6.101 Analog Electronics Final Project Proposal
Variable Power Supply Brick

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1. Introduction

With the release of the 2016 MacBook, Apple realized and implemented the concept of providing universal ports that handle not only power but as well as data using the USB-C standard for laptops. The new USB-C standard enables consumers to power devices with up to 100 watts, with electronic applications ranging from smartphones to laptops with the same reversible cord.

For our final project, we will attempt to design and construct a variable power supply brick that implements the USB protocol and power specifications. The finished prototype will accommodate both the standard USB 2.0 and 3.0 as well as the USB-C variation by providing different ports such that the different USB standard cords can be used to power devices. Using design concepts from the class, we will attempt to maximize power efficiency, minimize power losses, and provide device protection.

2. Overview

This power electronics project will attempt to accommodate both the ubiquitous USB 2.0, USB 3.0, as well as the USB-C standards. USB 2.0 and USB 3.0 has no distinguishable differences in the power provided; both protocols utilize a power supply of 5 volts at 2 amperes.

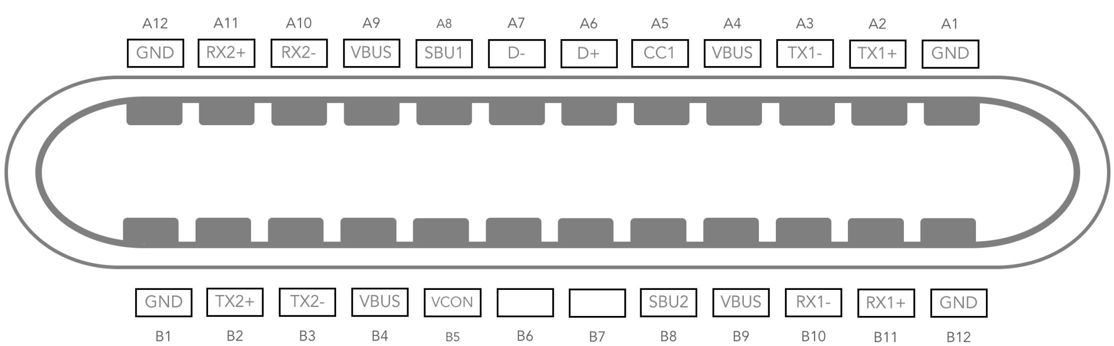


Figure 1. USB Type-C Connector Pin Diagram

However, the new USB-C implementation introduces a 24 pin, fully reversible plug connector that not only allows efficient transfer of energy but also data. Figure 1 refers to the pinout diagram of the USB-C 24 pin plug. Due to USB C's attempt to supply power to all types of electronics ranging from smartphones, tablets, to laptops, USB-C uses a system of profiles, identifying each device, to allow the host to supply safe and appropriate voltage depending on device.

In the USB-C power profile specification (Figure 2), five power configuration profiles exist to serve electronics with different power requirements. Due to power constraints and considerations of safety, we will not attempt to implement Profile 5, which requires a 100-watt power supply.

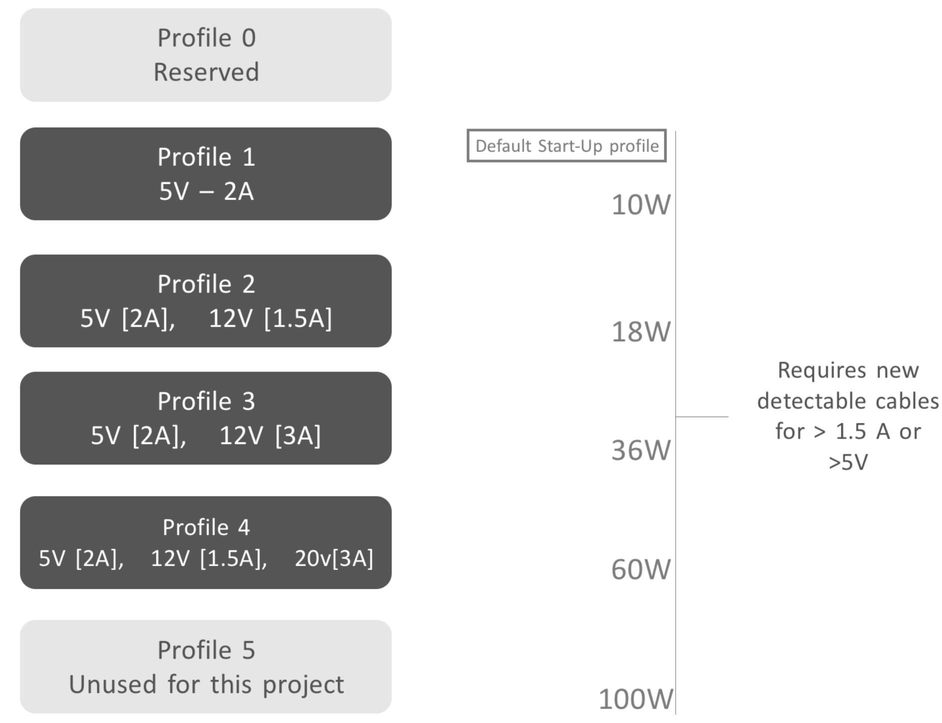


Figure 2. USB Type-C Power Profile Specifications

If a device with a drained battery is connected to an industry standard brick, the circuit will first attempt to provide enough power to turn on the device using the safest and lowest tier of the USB Profile, 5 volts at 2 amperes, common among the USB 2.0, USB 3.0 and USB-C circuits. Once the device is powered, the device can communicate to the circuit which profile is appropriate. This information is accessible via the Configuration Channel (CC) pins on the cord, in which current advertisements and thus power profiles can be deduced from an integrated chip solution.

3. Block Diagram

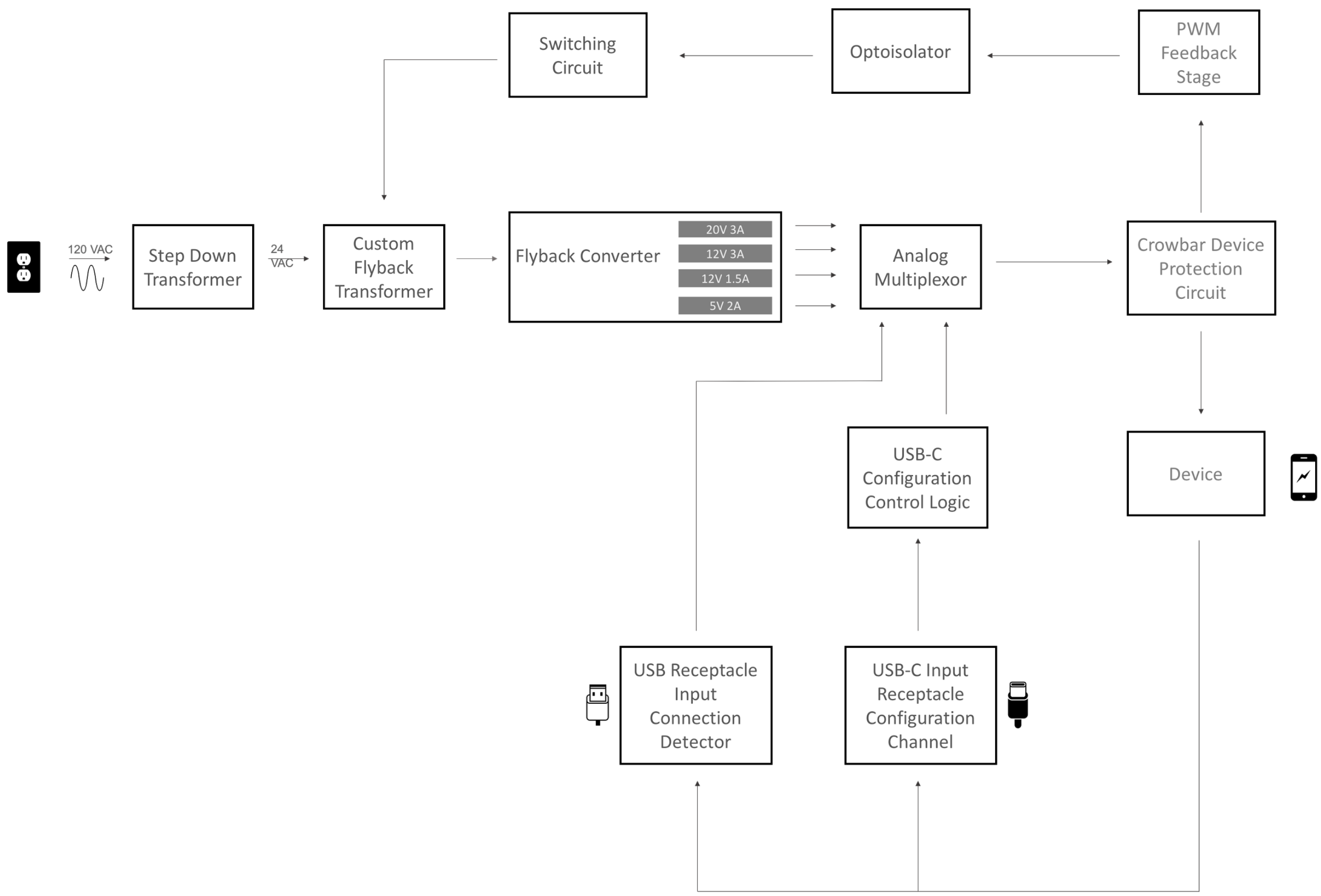


Figure 3: Block -Diagram of system

4. System Design

From the 120 volts AC wall outlet, a transformer will be used to step down to a safe 24 volts AC output from which the project will use to provide variable power and current based on the device that is plugged in. A custom made flyback transformer will be used to provide variable voltage. This transformer will be used in the implementation of a flyback converter, which provides electric isolation beyond the standard inductor in a buck or a boost converter. An analog multiplexer with the CC pin outputs will determine which variable voltage and current will be chosen to power the circuit in the case that a USB-C cord is used. Otherwise, the default circuit will be the safest profile, 5 volts at 2 amperes. A crowbar circuit will be used to provide a layer of device and consumer protection, and the output voltage will be used to power the device. In any power electronic circuit, feedback is crucial to provide the appropriate voltage and current. A PWM (Pulse Width Modulation) circuit will be used to provide feedback control of the flyback converter. An optoisolator or optocoupler will be used to provide galvanic isolation between the primary and the secondary of the flyback converted.

Finally, a switching circuit will be implemented to control the switching of the flyback converter, based on the output of the PWM circuit.

4.1 Flyback Transformer & Converter

As stated before, our power supply will 4 configurations of voltage and current depending on the device. The varying voltage must be controlled by the transformer itself. We plan on using a multi-tap transformer to have varying secondary voltage. This would like Figure 4.

4.2 Multi-Tap Transformer

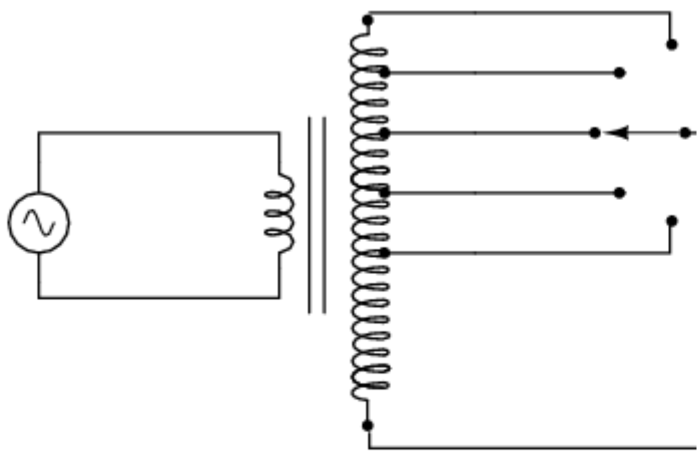
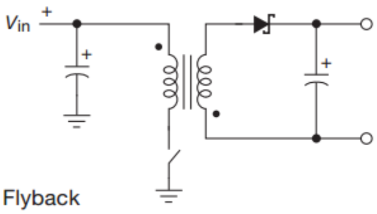


Figure 4: Multi-Tap Transformer

The multi-tap transformer allows us to have various windings ratios in the transformer leading to various output voltages because there are multiple center taps that we can utilize. Depending on the device we will select a specific center tap.

The multitap transformer will used in place of the transformer in figure 5A, a simple flyback converter topology is referenced. The transformer in a flyback converter is used in place of the inductor in a buck-boost converter in figure 5B for primary and secondary isolation.



A. Flyback

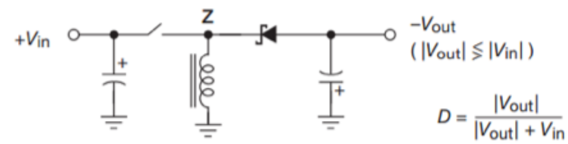


Figure 5B: Basic inverting (or "inverting buck-boost") topology (non-isolated).

Figure 5: Flyback vs Buck-boost

We will be using a flyback converter because of its isolation and inherent efficiency advantages. Typical inverting or "buck-boost" topologies are non-isolated. The flyback allows us to isolate the output voltage from the main supply which is desired for powering our devices. The flyback converter also eliminates the ground loop between primary and secondary circuits improving noise immunity.

Particularly for our application, where variable output voltages are needed, the flyback makes perfect sense since its regulator makes it easy to have multiple outputs.

Some considerations however are that flyback converters have large output ripple current and voltage. When designing, we will have to reduce this by filtering at the output. Flybacks additionally tend to be used for low power applications (below 50W). We will need to ensure that our design can still work for our maximum power of 60W without unwanted side effects.

4.2 Device Detection & Analog Multiplexer

Device detection consists of two implementations to differentiate between a USB 2.0 or USB 3.0 device and a USB C device. Since the project will provide both a USB and USB C receptacle in which the cord can be plugged into, it will not be difficult to determine the difference between the USB and USB C device.

However, device detection is crucial for the USB C device as the device in question can range from a smartphone to a laptop. As mentioned in the overview, the USB-C pins provided a channel to accessible the charging profile of a device through the Configuration Channel (CC). When a plug is connected to the receptacle, the CC pins determine not only the orientation of the cord, but also the current requisites of the device and whether the device is operating as an upward facing port (UFC), device, or a downward facing port (DFC), host.

The USB-C cord will be connected to a receptacle breakout board (Figure 7), enabling through hole access of the pins, which is normally surface mounted. The information at the CC pins will be put through the Texas Instruments TUSB321 chip with USB Type-C Configuration Channel Logic Control, which outputs the current mode through two output pins, OUT1 and OUT2 (Figure 7).

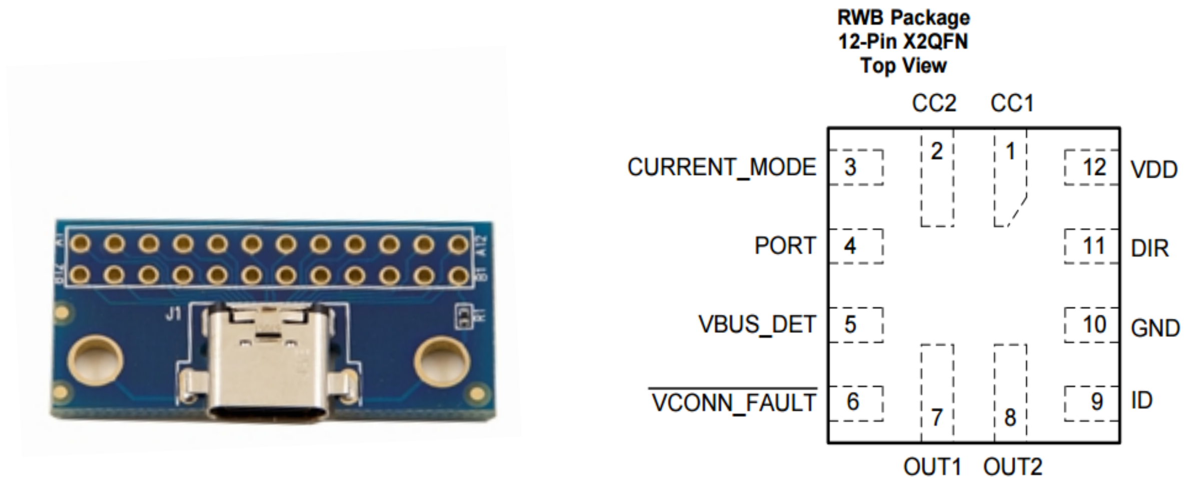


Figure 7: USB-C Connector Breakout Board and Device Detection Chip

The chip, through OUT1 and OUT2 voltages, indicates the Type-C current advertisement, which ranges from 500 milliamperes to 3 amperes. The following table below maps the possible outputs of OUT1 and OUT2 to the Type-C current advertisement.

Type-C CURRENT	UFP of DRP acting as UFP Current Detection	DFP or DRP acting as DFP Current Advertisement
Default: 500mA – USB 2.0 900 mA - USB 3.1	OUT1 = High, OUT2 = Low	CURRENT_MODE = L
Medium – 1.5 A	OUT1 = Low OUT2 = High	CURRENT_MODE = M
High – 3A	OUT1 = Low OUT2 = Low	CURRENT_MODE = H

Figure 9: USB-C Type current and Advertisement
and Detection (From TI.com)

An analog multiplexer will be implemented to choose which variable voltage and current to provide to the device from the flyback converter based on the OUT1 and OUT2 pins of the integrated chip. The analog multiplexer will be implemented using two bits, which determine the current requirements, to select the permutation of voltage and current that is appropriate for the device being powered via USB-C. Several design implementations will be experimentally tested to determine the most optimal multiplexer implementation based on accuracy and power efficiency. The following circuit implementations will be expanded from one bit, essentially a single pole single throw (SPST) switch, to two bits and tested.

4.4. Feedback & device protection

In any power electronics project, it is crucial for device protection and feedback to be present to provide the appropriate and constant voltage that a device requires. In our project, feedback is used to provide a constant, accurate, and safe power supply that the device, USB or USB-C, requires. Device protection is implemented through several circuits such as snubber, crowbar circuits, and optoisolators that ensure the device does not experience unsafe power input.

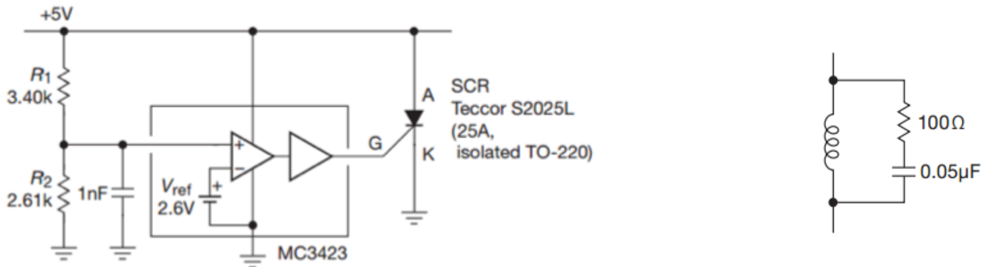


Figure 10: Crowbar circuit and RC Snubber

In a transformer with ideal components, the primary current transfers completely to the secondary when the switch is off. However, there exists a coupling between primary and secondary creates a leakage inductance. Because the inductors resist any current changes, will generate a positive voltage spike at the switch, which can damage the circuitry. As a result, the RC snubber network is used to counteract these effects.

The crowbar circuits offer protection against high voltages because of power supply malfunction or a power surge, which is essential in our final project (Figure 10). Finally, an optoisolator (Figure 10) is used to provide galvanic isolation between the primary and the secondary primaries by offering a physical separation.

We chose the pulse width modulation (PWM) circuit as a feedback method to control the switching circuitry of the flyback converter as a function of the error present at our device output. PWM is used commonly in power electronics as a control to provide a constant and reliable voltage. Figure 11 references the two possible configurations of a PWM circuit, in voltage mode and in current mode.

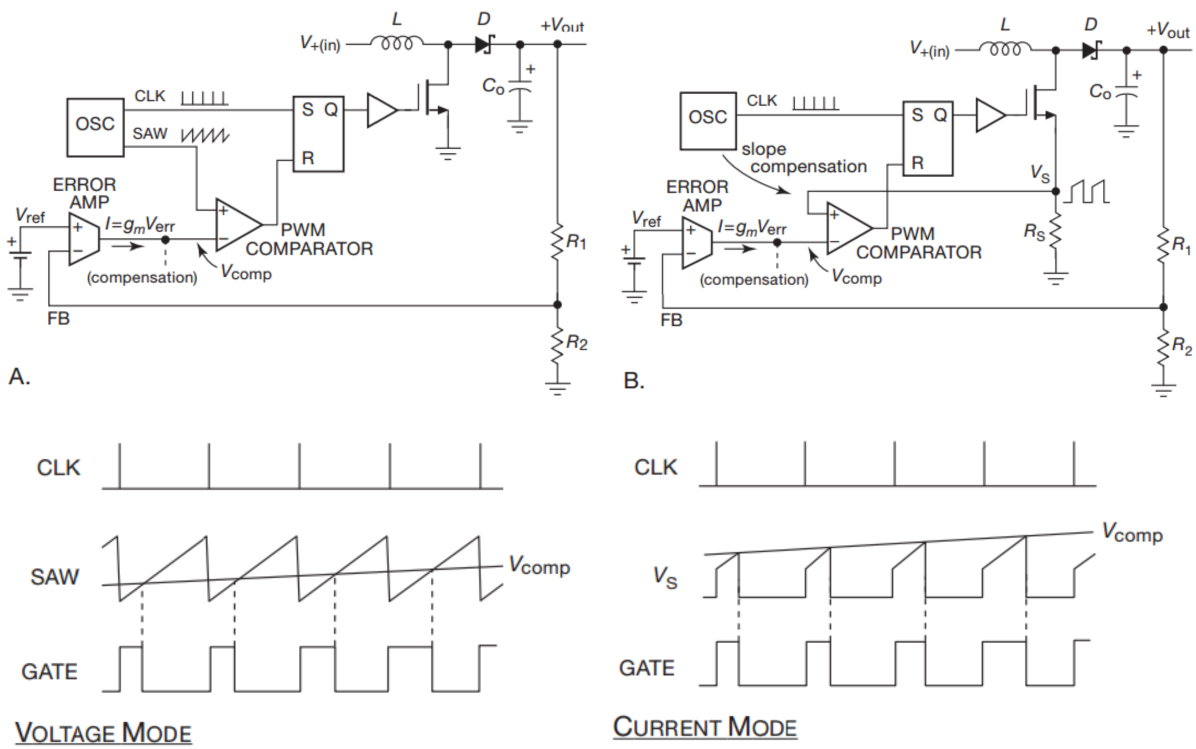


Figure 11: Voltage and Current mode PWM Feedback circuits

5 Testing

Due to the new technology of USB-C, most devices that uses USB-C as a power supply are usually laptops and smartphones, which are expensive and should not be used directly to test and verify that the project was successful. However, the device can be used to plug into the circuit such that the circuit can determine what kind of device is plugged in and choose an appropriate voltage and current.

Once the appropriate voltage and current is chosen by the circuit, instead of having the power being driven straight to the device, the power will be diverted to a load resistance, and the voltage as well as current will be measured at that node to confirm that the it meets profile of the USB or USB C device.

Furthermore, to avoid using expensive electronics to test the final circuit, inexpensive testing solutions such as power banks can be used to verify that charge is stored.

6 Project Outline

6.1. Components and Parts

The following components, circuit boards, and parts will be acquired for this project.

Texas Instruments TUSB321 USB Type-C Configuration Channel Control IC
Saiko Systems USB Type C Female Receptacle Breakout Board
120 Volt AC 60 Hz to 24 V AC 60 Hz Transformer
Low Voltage Diodes (Schottky Diodes)
Bobbin, Wires, Cores for Homemade Custom Inductors
USB-C and USB 2.0/3.0 power cords for testing
Op Amps (LM 741, LM 353, LM 356) for feedback, multiplexer, and protection
Capacitors and resistors for protection circuits and filtering out noise
MOSFETs for multiplexers and switching of the flyback converter

6.2. Timeline

Week of April 13th, 2017

Proposal discussions with 6.101 staff
Block diagram conferences, improve block diagram
Finish integrated chips and component orders

Week of April 20th, 2017

Begin to assembly separate circuit modules, including
- Custom made transformer winding [**Lokhin**]
- Construction of flyback converter **[Eswar]**
- Confirmation of working TUSB321 and USB-C breakout board **[Eswar]**
- Breadboarding analog multiplexer **[Lokhin]**
- Breadboarding pulse width modulation circuit **[Eswar]**
- Breadboarding device protection circuit (snubber and crowbar) **[Lokhin]**

Project presentation (April 20th, 7:00 - 8:30PM)

Week of April 27th, 2017

Submit project proposal revision (April 28th)
Finish breadboarding and prototyping of circuit modules
Testing of separate circuit modules in preparation of integration
Begin integration of circuit modules upon successful test of separate modules

Week of May 4th, 2017

Continuation of testing of circuit modules in integration
Continuation of improving integrated circuit
Debug circuits as needed

Project demonstration and checkoff to 6.101 staff (May 9th and 10th)

Week of May 15th, 2017

Complete project report for final submission

7. References

The Art of Electronics (Third edition) by Paul Horowitz and Winfield Hill