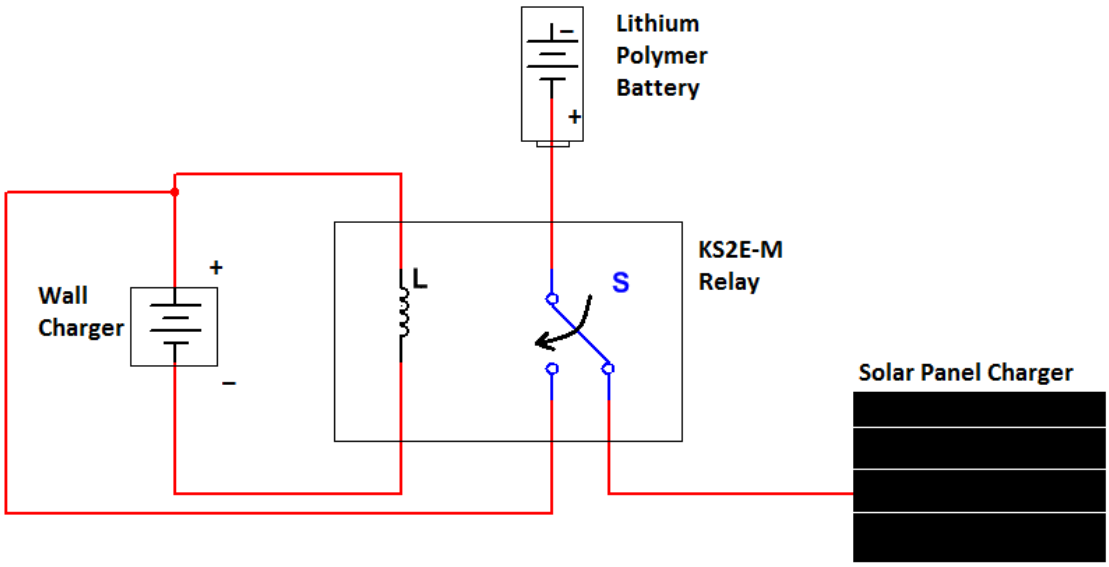


Figure 4.3.7.1 – Relay Switching Diagram

4.4 Final Case Design

4.4.1 Front Panel

The final front panel of the case built in SolidWorks is shown in Figure 4.4.1.1 and Figure 4.4.1.2 below.

Figure 4.4.1.1 – Final Design of Front Panel

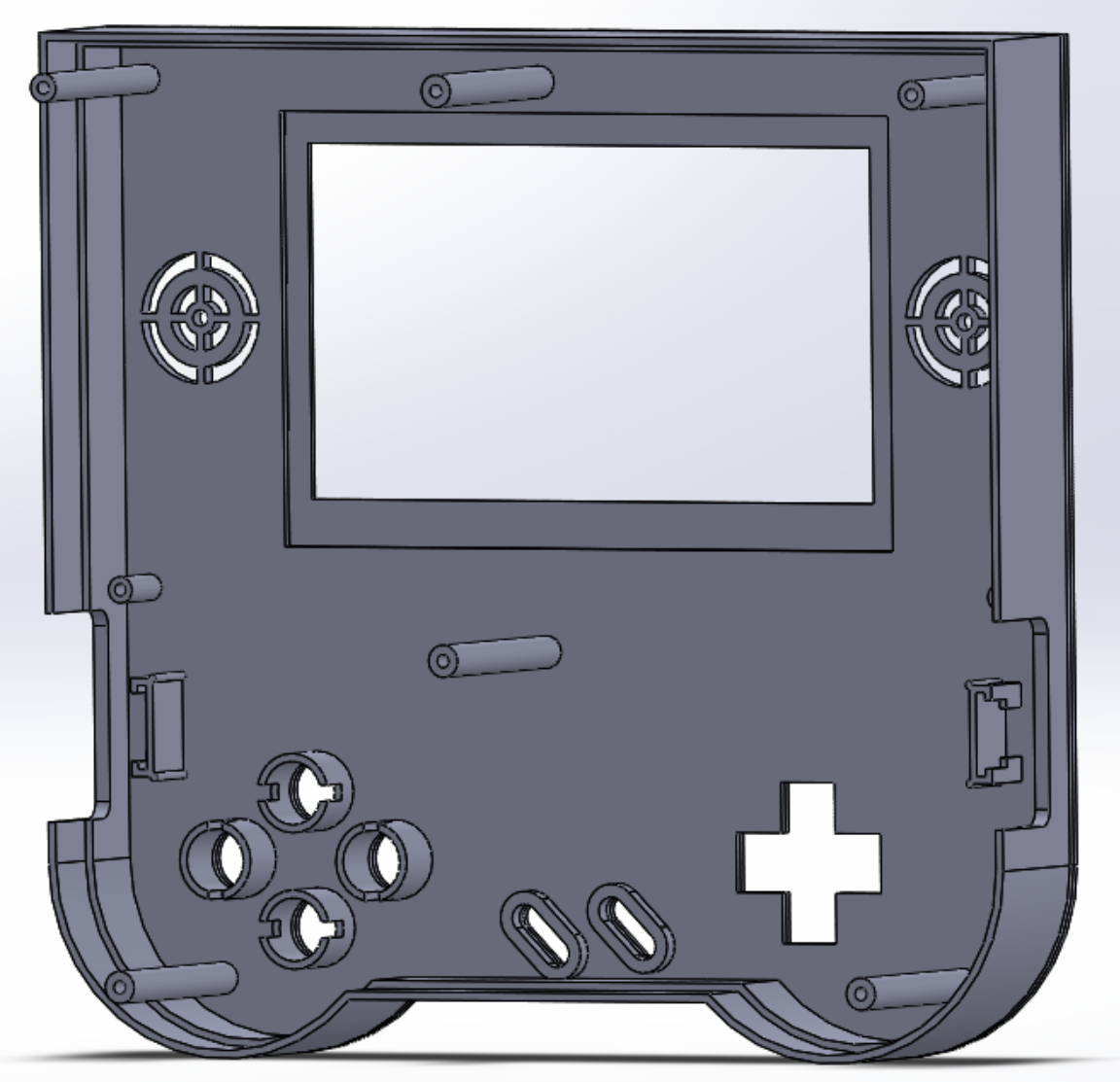


Figure 4.4.1.2 – Front Panel View from Inside

4.4.2 Back Panel

The final design of back panel built in SolidWorks is shown in Figure 4.4.2.1, Figure 4.4.2.2 and Figure 4.4.2.3 below.

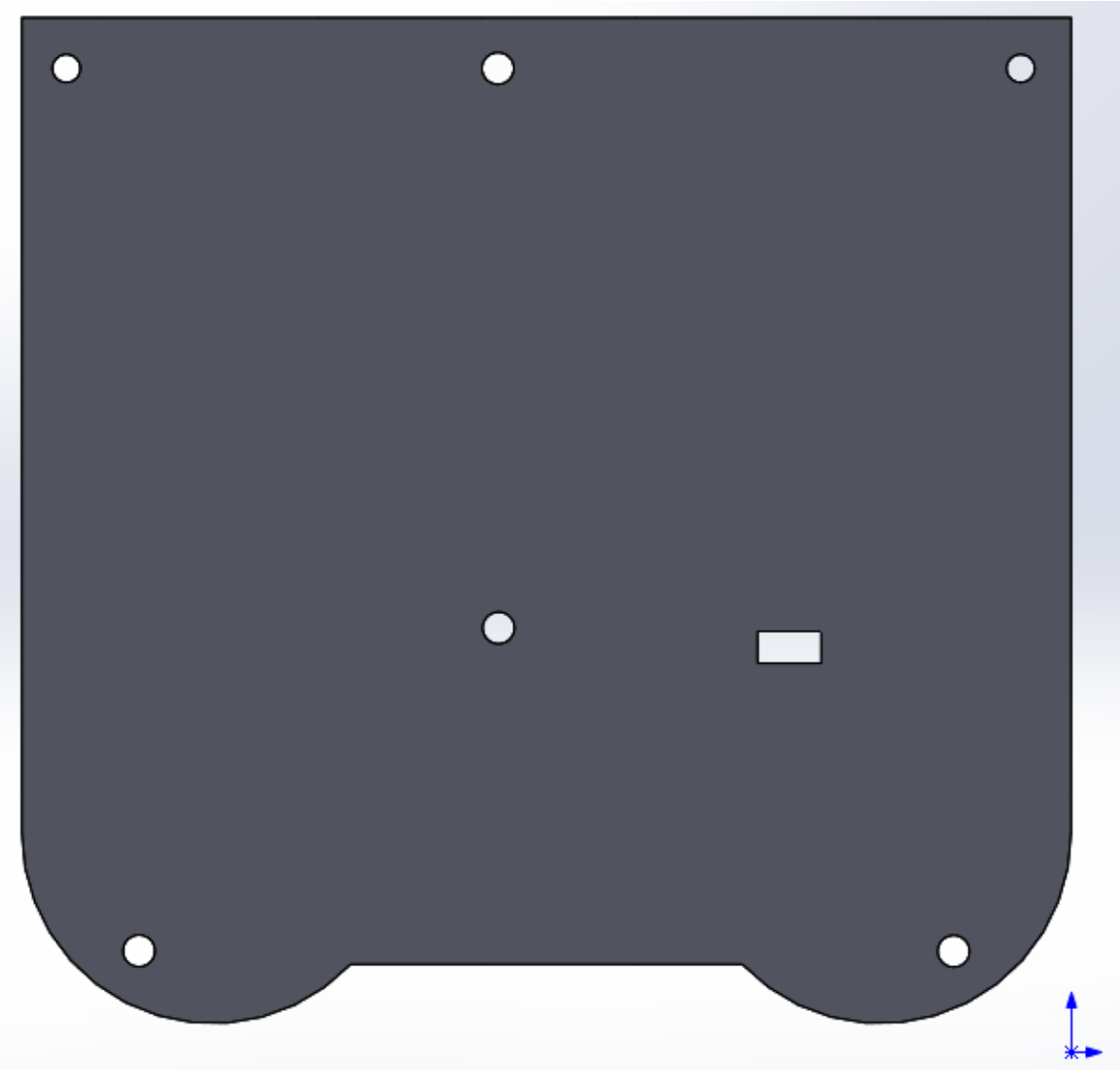


Figure 4.4.2.1 – Final Design of Back Panel

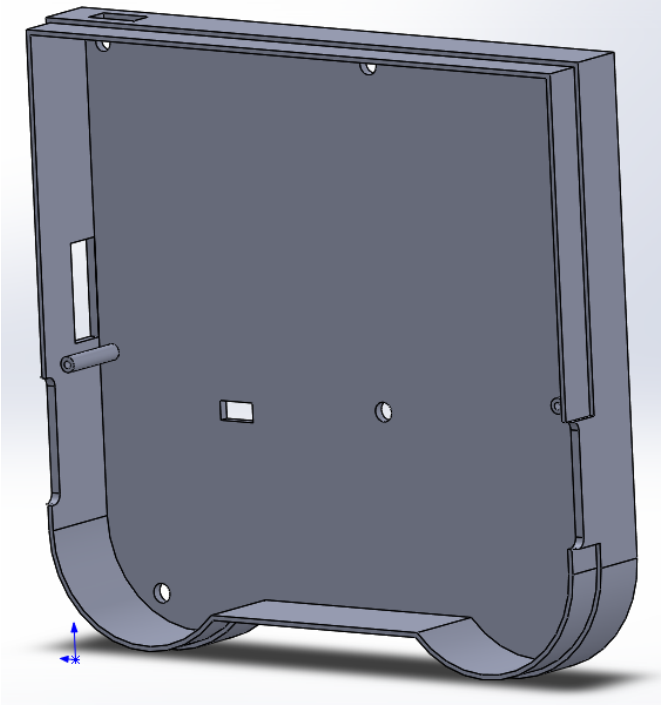


Figure 4.1.4.2 –Back Panel Inside View

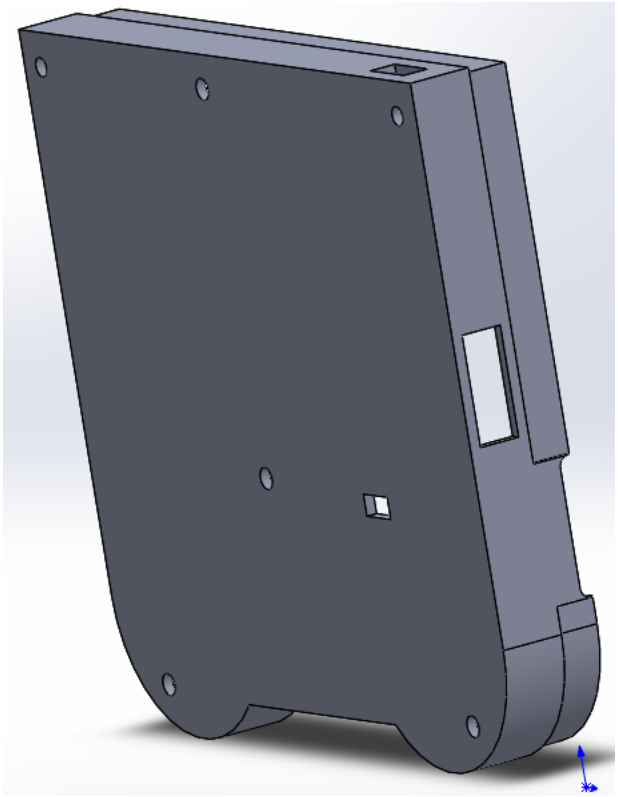


Figure 4.1.4.3 –Back Panel Side View

5. Prototype Construction

The prototyping of the project was incredibly important. We layed out an overall plan for acquisition and integration in order to ensure that the building of the FBC went as smoothly as possible. This section will first outline our plan for acquiring the hardware needed for the project, followed by a high level description of the integration of the various hardware components. A more in depth plan for combining the hardware components will follow the high level description of hardware integration.

5.1 Hardware Acquisition

Table 5.1.1 details the acquisition status for the hardware components for the project. If a project has not yet been acquired, a plan for acquisition was determined.

A full list of the hardware components that we needed is outlined in Table 5.1.2. This table lists the various hardware components that we have selected for our project and the amount that we needed for our project.

Component	Acquisition Status	Acquisition Plan
Resistors	Acquired	Order from DigiKey
Capacitors	Acquired	Order from DigiKey
Inductors	Acquired	Order from DigiKey
LEDs	Acquired	Order from DigiKey
LCD Screen	Acquired	
Raspberry Pi 2	Acquired	
ICs	Acquired	Order from DigiKey
Batteries	Acquired	Order from Adafruit
Plug Headers	Acquired	Order from DigiKey
Transistor	Acquired	Order from DigiKey
Buttons/Switch	Acquired	Order from DigiKey
PCB	Acquired	Order from OSH Park

Table 5.1.1 – Component Acquisition Information

Component	Quantity
Raspberry Pi 2	1
LCD Screen	1
RN4020	1
SLMD121H8L	4
BQ24210	1
105-2502-ND	1
LM4880	2
3352T	1
2500 mAh LiPo Battery	1
MCP73831	1
TPS61030	1
KS2E-M	1
BQ27200	1
MicroUSB Header	1
USB Header	1
Headphone Jack	1
PNP Transistor	1
SPDT Switch	1
PCB	2
Resistors	Assorted
Capacitors	Assorted
Inductors	Assorted
LEDs	Assorted

Table 5.1.2 – Component List

5.2 Hardware Overview

In this section we will reduce and integrate the various hardware modules to the best of our ability. The hardware modules contained in our system are the Bluetooth module, battery, solar charge module, wall charge module, power supply module, controller module, audio module, screen backlight control module, battery indicator module, the screen, and the Raspberry Pi 2. A high level design of the connection of these modules is shown in Figure 5.2.1. This design connects the smaller modules onto a single PCB which will connect with the Raspberry Pi 2, battery, and screen.

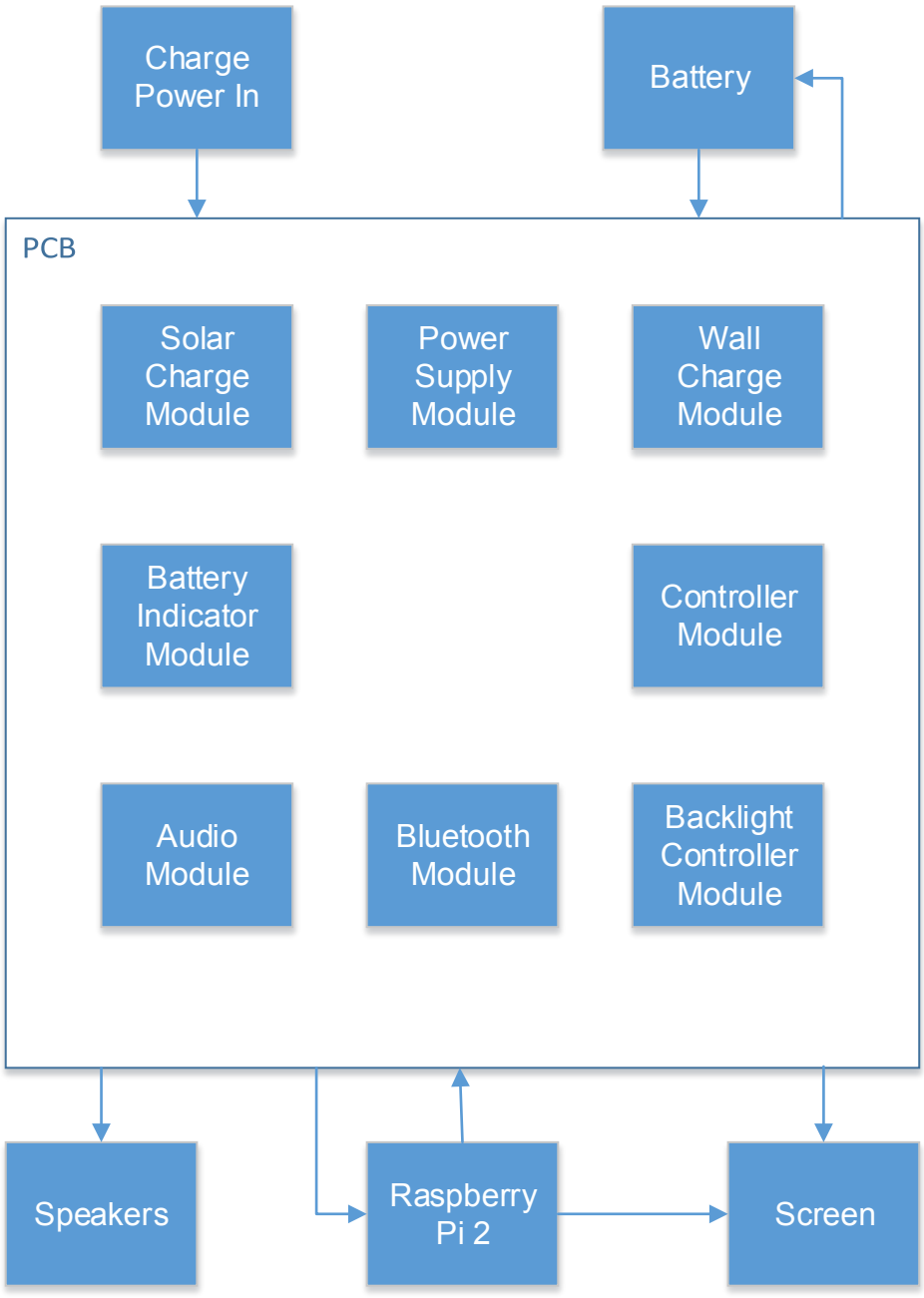


Figure 5.2.1 – High Level Hardware Integration

5.3 Hardware Integration

The actual integration of the hardware began with the design and acquisition of the PCB. The PCB integrated the solar charge module, wall charge module, and audio module. A Bluetooth dongle was added in place of using the Bluetooth chip because the RN4020 was determined to not work for our purposes. The power supply was moved to a separate PCB due to complexity in creating it.

5.3.1 PCB

The PCB connects to the Raspberry Pi 2, the screen, the battery, and external power. The PCB is small enough to fit in a portable case. It is shown in Figure 5.3.1.1. Our goal in this section is to determine how we would design the PCB and how we would acquire the PCB that we designed. Additionally, another PCB was created for the power system due to the TPS61030 being a very complex chip. This PCB is shown in Figure 5.3.1.2.

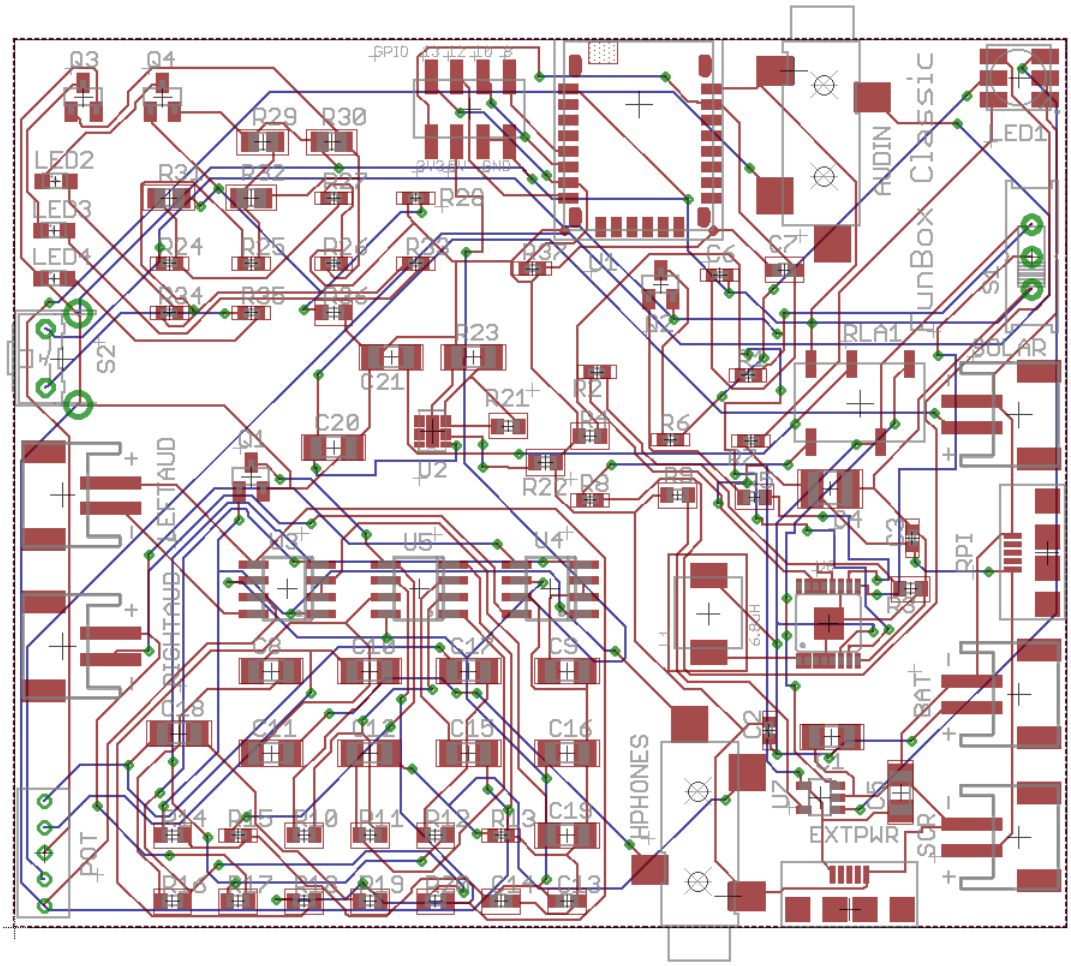


Figure 5.3.1.1 – FunBox Classic Initial PCB Design

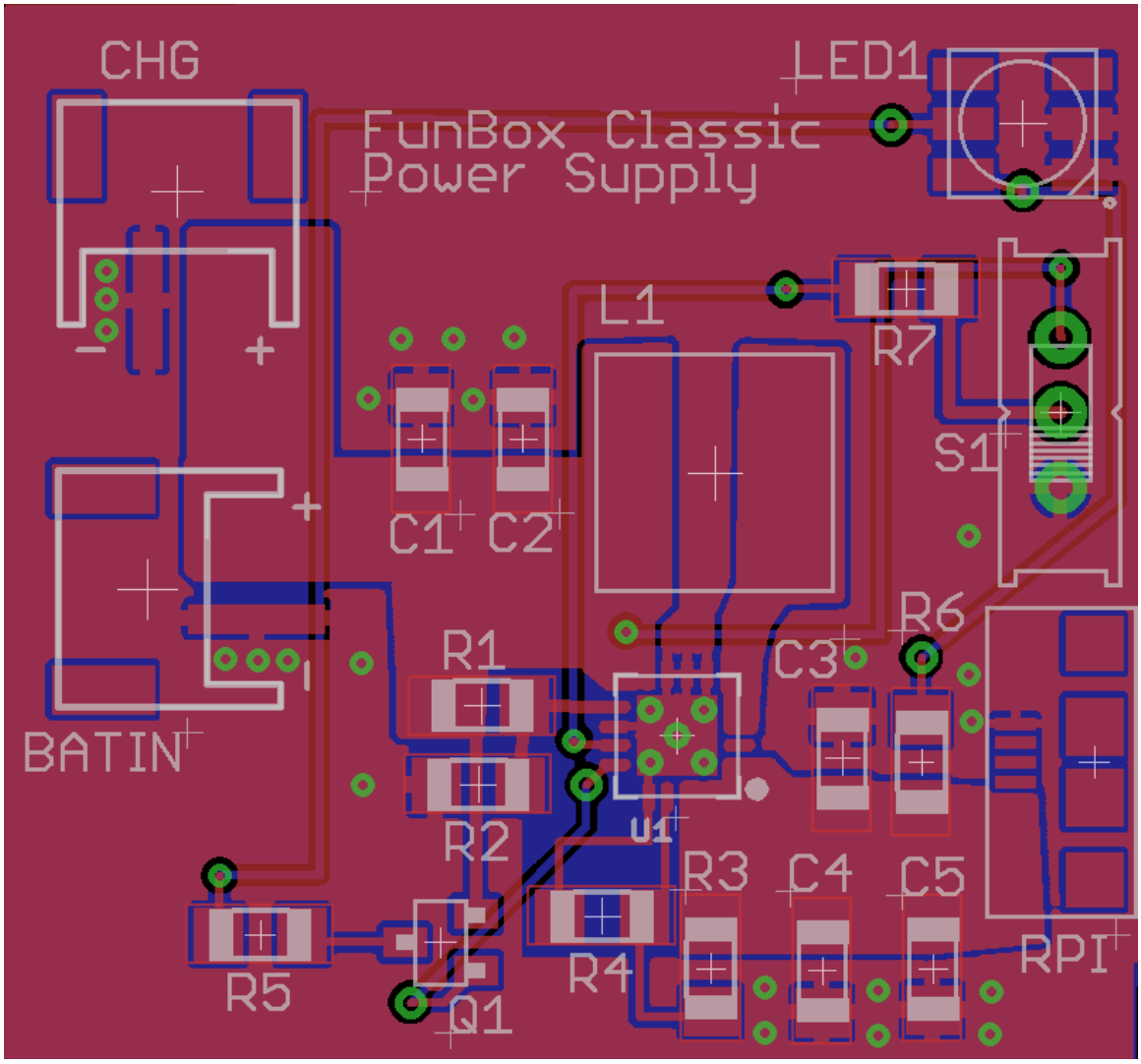


Figure 5.3.1.2 – FunBox Classic Power Supply PCB

5.3.1.1 Design

CADSoft Eagle is the most common software used in PCB design. There are a few other options that we explored, such as Fritzing, but ultimately we settled on making our PCB in the tried and true environment of Eagle. Eagle contains libraries of many components and also allows users to make their own components.

We gave our best efforts to make the PCB as minimalistic as possible in Eagle in order to preserve the portability of our system. Additionally, the PCB has all necessary connections to the battery, Raspberry Pi 2, and screen easily accessible on the sides of the PCB.

Figure 5.3.1.2 shows the modules on the PCB interconnected and connected to the hardware components not on the PCB.

5.3.1.2 Acquisition

After designing our PCB in Eagle we needed to order the PCB. There are many manufacturers that will make and ship PCBs when sent designs. We decided to order our PCB from OSH Park. OSH Park boards only cost $5 per square inch for 3 copies of a dual layer PCB. This is a reasonable price and left us with two extra PCBs to work with if the first one becomes damaged. We estimate the board to be 5 square inches or less. This will result in the cost of the PCB being $25 or less. OSH Park ships within 12 calendar days of ordering, which will allow us to begin testing our PCB in a timely fashion.

5.3.1.3 Mounting

We tinned the leads on the PCB and placed the surface mount components on them. We then used a hot air gun to reflow the solder on the PCB to attach the surface mount components to it. Additionally, Quality Manufacturing Services in Lake Mary, Florida was very helpful in populating the bigger PCB.

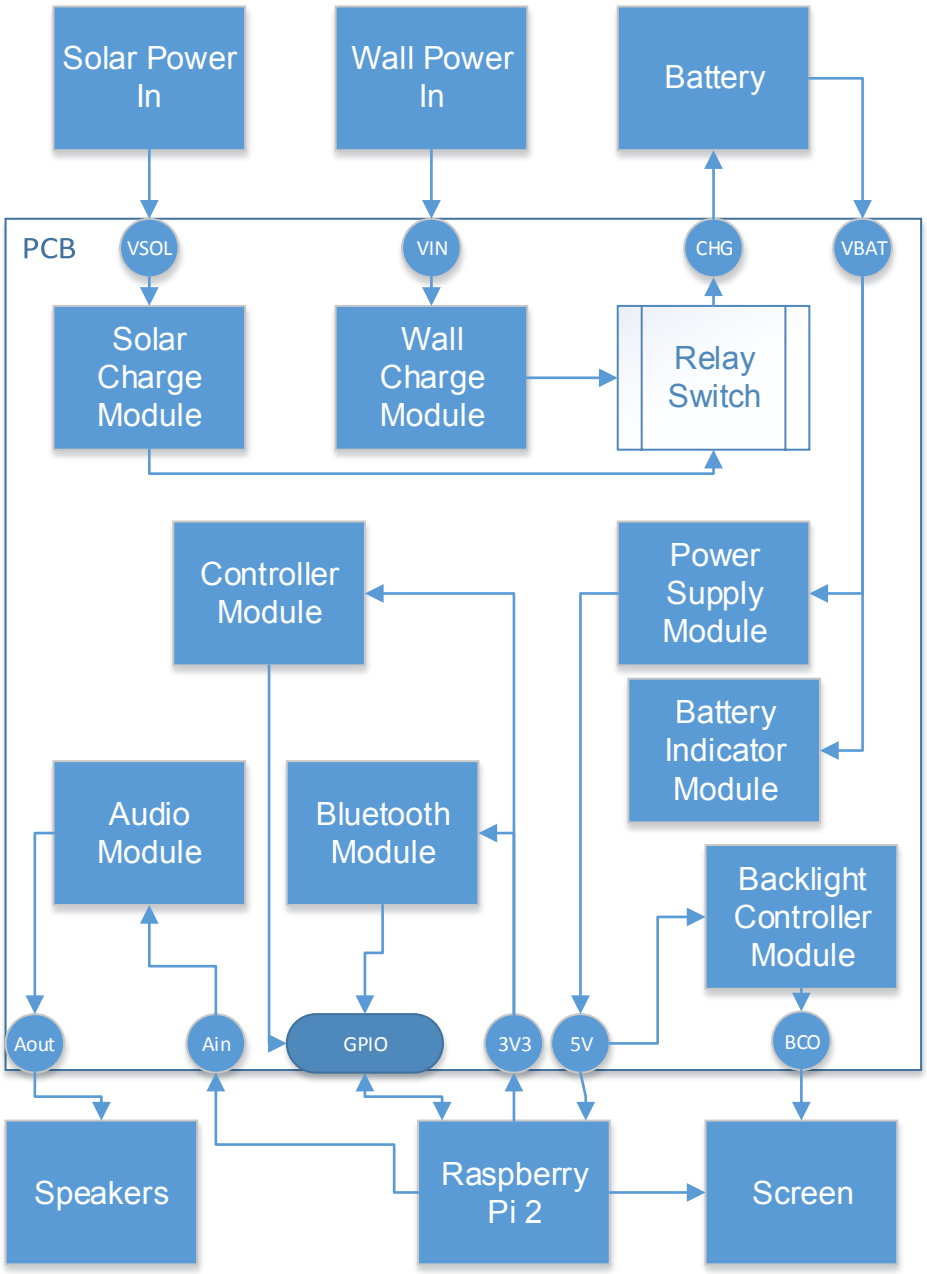


Figure 5.3.1.2 – High Level PCB Design

5.4 Software Overview

As seen in Figure 5.4.1, at boot the Raspberry Pi automatically loads the EmulationStation GUI. From there, user input from the controller, either external or internal, will choose the option desired: either an emulator or the settings application. From there the user can choose to use the emulator to play a game, change settings as desired, or return to the main GUI menu.

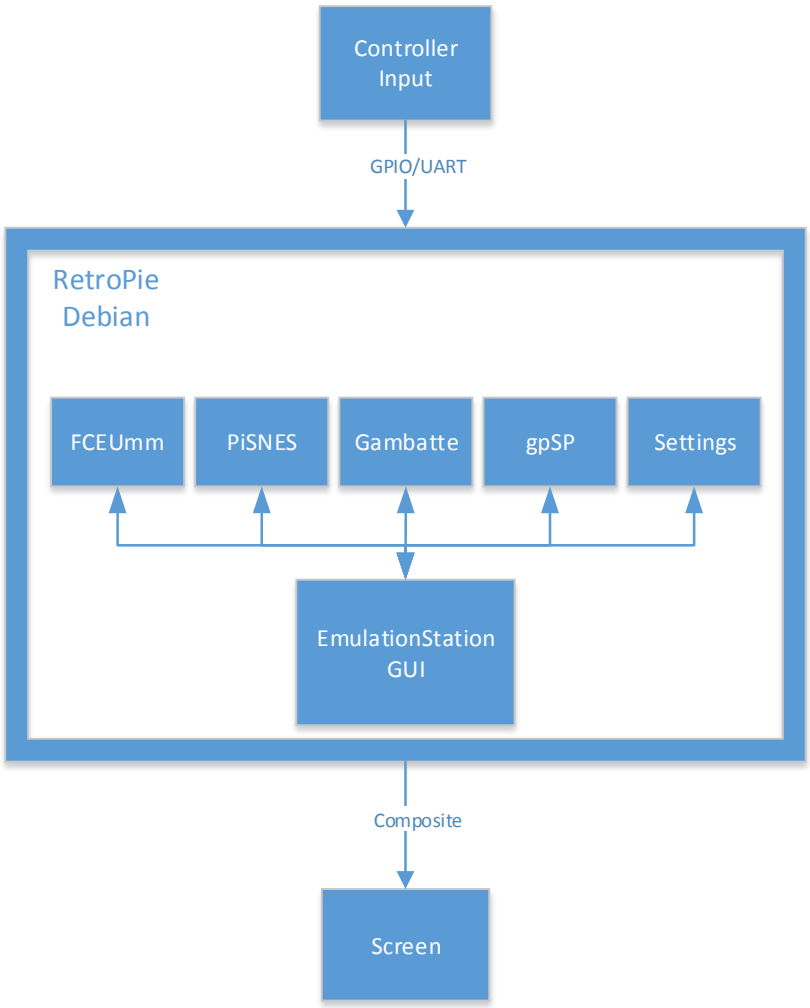


Figure 5.4.1 – Software Flowchart

5.4.1 Software Acquisition

In order to acquire our software, we performed the following steps:

1. Downloaded the latest Raspbian build (Debian Wheezy 3.18) from raspberrypi.org
2. Downloaded the latest RetroPie build (Version 3 BETA 2) from blog.petrockblock.com/retropie/retropie-downloads/
3. Used the installed software to download the emulators.
    a. Gambatte, PiSNES, gpSP, FCEUmm.
4. Downloaded SNESDev, a controller handler.
5. Acquired game images (ROMs) by using a modchip on each console to rip the games from their original cartridges.
6. Acquired system BIOSs by using a modchip on each console to rip the BIOS from its respective console.

5.4.2 Software Integration

In order to implement the software into our project, we performed the following steps:

1. Wrote the disk image file of Raspbian to our MicroSD.
2. Ran Raspi-Config to expand filesystem and enable overscan, as well as default output to the composite video.
3. Installed RetroPie on our Raspbian build
4. Ran the RetroPie setup script to enable easy download and installation of emulators.
5. Installed emulators.
6. Installed SNESDev.
7. Rebooted the system to load the device stack.
8. Inserted a blank USB drive to copy file structure of ROM folder automatically.
9. Copied ROMs to USB drive and replaced it in the FBC to copy test ROMs to FBC's MicroSD card.
    a. Non-removable after final assembly, thus this method is necessary
10. Confirmed basic functionality.

6. Prototype Testing

Extensively testing our prototype was exceedingly important to ensure that it worked properly during its prolonged use and in standard operating conditions. In order to best determine what parts may be causing issues we decided to test the device modularly. First we tested each hardware module individually. Then we tested the software. After the hardware modules and software were both shown to work properly they were added piece by piece to the device to test if they still work. Finally, the final combined prototype was tested. This testing method allowed us to pinpoint issues as they came along.

6.1 Hardware Testing

We tested each hardware module that was to be placed on the PCB. We also tested the battery, Raspberry Pi 2, speakers, screen, and charger. All tests were run in standard operating temperatures and normal lighting. The tests were performed in such a way as to allow insight into why a particular component may or may not work in order to help our troubleshooting process.

6.1.1 Raspberry Pi 2

In order to test the Raspberry Pi 2 we first simply plugged it in and saw if it turned on and output to a known working screen. If the Raspberry Pi 2 failed to turn on or output to the screen we would have known that it needed to be fixed or replaced prior to it being used as the workhorse for our project. Additionally, the RP2 has two built in test points labeled TP1 and TP2. Measuring the voltage drop from TP1 to TP2 should give a value between 4.75 and 5.25 volts. If the voltage shown is outside of that range the power being provided to the device may be the issue. TP2 can also be used to test the F3 Polyfuse on the RP2. If the voltage from one side of the F3 Polyfuse to TP2 differs from the voltage from the other side of the F3 Polyfuse to TP2 by more than 0.3 volts the polyfuse is most likely broken.

6.1.2 Screen

We tested the screen in two ways. First we tested the screen to make sure that it turned on and wakes upon receiving a video signal. If the screen worked we then attached various devices to the screen and compared the visual on the screen with the visual on a known working screen.

The screen was first tested using the composite input and power cable that it came with. The power cable on the screen will be connected to a standard 12-volt power supply. Both composite video inputs were tested by connecting to the composite video output of a known working Raspberry Pi 2. If the screen turned on and displayed the output of the Raspberry Pi 2 it was considered functional. If not it was determined faulty and a new screen needed to be acquired.

Next, the screen was tested using the composite input to connect to a Raspberry Pi 2, a Super Nintendo, and a Nintendo 64. These same devices were connected to a known working screens composite input and visually compared with the screen for our device. If there are any major discrepancies in the output visuals we found ways to fix them or got a different screen.

After the screen was removed from its case and no longer had its composite cables or power cable we tested the device in a different manner. We salvaged the composite video connectors from the old cables of the screen and use them to build an adapter on a breadboard. This way we were able to connect the adapter to the composite pins on the screen circuit board and tested different devices using the adapter. We also created an adapter for powering the screen in a similar fashion, but due to the bypassing of the regulator on the screen circuit we supplied the screen with 3.3 volts instead of 12 volts.

6.1.3 Wall Charge Module

The wall charge module was tested before the battery so that the battery would have a working charger to test with. The wall charge module was tested by attaching it to a known working mostly drained LiPo battery and a known working USB cable and wall adapter. The charge module was tested to ensure a few different things. The charge module was first tested to see if it would charge the battery properly. The charge module was then tested to ensure that the overcharge protection was working properly.

In order to test if the charge circuit properly charged a battery the first thing we tested was if the circuit output the correct constant current during the first part of the charge cycle. If the current output of the chip was not close to 500 mA then something was wrong with the circuit and it needed to be troubleshot. After the current output was determined to be correct the battery was be charged for 30 minutes. The battery was then tested for a change in voltage across its positive and negative terminals. If the voltage had not increased the charger circuit needed to be fixed. The battery was then reattached to the charger. The voltage output of the device was monitored while the battery charged. Once the voltage output reached the set limit of 4.2 volts the voltage should not have increased any further. If the voltage stayed at 4.2 volts then the constant current/constant voltage charging portion of the circuit worked properly.

In order to test for overcharge protection we continued the charging of the battery from where we stopped testing to see if the charging portion of the circuit worked properly. We began by measuring the output current instead of the voltage. The current should steadily decline until it reaches 5% of the charge current, around 25 mA. If the current continued below 25 mA then the overcharge protection was not working properly and needed to be fixed. If the current drops to 0 from 25 mA then the battery was removed from the charging circuit. The voltage across the

battery was tested. If it was 4.2 volts the overcharge protection of the charge circuit worked. If it was not 4.2 volts the circuit needed to be looked at and possibly reconfigured.

6.1.4 Battery

The testing of the battery was broken into two sections. First, the battery was tested to ensure that it charges properly, discharges properly, and retains charge properly. Second, the internal overdischarge protection circuitry of the battery was tested to ensure user safety in the end product. These tests determined whether the battery met our needs or not.

6.1.4.1 Battery Characteristics

The battery characteristics test had 3 parts: charging, discharging, and charge retention. The order of these tests depended on the initial state of the battery when it was ready for testing. So the very first step was to check the voltage across the battery. If the battery was fully charged, 4.2 volts, the first test was charge retention, second discharging, and finally charging. If the battery was initially discharged, <= 3 volts, the first test was charging, then charge retention, and then discharging. If the battery was somewhere in between it followed the same format as if it were initially discharged.

Testing charging was started by measuring and recording the voltage across the battery. The battery was then hooked up to a known working charging circuit. The battery was charged at a rate of 1/5 charge capacity for 30 minute. If the battery voltage had not changed the battery was faulty.

Testing discharging was also started by measuring and recording the voltage across the battery. The battery was then hooked up to a simple discharge circuit through a resistor to drain the battery at a rate of 1/5 charge capacity for 30 minutes. If the battery voltage had not changed the battery was faulty.

Testing charge retention was yet again started by measuring and recording the voltage across the battery. The battery sat isolated for 24 hours. If the voltage had not changed more than a very small amount then the battery was faulty.

6.1.4.2 Internal Overdischarge Protection Circuit

The internal overdischarge protection circuitry was tested by draining the battery normally until it reached a voltage of 3.1 volts across its terminals. Then the battery was carefully drained until it reached 3 volts. If the battery continued to drain the internal protection circuit was faulty.

6.1.5 Solar Charge Module

The solar charge module was tested in a very similar fashion to the wall charge module. A known working mostly drained LiPo battery was connected. The solar charge module was tested to determine if it charged the battery correctly. The solar charge module was then tested to determine if the overcharge protection was working properly.

In order to test if the solar charge circuit properly charges a battery the first thing we tested is if the circuit outputs the correct constant current during the first part of the charge cycle. If the current output of the chip was not close to 200 mA then something was wrong with the circuit and it needs to be troubleshot. After the current output is determined to be correct the battery will be charged for 30 minutes. The battery was then tested for a change in voltage across its positive and negative terminals. If the voltage had not increased the solar charger circuit needed to be fixed. The battery would then be reattached to the charger. The voltage output of the device was monitored while the battery charged. Once the voltage output reached the set limit of 4.2 volts the voltage should not increase any further. If the voltage stayed at 4.2 volts then the constant current/constant voltage charging portion of the circuit worked properly.

In order to test for overcharge protection we continued the charging of the battery from where we stopped testing to see if the charging portion of the circuit worked properly. We began by measuring the output current instead of the voltage. The current should have steadily declined until it reaches 5% of the charge current, around 10 mA. If the current continued below 10 mA then the overcharge protection was not working properly and needed to be fixed. If the current dropped to 0 from 10 mA then the battery was removed from the charging circuit. The voltage across the battery was tested. If it was 4.2 volts the overcharge protection of the charge circuit worked. If it is not 4.2 volts the circuit needed to be looked at and possibly reconfigured.

6.1.6 Power Supply Module

The power supply module was first tested to make sure that the module does not output any voltage when the power switch is off. Next it was tested when on to ensure that the voltage output of the power supply was a regulated 5 volts no matter what the voltage across the battery currently was. The last test of the power supply was to ensure that the low battery LED turned on and that it did so at the correct time.

The power switch simply switches the enable pin on the DC-to-DC converter chip between VBAT and ground. First, without the battery connected, we will use a multimeter to check for continuity between the enable pin and ground when the switch is off and to check for continuity between the enable pin and VBAT when the switch is on. Then the same test was done in reverse to ensure that the switch was not bridged. The battery was then be connected with the power switch off. The output voltage of the power supply should have been 0 volts. If it

was not then the power supply module was not working properly. Next the power switch was turned on. The output voltage of the power supply should have been 5.2 volts. If it was not very close to 5.2 volts then the power supply module is not working properly.

Now that we had determined the power supply puts out 5.2 volts, we needed to test it with the different voltages the battery will reach in a charge/discharge cycle. The battery was charged to 4.2 volts and connected to the power supply and the switch was turned on. If the output voltage was not 5.2 volts the power supply is malfunctioning. If the output voltage was 5.2 volts the power supply was working properly. Next the battery was discharged to 3.3 volts and connected to the power supply. If the output voltage was not 5.2 volts the power supply was malfunctioning.

The last test was to check that the low battery indicator works properly. The low battery light is supposed to turn on around 3.25 volts. The way to test this was to drain the battery to around 3.3 volts and then hook it up to the power supply and see if the light turned on. If it did it needed to be reconfigured. If it did not, disconnect the battery from the power supply and discharge down to 3.25 volts. Reconnect to the power supply and see if the light turned on. If it did not it is malfunction. If it did then the low battery indicator is working.

6.1.7 Battery Indicator Module

The batter indicator module will be tested by charging and draining a battery while attached to the battery indicator circuit. After the battery has fully charged we will drain the battery at 1/5 capacity for an hour. If the battery indicator does not show around 80% then it is malfunctioning. Likewise, this test will be performed hourly until the battery is drained, subtracting 20% capacity for each hour of the test.

This was the plan before the battery indicator circuit was found to be incredibly flawed and was ultimately removed from the project.

6.1.8 Backlight Controller Module

The backlight controller module will be tested by attaching it to a known working screen and utilizing the buttons to increase and lower the brightness. If the brightness of the screen does not change then the module is malfunction. Otherwise, the backlight controller module is functioning as desired.

This was the plan but the backlight controller module was never designed and was ultimately removed from the project.

6.1.9 Bluetooth Module

The Bluetooth module will be tested by connecting it via UART to a known working Raspberry Pi 2. We will then attempt to connect a variety of Bluetooth devices (controllers, keyboards, mice) to the Raspberry Pi 2. If the devices find the Raspberry Pi 2 and vice versa then the Bluetooth module works. Otherwise the Bluetooth module needs to be fixed.

This was the plan until the Bluetooth chip was found not to work for our needs and we had to instead use a Bluetooth dongle in the USB port of the RP2. We tested this by connecting a Bluetooth controller to it.

6.1.10 Controller Module

The controller module will be tested by connecting it to the GPIO pins of a known Raspberry Pi 2. First we will make sure that the controller is recognized by the system. Once the controller has been recognized by the device, we need to make sure that each button works as intended. Once all buttons have been tested and configured, a game needs to be played on the Raspberry Pi 2 using the controller to make sure that the response time of the buttons is adequate for the games being played, and that the controller does not suffer from noticeable ghosting.

This was the plan until we decided to instead connect the controller via USB. We tested by configuring all the buttons on the RP2. If all the buttons were recognized the controller worked.

6.1.11 Speakers

The speakers were tested by connecting them to a known working amplifier and attempting to play some audio through them. If no sound came out then the speakers were faulty. Otherwise the quality of this audio was compared with the quality of audio output from other portable game consoles. If the speakers were of a similar or better quality then they were considered working. Otherwise they were considered faulty or inadequate.

6.1.12 Audio Module

The audio module was tested by connecting it to a known working composite stereo sound output and a known working pair of 8 ohm speakers. If the speakers did not correctly output the composite sound, then the audio module was faulty and needed to be fixed. If the speakers did output the correct sound then the volume control was tested by moving it up and down to change the audio output volume. If the level of sound did not change then the audio module was faulty and needed to be fixed. If the level of sound did change then the audio module was considered working.

6.2 Software Testing

We made use of both premade tools within the system as well as our own senses and knowledge to test all important aspects of the software. All tests were run with the system in standard operating temperatures with adequate lighting for the screen, to reduce hardware bias.

The premade tools allowed us to test things that we can't judge with sight and sound alone, such as framerate. These were the most objective tests, as they relied on quantitative analysis.

Using our own senses allowed us to test things that cannot be judged purely quantitatively, such as artifacting. The metric for these tests were simpler: if it looks or sounds wrong, it fails.

6.2.1 Emulator Tests

For each emulator, we tested three games. The first will be a low end game, the second will mid to high end game, and the third will be a high end game, pushing one or more aspects of the system to its limits.

In this way we ensured that the entire spectrum of games were supported, with a few exceptions that, for example, did not follow Nintendo's programming guidelines.

For general testing, each game was checked for framerate, resolution, graphics artifacting, and audio glitches. Special features of each console, such as the SuperFX chip for the SNES, was also checked.

Games must reach a minimum of 50 frames per second, which is the requirement for PAL games. NTSC games will be required to output at no less than 59.97 fps. Additionally, all games must display at full resolution (or higher) with no cutoff portions. Graphics must be free of artifacts to the point that the gaming experience is not interrupted. Audio must be free of glitches such that the music feels consistent.

Additionally, we tested the basic functions and usability of the GUI for the system, ensuring proper operation at all times.

6.2.1.1 Game Boy

For the Game Boy, the first game we tested will be Pokemon Red Version. Graphically non-taxing as it was, this was a solid game that spawned an empire. The graphics and the audio are immediately recognizable to almost anyone in our generation, making testing for accuracy easy.

Donkey Kong Land was the second game tested. This game was an attempt by RARE to capture the spirit and style of the SNES Donkey Kong as accurately as possible. With detailed sprites and animation that simulated a 3D experience, this game is technologically demanding and visually pleasing. Additionally, we had experience playing this game, and thus knew what to look for when it comes to testing.

Finally, we looked into a little known title called Faceball 2000. This is a port of an Atari multiplayer shooter, which resembles a very low quality version of Doom. With pre-rendered graphics, convincing pseudo-3D, first person view, and the insane support for 16-player deathmatch, this is a game that truly pushes the Game Boy to its limits.

6.2.1.2 Game Boy Color

We started off with a non-taxing, but still well made and excellent game: The Legend of Zelda: Oracle of Ages. This game did not have much in the way of technical requirements, but easily recognizable graphics and iconic sound from the Zelda franchise will make emulation mistakes easy to spot. We'd also like to test the "Game Boy Advance" special features, which are only accessible on a Game Boy Advance, to see if our system can fake that.

Cannon Fodder was a relatively obscure port of an Amiga game which, while most of the game wasn't anything special, had one main feature that set it apart. It had a PC quality full motion video to open the game, and used the largest cartridge size possible to store that. Many emulation systems have trouble emulating this video properly, due to the hardware wizardry required to have it work on a small system like the Game Boy Color. We think this will serve as a good, midrange stress test for our system.

Shantae was the final game we will test for the Game Boy Color. Commonly cited as one of the best games to come out of the GBC's final years, Shantae combines color and animation on par with early GBA games with advanced lighting and scaling effects, as well as a rich and detailed soundtrack. These make the game perfect for pushing our emulated system to its absolute limits

6.2.1.3 Game Boy Advance

Wario Ware Inc. Mega Microgame$ started off our tests. Simple graphics, simple layering, simple audio, this game was maddeningly fun but by no means pushed the hardware to its limits. The gameplay is simple as well, taking place with 5 second long microgames, getting faster and faster as you progress. It will be easy to see if the game is being emulated properly just by measuring game time. If it's not the full five seconds, the game is clearly not being emulated properly and is experiencing slowdown.

Advance Wars 2: Black Hole Rising was a turn-based tactics game. It has simple graphics, but with advanced use of graphics layers as well as an AI that has to consider every possible move on a “board” far larger than a chessboard, the game still manages to tax the system. Two of the biggest things we will be testing with this game is the accuracy of the AI compared to the original system and the speed with which it computes optimal moves.

The Castlevania: Double Pack was our final test game under the GBA. It combines two complex games, Castlevania: Harmony of Dissonance and Castlevania: Aria of Sorrow into one cartridge, increasing emulation complexity. With fast platforming, rich soundtracks, and gorgeous graphics, these games pushed the GBA to its limits. One thing we will be checking in particular with this title is the ability to properly load each game into memory, without sector overlap. This has been an issue with non-x86 emulation in the past, and we hope to make sure that is not the case here.

6.2.1.4 Nintendo Entertainment System

For the NES, you have to start with Super Mario Bros, one of the most iconic and beloved games of all time. Simple graphics, quick and easy gameplay, and a classic soundtrack, this game won’t push the system by any means. It lacks the memory mapper chips of other, later NES games, making emulation easy by comparison. The main thing we will be looking at is if it controls as tightly as the original game, as the graphics and sound should be a non-issue. Additionally, we will check to make sure original glitches, like the Minus World, are present, as these will mean that the game is being emulated perfectly. There’s no better way to check imitation than to see if the same bugs are repeated.

The Legend of Zelda comes up next. Fitting a massive world into the space of a normal NES cartridge just wasn’t possible, and so this game was one of the first to take advantage of the MMC1 expansion chip. It allowed save games, a rarity at the time, multi-directional scrolling, and a greater ROM size. As a result, emulation complexity increased substantially. With a rich and varied soundtrack, smooth graphic transitions, and the ability to support many enemies on screen at once, we feel this is a good game to test the mid-range capabilities of the NES. We will mainly be making sure that the memory mapper emulation capability works as intended, as the graphics and sound will most likely not be an issue beyond that.

Kirby’s Adventure was a game that truly pushed the limits of the NES. First off, the largest cartridge of the NES, 6Mbit, was designed specifically for this game. Second, it used the MMC3, a more advanced version of the MMC1 which also implemented a scanline based IRQ counter that made layered scrolling easier, and even more ROM in the form of additional banks. This game could not be fully contained even on the largest cartridge available. Additionally, it pushed 8-bit

graphics to their limits, with rich color, smooth animations, and even advanced features like parallax scrolling. This game pushed the system to its limits, and we are eager to see if our system can handle this game while continuing to run at full speed and with no issues.

6.2.1.5 Super Nintendo Entertainment System

Unlike the other controls, which either had one or no hardware add-ons, the SNES had eleven different types of so-called “enhancement” chips, ranging from trigonometric calculations to full simulated 3D graphics. The difficulty in emulating these various co-processors led to less accurate emulation for years while figuring out their inner workings. Additionally, the SNES uses advanced graphics rendering techniques, like Mode 7, which are not easy to duplicate. The SNES testing will mainly focus on making sure these capabilities function.
Tools built into EmulationStation and the RetroPie core of the FunBox Classic will allow us to test each emulator for its accuracy and speed in games on the system.
We will use the framerate monitor in EmulationStation, the resolution measurement capabilities of the RetroPie core, and use the logging capabilities of each emulator.

We started with Chrono Trigger, widely considered one of the best games of all time. With crisp graphics, a beloved soundtrack, and an advanced battle system, Chrono Trigger still holds its own against the games of today. However, we placed it in the low-end category due to its lack of any enhancement chips or special features beyond the base SNES gameplay. This is one of the finest, if not the finest, example of what a technically “low-end” game can be and its proper operation on our system is a must.

Star Fox was a shooter, although not your typical one. It was one of the first console games to adopt and take advantage of 3D polygons. This feat, before only accomplished by coin operated arcade machines dedicated to that purpose, was made possible by the use of the Super FX chip. This graphics co-processor enabled true 3D graphics, albeit very low resolution ones. As a result, the rest of the system was free to handle the non-graphics tasks, and it made for a very fast paced game. The accuracy in emulating the Super FX chip will be our primary test here. Any kind of polygon artifacting or other error will result in a failure for this test.

Finally, we came to easily the most advanced game on the SNES: Star Ocean. Released only in Japan, this game combined tried to fit 48Mbits of data into the largest available SNES cartridge of 32Mbits. This was only made possible through the use of the S-DD1 enhancement chip, which handled on-the-fly decompression of game assets. This chip was so difficult to emulate that, up until very recently, additional graphics packs had to be included with game rips for proper emulation. It used software drivers to overcome the 64Kbit limit of the

onboard SPC700 sound chip, swapping bits in and out of the chip to greatly increase the level of audio quality. This is never more evident than in the fact that it was able to support full surround sound in those 64Kbits. In addition, it did its Mode 7 graphics processing using software tricks and not the onboard graphics. This allowed a much greater range of effects than the chip was limited to.

As a result of all of these hardware and software tweaks, this was easily the most difficult system to emulate on our list. We extensively checked for errors in graphics processing, such as not fully decompressed graphics, to make sure this game operates properly. In addition to testing all capabilities of the chip, we applied the unofficial English translation from DeJap to the ROM. This ensured that our system played “unofficial” games in addition to 1:1 rips.

6.2.1.6 EmulationStation GUI

To make the EmulationStation experience enjoyable, we needed to make sure that logos and such are clearly visible. To that end, we tested visibility and usability.
One of the first things we needed to test is overscan or underscan. This was a very real issue for the device, as it is using a composite output. As a result, it was necessary to see if any graphics or text are being cropped and to adjust accordingly.

Additionally, we needed to test readability. EmulationStation outputs at 720p by default, clearly a far larger resolution than our screen supports. Additionally, with a 4:3 aspect ratio on a 4.3” screen, we expected the text to be somewhat small after scaling. We checked to make sure that all text, be it for settings or other areas of information, are completely legible and easy to make out for any potential user.

We, of course, also tested whether or not the control scheme for our internal controller works properly and fluidly with the GUI. Ideally it should have been seamless, with none of the lag so often associated with pulling someone out of an experience. A lag as little as 0.1 ms is enough to be jarring to a user. As a result, we timed the display with internal software timers for testing, ensuring that all transitions take less time between frames than this crucial milestone. Making sure that all button presses are correctly interpreted by the system is also key, as the user should not have to play the game of “guess the button”.

Finally, we did usability testing. We will have an unfamiliar user use the device for the first time and see if there is any portion of the interface they have a hard time either using or figuring out. We will make appropriate changes to the interface pending those results.

All tests worked as planned and the system passed with flying colors.

6.3 Final Integrated System Tests

These tests were done as the components of the system were put together. They ensured that as each component was added the system continued to work. If a new component was added and the system no longer worked we were able to determine what caused the issue. Afterwards we tested the system as a whole in a variety of ways.

6.3.1 Integration Tests

We started the overall integration testing by combining the solar charge module and wall charge module by using a relay switch and connecting them to the battery. We tested this by testing the output of the relay switch when the wall charger was not plugged in. If the output voltage was not the same voltage as the output voltage of the solar charge module then the combination was faulty. Otherwise the wall charger was plugged in. The output of the relay switch was tested and compared with the output voltage of the wall charge module. If the voltages were not the same then the combination needed to be fixed. Otherwise the combination was working.

Next the power supply module was connected. We tested this new addition by testing that the output of the power supply was 5 volts when on and 0 volts when off. If this was not the case then the addition of the power supply module caused something to go wrong.

The battery indicator module was attached next. The newly combined circuit was tested by checking the battery indicator at various states of charge. If the system still worked as intended we connected the current module to the Raspberry Pi 2. If the Raspberry Pi 2 turned on when the power switch on the power supply was on then this combination was working. If not then there was some issue with the connection between the power supply and the Raspberry Pi 2.

Next we attached the screen to the RP2. If the screen turned on and displayed the RP2 output when the power supply was turned on then the addition of the screen was working properly. Otherwise the connection between the screen and Raspberry Pi 2 was likely faulty. The next thing that was to be added was the backlight controller. This was removed from the overall design.

The controller module was added to the system next. If the system recognized the controller and it functioned properly then we would add the next module. If any issues arose we troubleshot why adding the controller module caused an issue.

The next module to integrate was the audio module and speakers. If the audio module and speakers correctly played the sound from the system then we could

move on to the last component. Otherwise we needed to figure out what was wrong with the connection between the audio module and the RP2.

The last module to get added was the Bluetooth module. If we were able to find and connect to an external Bluetooth device from the system then the Bluetooth was working properly. If not the Bluetooth and Raspberry Pi 2 connection was probably faulty.

6.3.2 Final System Tests

The first way we tested the system was simply by using it to play games. If the console efficiently and effectively played games and was comfortable to use for an extended period of time then we could move on to the next test. Otherwise we needed to figure out why it was not working properly or what we could do to make it more comfortable.

The next test we did was a charge duration test. We charged the battery to full. We then used the console away from sunlight and recorded how long the battery lasts before the console dies. We then performed the same test in sunlight to determine how long the solar panels extended our battery life.

The next test we did was a stress test. While we did not need the system to survive in extreme conditions, it needed to be able to handle a small fall or two. We dropped the system onto a couch from 2 feet above it. We then attempted to turn the system on and check all the components. If everything still worked we repeated this test a few more times. If not then the structural integrity of the device needed to be revisited.

The last test we did is a temperature test. We wanted the device playable in both cold and hot areas, seeing as it is meant to be portable. We placed the device in the fridge for an hour and then attempted to use it. If it worked still we moved on to the hot test. If it did not we needed to find a way to better insulate the device. To perform the hot test we placed the device in an oven at 110 degrees for an hour and then attempted to use it. If it worked still the testing of the device was finished. If not then we needed to find a way to make the device be able to survive a hot day in Arizona.

7. Administrative Content

7.1 Milestones

Milestones are important for the purpose of sticking to a schedule. The charts below, in Tables 7.1.1, 7.1.2, and 7.1.3 detail the milestones, their expected completion dates, and whether those were met, met late, are in progress, or were not met.

Milestone	Action	Date	Met
Project	Chosen	1/28/2015	Yes
Initial Design	Completed	4/9/2015	Yes
Research	Completed	4/20/2015	Yes
Final Documentation	Completed	4/23/2015	Yes - Late

Figure 7.1.1 - Senior Design 1 Milestones

Milestone	Action	Date	Met
Order Parts	Completed	5/16/2015	Yes
Screen	Displays Input	5/23/2015	Yes
PCB	Designed	6/1/2015	Yes
PCB	Completed	6/8/2015	Yes
Power Subsystem	Regulates Power	6/5/2015	Yes
Power Subsystem	Completed	6/15/2015	Yes
Audio Subsystem	Completed	6/15/2015	Yes
Bluetooth Controller	Completed	6/15/2015	Yes
Case	Designed	6/5/2015	Yes - Late
Case	Printed	6/10/2015	Yes - Late
Controller Subsystem	Completed	6/15/2015	Yes
Integration Testing	Completed	6/30/2015	Yes
Prototype	Completed	7/8/2015	Yes - Late
Final Documentation	Completed	7/13/2015	Yes - Late

Figure 7.1.2 - Senior Design 2 Main System Milestones

7.2 Workload Distribution

The workload for this project was divided amongst the group members, keeping in mind individual strengths, requests for sections, and time and effort involved. All responsibilities are detailed in Figure 7.2.1. While most parts are insulated and modular, each group member still played a key role in developing the overall

system. Roles were decided on by group consensus and parts were purchased according to the need of each individual member. Each group member worked on the sections they were assigned for the paper, and then administrative sections were discussed and written jointly.

Case Design	Raspberry Pi	PCB	Bluetooth	Solar Battery	Power	Audio	Website
	Stephen	Stephen			Stephen		
	Kyle	Kyle		Kyle	Kyle		
Anna			Anna				Anna
				Nick		Nick	

Figure 7.2.1 – Workload Distribution

7.3 Budget and Finances

The FunBox Classic was estimated to cost approximately $400. This could have definitely been cut down if we were to make it again, but initial investments on tools and other materials certainly helped to bring the cost up. We decided not to apply for a sponsorship, as we wanted to keep the device ourselves. We will be splitting all costs equally, as we think that $100 each is a reasonable price to pay. The budget is laid out in Table 7.3.1.

Item	Cost
Battery	$15
Bluetooth	$11
Case	$20
Extra Parts	$50
Microcontrollers	$10
Misc. Components	$20
PCBs	$75
Raspberry Pi 2	$35
Screen	$20
Speakers	$10
Tools	$150
Total	$416

Table 7.3.1 – Project Budget

However, we greatly exceeded this budget and our actual finances are shown below in Table 7.3.2. The issues came with design considerations, re-ordered parts, and most importantly: time. They say time is money and we certainly

learned that, with rush order and shipping charges adding up to a significant portion of our total spent.

Digikey	$ 255.85
Shipping	$ 79.15
Adafruit	$ 71.61
Shipping	$ 46.80
Jameco	$ 11.00
Shipping	$ 2.71
Sparkfun	$ 9.00
Shipping	$ 16.04
Mouser	$ 10.60
Shipping	$ 6.99
Oshpark	$ 43.20
Shipping	$ 5.00
Sunstone	$ 139.15
Shipping	$ 76.00
4PCB	$ 33.00
Shipping	$ 83.78
RP2	$ 35.00
Shipping	$ 9.99
Amazon	$ 229.84
Shipping	$ 3.99
Radioshack	$ 197.57
Home Depot	$ 23.38
Shipping Total	**$ 353.83**
Parts Total	**$ 1,035.82**
Total	**$ 1,389.65**

Table 7.3.2 – Total Cost

8. User Manual

8.1. System Power

8.1.1 Charging the System

In order to charge your FunBox Classic, you can make use of one of two methods.

The first, and fastest, is to plug in a standard MicroUSB cable into the port located on the left of the device. A green light will illuminate to let you know the device has entered charging mode.

The second is to simply be in sunlight. Thanks to the solar panels on the rear of the device, your FunBox Classic can charge by being outside. Please note that this is a far slower and less powerful method of charging and that the green light will not illuminate for this method, for power-saving reasons.

Concurrent solar and MicroUSB charging will not occur, and the charging cable will shut off solar power.

8.1.2 Powering on the System

In order to turn your FunBox Classic on, please switch the large power switch on the right of the device to the up position. A blue light will illuminate to let you know that the device is on, and activity lights will flash in the upper right of the device.

The switch can be pushed down to power off the device.

8.1.3 Low Power

Please note that when the system has 10 to 15 minutes of power remaining, a red light will turn on in the power light. This will give the light a purple appearance instead of a blue one. Please save your game and begin recharging the device as soon as possible to prevent a loss of data or progress.

8.2. Using the EmulationStation Menu

Upon the full boot of the system, you will find yourself on the screen in Figure 8.2.1.1 below.

Figure 8.2.1.1 – Boot Screen

In order to access system menu functions, hit the start button. You will find yourself presented with the screen in Figure 8.2.1.2 below.

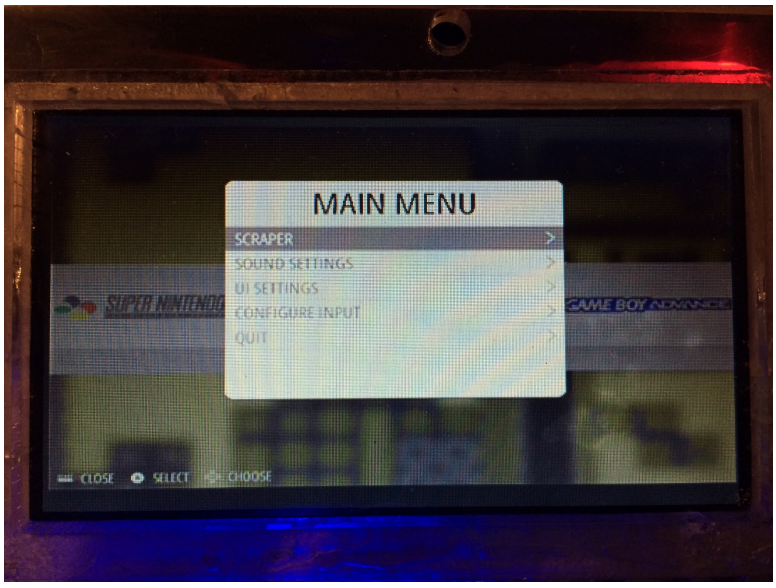


Figure 8.2.1.2 – System Settings Menu

8.2.1 Scraper

The Scraper will not work without an Internet connection. If you plug an Ethernet cable into the device, you will then be able to use this function to grab information and pictures about your newly added games from the internet.

8.2.2 Sound Settings

Here you are able to modify the absolute maximum volume for the system. It is set to 100% as default.

8.2.3 UI Settings

Here you are able to modify various settings, such as a screensaver, on-screen help, and transition styles.

8.2.4 Configure Input

Here you are able to configure input mappings for the internal controller as well as any external controllers you may have connected.

8.2.5 Quit

Here you are able to shutdown the software before powering off the device. Note that this is not necessary.

8.3 Playing Games

From the main menu, simply select an emulator with the directional pad and press the A button. You will be taken to a screen similar to the one shown in Figure 8.3.1.1 below.

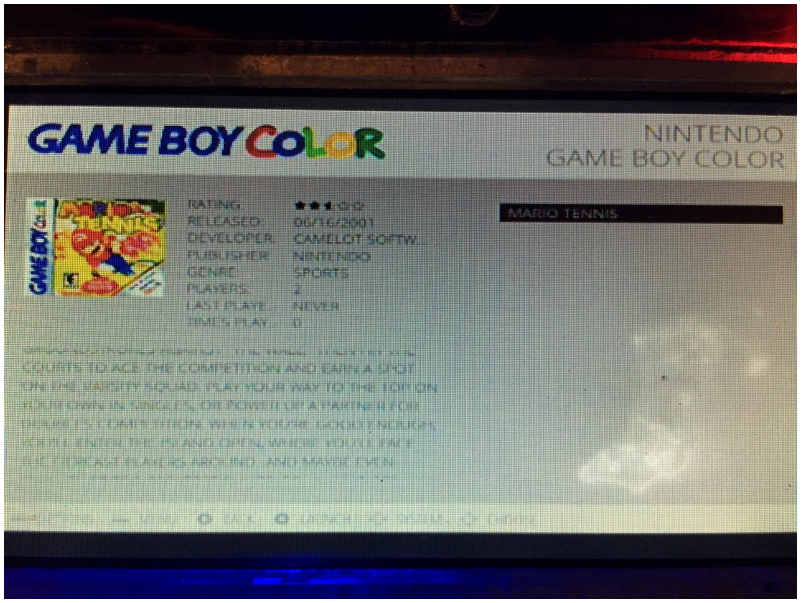


Figure 8.3.1.1 – Emulator Menu

From there, you may browser through your games using the up and down directions on the D-pad, or switch emulators with left and right. Once you've found the game you want to play, simply hit the A button to be taken right into playing it. If you find that you wish to play another game, simply press the start and select buttons at the same time to be returned to the emulator menu. You may also turn the device off if you prefer.

Volume can be controlled through the hardware volume wheel in the upper left corner of the device. Headphones may be plugged in near the charging port if you prefer.

For multiplayer, simply turn on the included external controller and load a game that has support for more than one player. Please note that the controller will stay on until the device has been powered down, so please shut off the device after playing a multiplayer game to conserve power.

Additional games can be loaded through the internal USB port. Simply plug your device in with the games on it and they will automatically load into the system. Please do respect the directory hierarchy and place games inside the appropriate folders on the USB. Failure to do so will result in games not loading.

We hope you enjoy your new FunBox Classic gaming device.

9. Conclusion

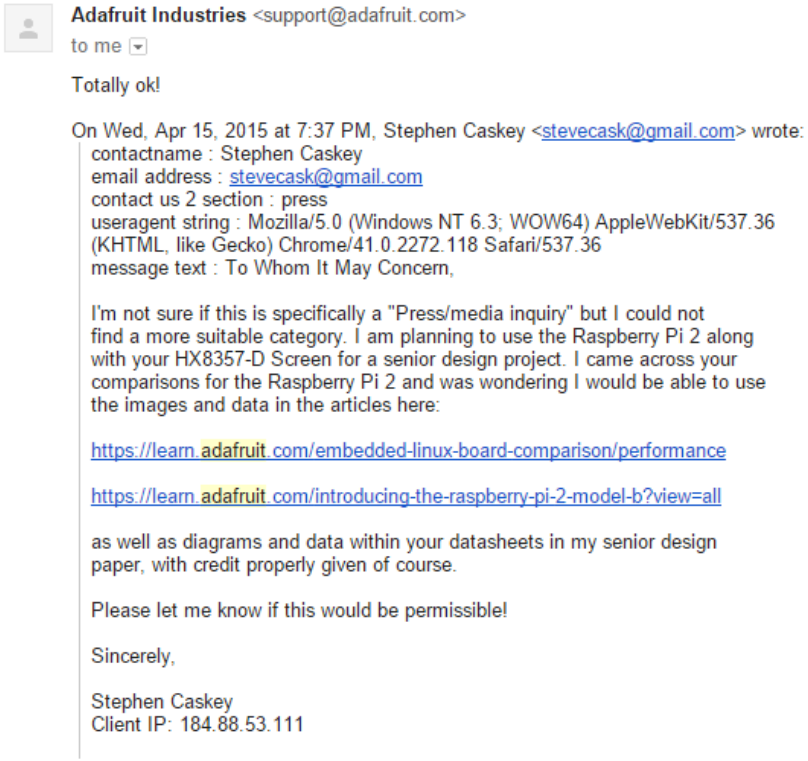
When the project was, at last, completed, the group felt it had a much clearer understanding of what was necessary to reach a final production ready system in the working world. Each group member became intimately familiar with their individual component research areas while still not losing sight of the overall project definition. While each member was qualified for the tasks ahead, designing schematics and diagrams was a new endeavor for most, and required the utmost care and attention to succeed. Each step of the design process, each decision made was carefully and completely documented and laid out in this paper. This added accountability and justification for every step, ensuring that the right choices had been made.

What started as an overly ambitious and underestimated, in terms of work, project turned into the FunBox Classic as it stands today. Gone were the lofty goals of a custom operating system and a cartridge slot, replaced with the more reasonable Linux and MicroSD slot. What started as vague ideas and frantically talked about plans began to take shape into individual components, overarching modularity, and the central system that would tie them all together. When all was said and done for, we had our project: A Raspberry Pi 2 connected to a custom support PCB with Bluetooth, custom power regulation, audio splitters, and a controller, all outputting to a composite screen and contained within a custom case. Detailed and exhaustive testing procedures exist to ensure the proper and complete operation of the FunBox Classic, no matter the situation.

This Senior Design project pushed the group members into things that had not been taught before. Skills like soldering, PCB design, and proper and extensive schematic design. These were things that either weren't taught or were glossed over in the classroom, which were important to learn due to their essential nature to the industry at large. We learned time-management, although not without a great deal of reticence, practiced and improved technical writing, and made our best attempts at working on communication and group dynamics. The biggest thing learned, however, was how to take a vague concept, tweak it, build on it, and improve it until it stopped being just an idea, turning into a fully fleshed out product design. Throughout the process, group members became intimately familiar with things such as power regulation, Bluetooth, solar power, and how older devices compensated for low system specifications. This project spanned several classes worth of ideas, from the simplest electrical networks all the way up to operational amplifiers, which can be used for almost an astounding number of different things. We are pleased that we have completed our project design document and are ready to get to work building and testing our other such projects in the working world.

Appendices

Appendix A – Copyright Permissions



Adafruit Industries <support@adafruit.com>
to me

Totally ok!

On Wed, Apr 15, 2015 at 7:37 PM, Stephen Caskey <stevecask@gmail.com> wrote:

contactname : Stephen Caskey
email address : stevecask@gmail.com
contact us 2 section : press
useragent string : Mozilla/5.0 (Windows NT 6.3; WOW64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/41.0.2272.118 Safari/537.36
message text : To Whom It May Concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planning to use the Raspberry Pi 2 along with your HX8357-D Screen for a senior design project. I came across your comparisons for the Raspberry Pi 2 and was wondering I would be able to use the images and data in the articles here:

https://learn.adafruit.com/embedded-linux-board-comparison/performance

https://learn.adafruit.com/introducing-the-raspberry-pi-2-model-b?view=all

as well as diagrams and data within your datasheets in my senior design paper, with credit properly given of course.

Please let me know if this would be permissible!

Sincerely,

Stephen Caskey
Client IP: 184.88.53.111

Press/Media Inquire

2 messages

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 7:44 PM
To: info-en-c@wikimedia.org

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am conducting research for a Senior Design project here at the University of Central Florida. Our report researches audio jack technology, and I was wondering if I could use the jack schematic from your page
http://en.wikipedia.org/wiki/Phone_connector_(audio)
All credit from the diagram would be credited to Wikipedia in the report.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

EN-Copyvio <info-en-c@wikipedia.org> Tue, Apr 28, 2015 at 8:12 PM
To: nick.j8809@gmail.com

Dear Nick Johnson,

In principle, text on Wikipedia is available under CC-BY-SA license, and may be used free of charge for any purpose. Reading more about the license should help explain it in simpler terms: <https://creativecommons.org/licenses/by-sa/3.0/>.

Some embedded images and media are under specific licenses, which can be seen upon clicking on the desired image or file. Most images are available under free licenses such as CC-BY-SA, but some copyrighted content (such as book covers) falls under the "fair use" clause. For more information, see the page <https://en.Wikipedia.org/wiki/Wikipedia:Copyrights>.

A specific permission for reusing Wikipedia's freely licensed content is not necessary, as long as the re-user observes the license conditions. For most cases, this means:

* An attribution is required, which can simply be a link to the history page of an article or image <https://en.Wikipedia.org/wiki/Help:Tracking_changes#Page_history>. For images, mentioning the creator is a good idea. E.g. for this image <https://en.wikipedia.org/wiki/Phone_connector_(audio)#/media/File:Phone_jack_symbols.png>, the creator is "Omegatron" (as can be seen after clicking "View author information"). So, you can mention something like "Image credit: Omegatron, Wikipedia".

* If you modify the content, you must re-release it under a similar free license, which allows others to use the new content freely <https://en.wikipedia.org/wiki/Share-alike> ('SA' or 'ShareAlike').

For more information please see: <https://en.Wikipedia.org/wiki/Wikipedia:Copyrights#Reusers.27_rights_and_obligations> or <https://commons.wikimedia.org/wiki/Commons:Reuse>.

If you have any questions, you can ask them at the Wikipedia Help Desk: https://en.wikipedia.org/wiki/Wikipedia:Help_desk

Please note: Neither the Wikimedia Foundation, nor the authors of articles on Wikimedia sites, nor the volunteers answering mail to this address provide legal advice. It is your responsibility, if you intend to reuse content from Wikimedia sites, to determine how the licenses of the content that we host apply to your intended uses.

Yours sincerely,
Utkarsh Atmaram

Press/Media Inquire

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 7:38 PM
To: bourns.marcom@bourns.com

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not
find a more suitable category. I am planning to use the Bourns 3352T-103LF-ND potentiometer

for a Senior Design project here at the University of Central Florida. I was wondering if I could use dimension diagrams from the 3352T-103LF-ND datasheet here for our report:
http://www.bourns.com/data/global/PDFs/3352.pdf
All credit from the diagrams will be credited to Bourns.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

Press/Media Inquire

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 7:34 PM
To: sysdev@microsoft.com

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not
find a more suitable category. I am conducting research for a Senior Design project here at the University of Central Florida. Our project involves studies in potentiometers, and I was wondering if we could use the DAC potentiometer response diagrams from your company website here:

https://msdn.microsoft.com/en-us/library/windows/desktop/dd370798(v=vs.85).aspx

All credit from diagrams used will be credited to Windows in the report.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

Press/Media Inquire

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 7:28 PM
To: sales@maximintegrated.com

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not
find a more suitable category. I am researching for a Senior Design Project here at the University of Central Florida. Our project includes research in potentiometers, and I was wondering if I could us the linear and logarithmic response diagrams from your company website here:
http://www.maximintegrated.com/en/app-notes/index.mvp/id/838
All credit from the site used will be credited to Maxim Integrated in the report.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

Press/Media Inquires

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 1:56 PM
To: stefan.schmidt@osram.com

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planning to use the LG R971 LED in a Senior Design project here at the University of Central Florida. I was wondering if I would be able to use diagrams and charts from the LG R971 datasheet:
http://www.osram-os.com/Graphics/XPic9/00078860_0.pdf
With all credit to the used material going to Osram Opto Semiconductors in the report.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

Press/Media Inquires

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 1:52 PM
To: matris@matrisled.com

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planning a research report for a Senior Design project here at the University of Central Florida. A significant part of the project investigates LED research. I was wondering if I could use the LED Viewing Angle diagram found on your company's page:
http://www.matrisled.com/led_screen_viewing_angle.htm
All credit to the diagram will be given to Matrisled in the report.

Please let me know if this would be permissible!

Sincerely,
Nick Johnson

Press/Media Inquires

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 1:33 PM
To: press.relations@avagotech.com

To Whom It May Concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planning to use the Avago HSMF-A341-xxxxx tri-color led for a Senior Design project here at the University of Central Florida. I am wondering if I would be able to use the supplied diagrams from the HSMF-A341-xxxxx datasheet in our report. All credit to Avago Technologies will be given within the report.

Please let me know if this would be permissible!
Sincerely,
Nick Johnson

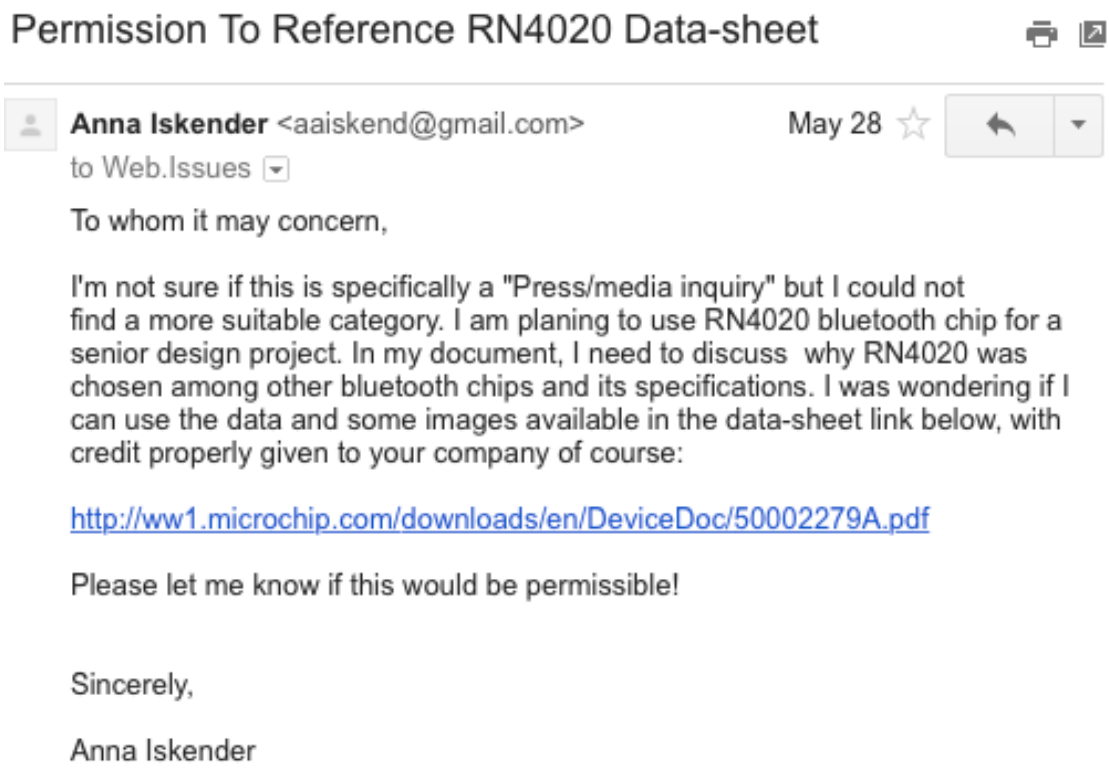
Press/Media Inquires

Nick Johnson <nick.j8809@gmail.com> Tue, Apr 28, 2015 at 1:23 PM
To: sales@mec-corp.com

To Whom It May Concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planning to use the IXYS SLMD121H87 solar cell for a Senior Design Project here at the University of Central Florida. I'm wondering if I would be able to use your images and diagrams from the SLMD121H87 data sheet for the report:
http://ixapps.ixys.com/DataSheet/20110107-SLMD121H08-DATA-SHEET.pdf
All credit will be given to the IXYS Corporation within our report as well.

Please let me know if this would be permissible!
Sincerely,
Nick Johnson



Permission To Reference RN4020 Data-sheet

Anna Iskender <aaiskend@gmail.com> May 28

to Web.Issues

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planing to use RN4020 bluetooth chip for a senior design project. In my document, I need to discuss why RN4020 was chosen among other bluetooth chips and its specifications. I was wondering if I can use the data and some images available in the data-sheet link below, with credit properly given to your company of course:

http://ww1.microchip.com/downloads/en/DeviceDoc/50002279A.pdf

Please let me know if this would be permissible!

Sincerely,

Anna Iskender

Permission was received over the phone, as the company remained unresponsive to email.

Permission to Use an Image of Retro Duo Game Console

Inbox x

Anna Iskender <aaiskend@gmail.com> May 28

to info

To whom it may concern,

I'm not sure if this is specifically a "Press/media inquiry" but I could not find a more suitable category. I am planing to reference a case-design of Retro Bit game-console for a senior design project. I was wondering if I would be able to use an image of the Retro Duo console attached to this email, with the credit properly given to your company of course:

Please let me know if this would be permissible!

Sincerely,

Anna Iskender

---

info@retro-bit.com May 28

to me

Good afternoon Anna,

Thank you for taking the time to reach out to us. Please feel free to use the image of your choice for the RDP console. Please keep in mind that the image you attached is of the Retro Duo Portable, and not of the Retro Duo. Both are actually different consoles.

Please let me know if you have any questions.

Best regards,
Kristopher

retro-bit®

Follow us @retrobitgaming

-
-

60-Day Warranty (Guidelines)

- The original receipt is required for proof of purchase.
- The date on the receipt must be 60-days prior to the inquiry.
- The product must not appear damaged or misused.
- A refurbished replacement could be sent in exchange.

All other inquiries, please contact the store where the item was originally purchased.

From: Anna Iskender [mailto:aaiskend@gmail.com]
Sent: Thursday, May 28, 2015 11:59 AM
To: info@retro-bit.com
Subject: Permission to Use an Image of Retro Duo Game Console