ECE 322 Variable Power Supply

Nick McComb
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1. Revision History

Revision	Date	Description	Contributor
	1/1/07	Initial Creation	Donald Heer
	1/8/07	Updated Testing Specifications	Donald Heer
	1/15/07	Formatting / Parts List / Target Feature Set	Donald Heer
	1/31/07	Testing Plan / Parts List	Donald Heer
	3/1/07	Style Selections/Formatting – Locked Styles	Donald Heer
	1/7/08	Updated Requirements	Donald Heer
	1/6/09	Improved Testing Plan	Donald Heer
1.2	10/22/2015	Modified Section 6.2 and 8	Nick McComb
1.3	11/19/2015	Modified Section 6.3, 6.4 and cost analysis	Nick McComb
1.4	11/2/2015	Modified Section 6.1, 6.5, 6.6, 6.8, and 8	Nick McComb

2. Introduction

The project described in this document is a two channel DC variable DC power supply intended to be constructed by students in the ECE322 course at Oregon State University. This project will be loosely associated with the TekBots program and should be based on previous student experience.

The project needs to be the best fit for the following priorities; Educational Merit, Student Time Commitment, Instructor Buy-in, Future Re-usability, and cost.

Customer Requirements & Product Background

The ECE322 course lab component has not been updated to reflect new teaching methods our new content since 1996. This course is badly in need of these updates. The TekBots group was asked to help to develop a new lab experience to better fit modern methods and information. No restriction were placed on the development other than those enforced by the lecture portion of the course in terms of duration, student enrollment, lab facilities, and previous student experience.

From this information, many possible themes and/or ideas were generated with a DC power supply being the best candidate selected. The deliberations and trade-offs made to decide on a DC power supply are outside the scope of this document and are not covered.

Criteria of Interest

Educational Merit – The project needs to help students learn new information as efficiently as possible. The metric of educational merit is a some what ambiguous term. Educational merit is ascribed on a rating of 2, 1, or 0 points. Points are assigned through group deliberations with a group assignment of merit. Factors that are reviewed during group deliberation are:

Connection to Lecture: Rather than having a lab in a vacuum, it is best to lab the lab material and tasks support the lecture material and visa versa. Students learning using multi-sensory approaches and performing tasks that require knowledge synthesis are better able to retain and use knowledge.

Fundamentals: Projects that help to expose more fundamental knowledge rather than specific niche topics give the students a stronger basis for later coursework.

Sophistication: Is the project appropriate for the student level? Typical student transcripts are reviewed and project difficulty is matched to student experience. How many different areas of knowledge are required? Is the number of missing topics acceptable? Can a student be expected to learn what is missing?

Real World Similarity: Does the project adequately show the real world of engineering? Is the project contrived or to idealized to show the ‘messy’ nature of engineering. Does the project force students to connect multiple disciplines inside and outside of electrical engineering?

Student Time Commitment – This is the expected number of hours per week a student will spend on the project. This time includes scheduled lab time and time outside of lab as well.

Instructor Buy-in – If the instructor likes the project they are more likely to involve the project in their lecture material. This creates a tighter connection between lecture and lab and promotes better student understanding.

Future Re-usability – Will the project be re-usable by the student either for classes or for some external purpose? Projects that have a clear path for reuse allow for amortization of student effort and monetary investment. This allows for a justification of more sophistication.

Cost – This is the actual cost in dollars of the project.

3. Product Space Analysis

DC power supplies commonly fall into one of two categories, switching and linear. Switching supplies are more modern and involve voltage conversion through charging and discharging of capacitors and inductors. This method allows for both step-down voltage conversion and step-up voltage conversion.

Linear voltage regulation allows for only step-down conversion with excess voltage converted to heat and waste.

3.1. Target Feature Set

- Two channels, one positive and the other negative when referenced ground.
- Each channel must:
    - Supply a minimum of ±2 volts for all loads (lower is better)
    - Be capable of supplying ±12 volts while loaded to 900mA.
- At any load less than 900mA the power supply still needs to be able to achieve ±2 (or less) and ±12 volts (or more)
- Current limiting circuitry for each channel, protecting above 1 amp +/- 10%.
- Voltage ripple less than 0.75Vp-p per channel with both channels fully loaded to 900mA.
- External connections for leads and voltage adjustment.
- Safely equipped with a cooling fan that should not normally be running at 70F but should reach rated speed around 95F.
- Discharges the filter capacitor on each channel to under 3 volts in 5 seconds or less when the main power switch is turned to off and there is no load present on the output of the supply.
- Maximally student designed
- Utilizes a safety fuse.
- Human safe with short circuit protection
- Easily accessible AC power switch.
- A clearly visible power indication light.
- Core concepts drawn from lecture portion of ECE322
- Voltage Regulators must use BJTs
- Force design specification skills
- Introduce physical prototyping skills
- Help student to understand value of simulation before build
- Motivate proper diligence through student responsibility

4. Architectural Overview

4.1. Implementation Approaches

The project will be done with linear voltage regulation as it more directly relies on the concepts taught in ECE322. The concept of DC analysis and input/output impedance is strongly emphasized in linear regulators. Switching supplies while more efficient and relying on similar concepts introduce transient elements that are not in the scope of the course and could needlessly confuse students.

The enforced use of BJTs also causes students to work more with the concepts from the course. While this is an artificial restriction, it should result in better prepared students.

The design must be able to supply rated current at the specified voltage range. This restriction will force students to explore input and output impedances to best design their circuits. This approach shows the interconnection of circuits, as no circuit (including power supplies) exists in a vacuum.

A purchased kit with included custom PCB while allowing for easy student success would not meet the goals of a student authored design. Even if many of the parts were removed and students asked to calculate values, the lab would feel contrived and very few solutions would exist. Flexibility was deemed more important than ease of use.

5. Top Level Description

5.1. Theory of Operation

The designed power supply connects to a US standard AC wall outlet of 120VAC. It draws no more than 500mA while delivering fully power to its two DC voltage outputs. There are two output channels, one positive and one negative. Both channels share a single common ground. Each output is to be adjustable by a potentiometer. Each voltage output will supply voltages fro 2 to 12 volts. As current is drawn from the outputs, the voltage will remain steady until 900mA is reached. At 900mA of current, the power supply will be come a constant current source allowing for over current protection. Optionally there will be indicator LED denoting when the power supply over currents.

Internal to the power supply is a thermal protection circuit that monitors the power supply temperature. It will activate a fan to cool the supply when it begins to over heat. Optionally if the fan is not sufficient to handle the over heating, the power supply will be deactivated before permanent damage occurs.

5.2. Top level block diagram

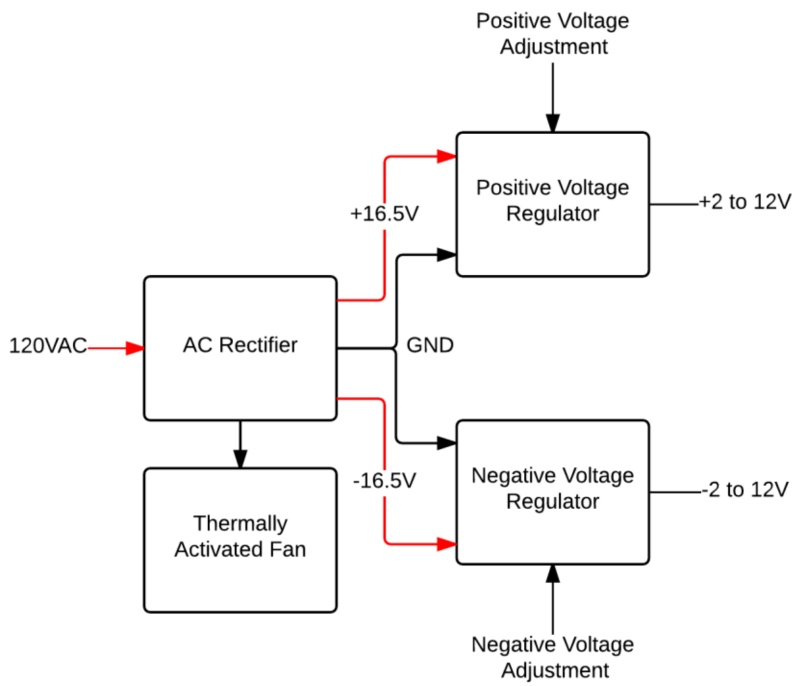

Figure 1: Basic Power Supply Diagram

5.2.1. Top level interface definition

Name	Type	Description
AC Input	Input	Frequency: 60Hz Voltage: 120VAC Maximum Current: .5 Amps
Positive Voltage Output	Output	Voltage Range: o Supply a minimum of 2 volts for all loads (lower is better) o Be capable of supplying 12 volts while loaded to 900mA Max Current @ All Voltages: .9 Amp Current Limit: 1 Amps +/- 10% Maximum Ripple: .75 V_{PP}
Negative Voltage Output	Output	Voltage Range: o Supply a minimum of -2 volts for all loads (lower is better) o Be capable of supplying -12 volts while loaded to 900mA Max Current @ All Voltages: .9 Amp Current Limit: 1 Amps +/- 10% Maximum Ripple: .75 V_{PP}
Positive Supply Over Current Indicator (optional)	Output	Turn On: 1 Amps +/- 10% Indication: Visual or Audible
Negative Supply Over Current Indicator (optional)	Output	Turn On: 1 Amps +/- 10% Indication: Visual or Audible
Positive Voltage Adjustment	Input	Adjustment Method: Dial/Potentiometer Full Scale: Single Turn
Negative Voltage Adjustment	Input	Adjustment Method: Dial/Potentiometer Full Scale: Single Turn
V+	Internal Power	Nominal Voltage: 18VDC Max Current: 900mA Maximum Ripple: .75 V_{PP}
V-	Internal Power	Nominal Voltage: -18VDC Max Current: 900mA Maximum Ripple: .75 V_{PP}
Fan Supply	Internal Power	Nominal Voltage: 18VDC Max Current: 900mA Maximum Ripple: .75 V_{PP}

Table 1: Top-Level Specifications

6. Functional Unit Descriptions
6.1. Chassis
6.1.1. Chassis Drawings

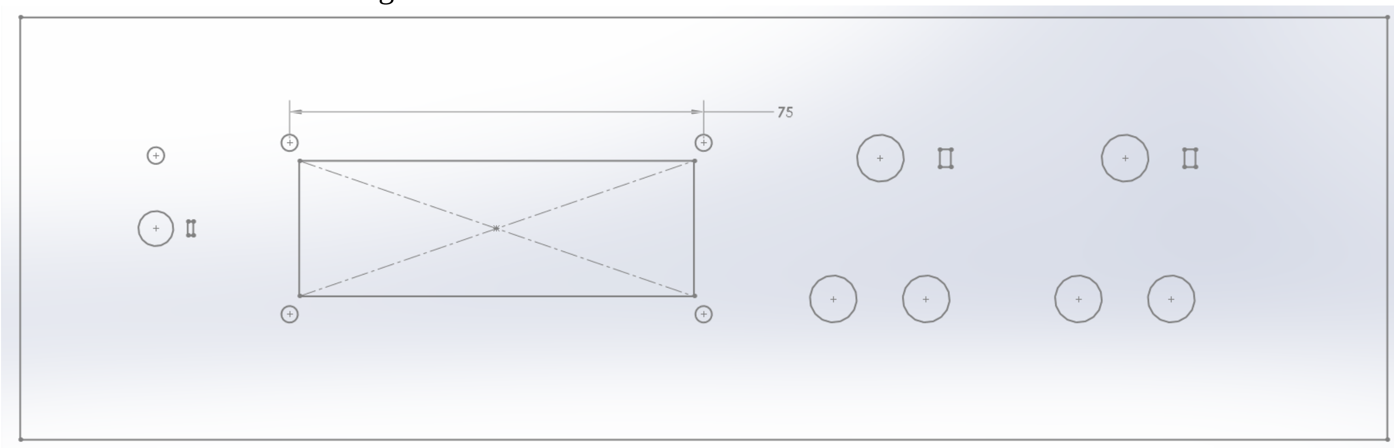

Figure 2: Front Panel Sketch

Figure 3: Rear Panel Sketch

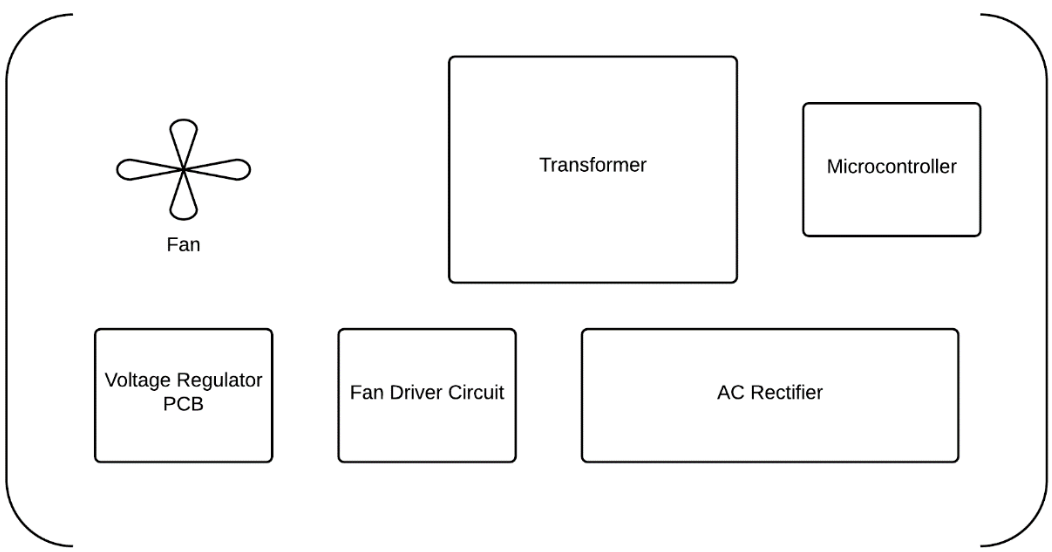

Figure 4: Rough outline of the interior of the case

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6.2. AC Rectifier Block Diagram

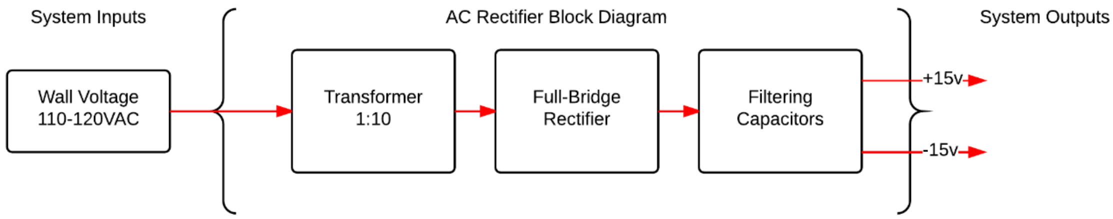

Figure 5: AC Rectifier Block Diagram

Name	Type	Description
System Input Wall Voltage In	Input	Frequency: 60Hz Voltage: 120VAC Maximum Current: .5 Amps
Positive Rectified Voltage Output	Output	Voltage Range: ~16 volts to 18volts
Negative Rectified Voltage Output	Output	Voltage Range: ~-16 volts to -18 volts
Reference	Output	The reference voltage (GND)

Table 2: AC Rectifier Interface Diagram

6.2.1. AC Rectifier interface definition

This is a detailed tabular description of the interfaces in and out of the functional unit. At this level and below, interface definitions will likely become more detailed.

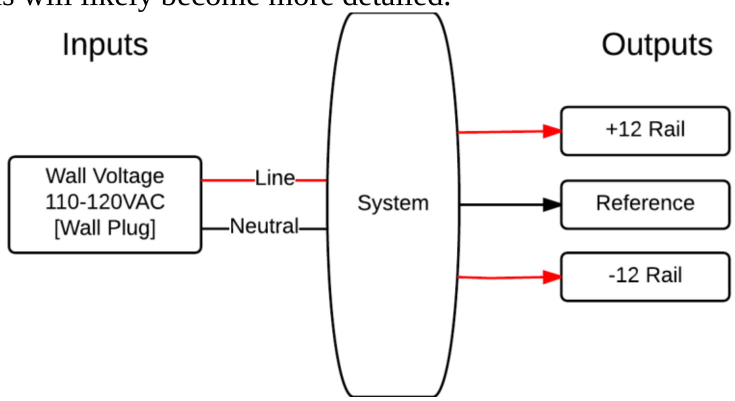

Figure 6: AC Rectifier Interface Definition

6.2.2. AC Rectifier Schematic and Theory of Operation

This section should cover how the schematic you have designed operates. It needs to be as detailed as you can make it, and include information about when your schematic does not, for example maybe at high temperatures.

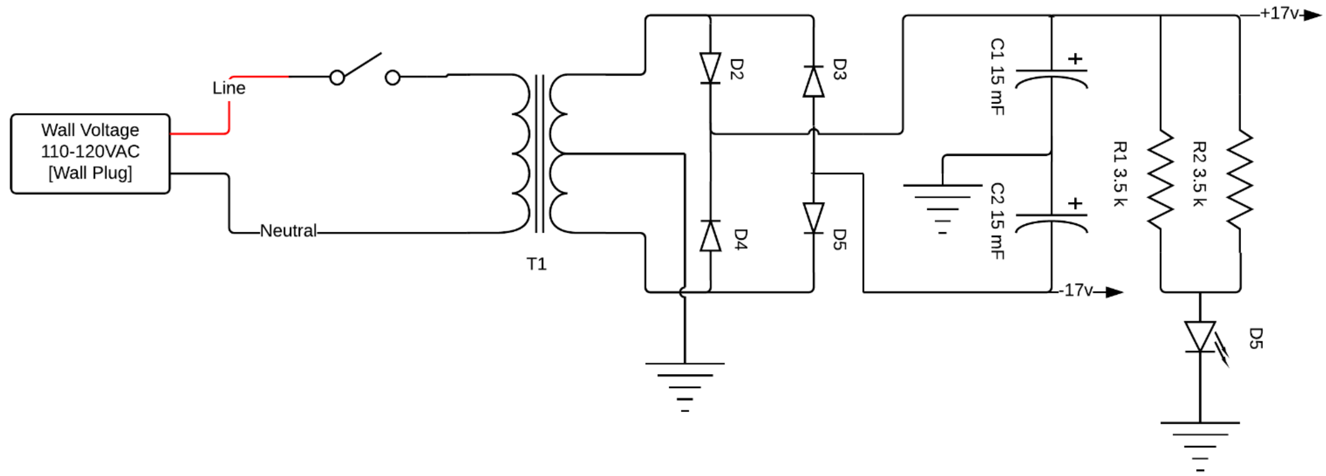

Figure 7: AC Rectifier Schematic Diagram

For this device, an input “wall” AC voltage is rectified and then filtered into DC voltage, which is 12VRMS or about 17VDC. The measured ripple for this circuit is less than .75 Vpp.

6.3. Positive Voltage Regulator Block Diagram

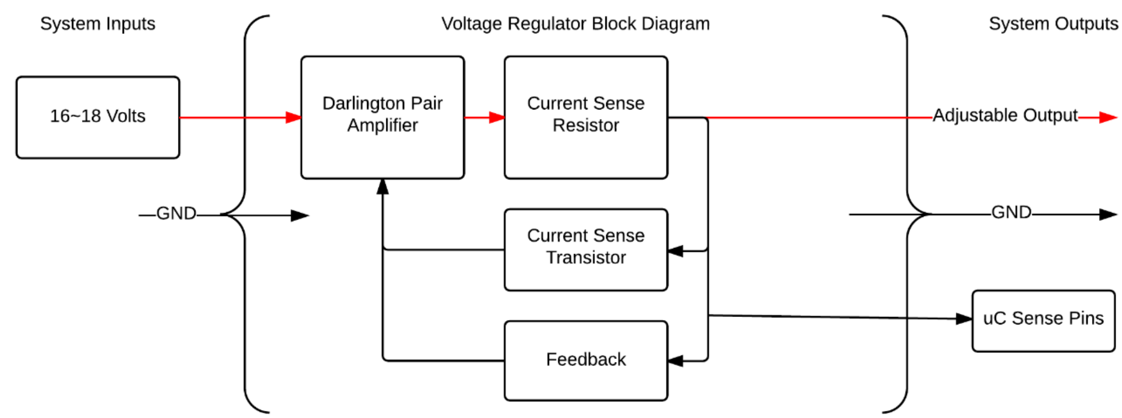

Figure 8: Positive Voltage Regulator Block Diagram

6.3.1. Positive Voltage Regulator interface definition

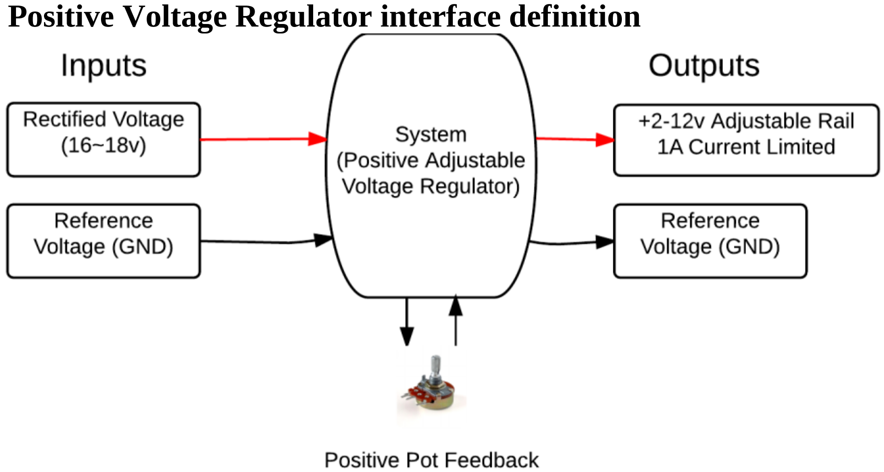

Figure 9: Positive Voltage Regulator Interface

Name	Type	Description
Rectified Voltage In	Input	Voltage Range: ~16 volts to 18volts
Reference	Input	The reference voltage (GND)
Positive Regulated Voltage Output	Output	Voltage Range: ○ Supply a minimum of 2 volts for all loads ○ Be capable of supplying 12 volts while loaded to 900mA Max Current @ All Voltages: .9 Amp Current Limit: 1 Amps +/- 10% Maximum Ripple: .75 V_{PP}
Reference	Output	The reference voltage (GND)
Potentiometer Feedback	I/O	The Potentiometer is external to the PCB so it was included in this definition, it is used internally to the voltage regulator, but mounted to the case.
uC Sense Pins	Output	Outputs a voltage-divider with the regulated voltage so that the microcontroller can read the output.

Table 3: Table describing the voltage regulator interface specification

6.3.2. Positive Voltage Regulator Schematic and Theory of Operation

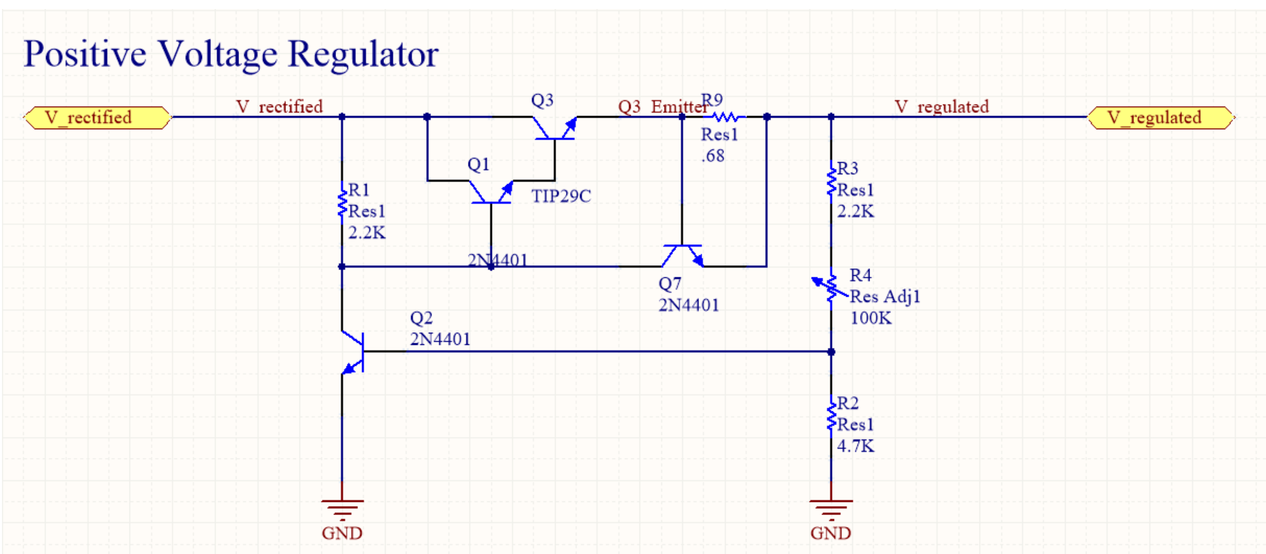

Figure 10: Positive Voltage Regulator Schematic Diagram

The output voltage is set by the voltage divider that is created by the resistors in my circuit. The output current doesn't affect the voltage across the load because the voltage is set by the voltage divider, so that when the "output voltage" drops, the feedback of it dropping then increases the current going into the base of the Darlington pair, which raises the voltage back to what it was supposed to be.

The potentiometer is able to change this output voltage by changing the characteristics of the voltage divider.

The current limiting also takes advantage of this feedback system, as when the voltage across the current limiting resistor is greater than Vbe(on) for the current limiting transistor, it's feedback reduces the voltage, and therefore the current that flows through the load.

6.4. Negative Voltage Regulator Block Diagram

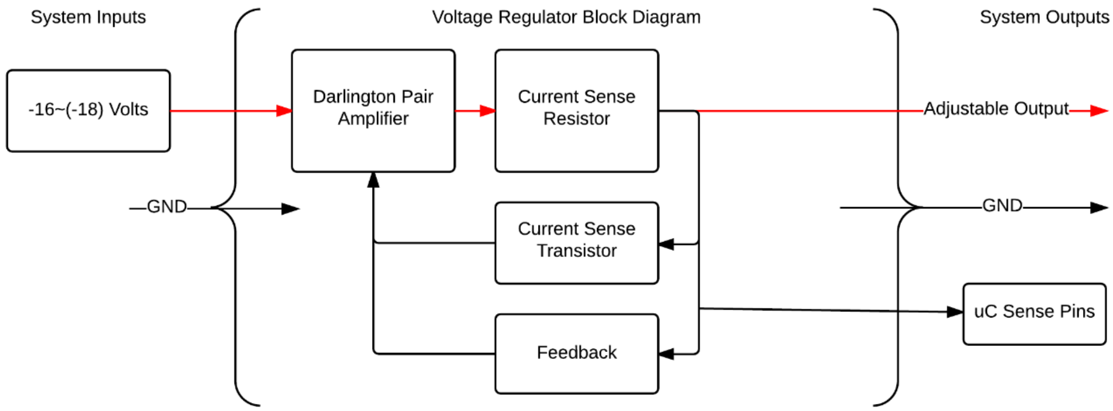

Figure 11: Negative Voltage Regulator Block Diagram

6.4.1. Negative Voltage Regulator interface definition

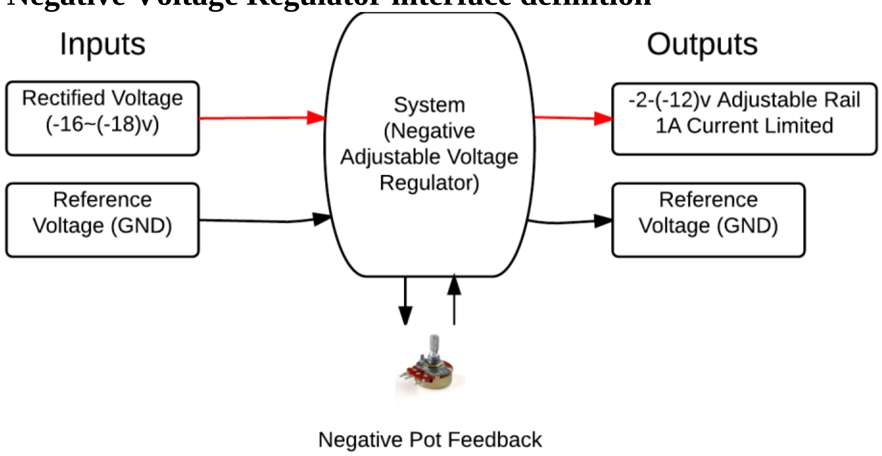

Figure 12: Negative Voltage Regulator Specification

Name	Type	Description
Negative Rectified Voltage In	Input	Voltage Range: ~-16 volts to -18volts
Reference	Input	The reference voltage (GND)
Negative Regulated Voltage Output	Output	Voltage Range: ○ Supply a maximum of -2 volts for all loads ○ Be capable of supplying -12 volts while loaded to 900mA Max Current @ All Voltages: .9 Amp Current Limit: 1 Amps +/- 10% Maximum Ripple: .75 V_{PP}
Reference	Output	The reference voltage (GND)
Potentiometer Feedback	I/O	The Potentiometer is external to the PCB so it was included in this definition, it is used internally to the voltage regulator, but mounted to the case.
uC Sense Pins	Output	Outputs a voltage-divider with the regulated voltage so that the microcontroller can read the output.

Table 4: Table describing the voltage regulator interface spec

6.4.2. Negative Voltage Regulator Schematic and Theory of Operation

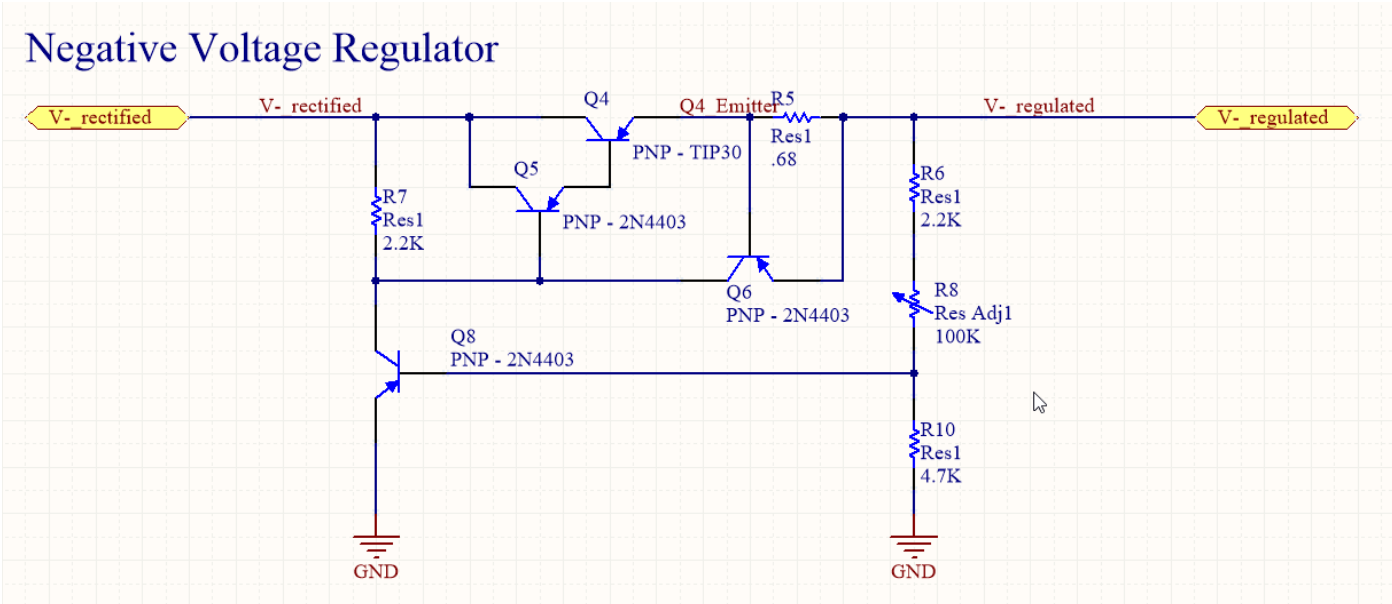

Figure 13: Negative Voltage Regulator Schematic Diagram

The theory of operation for the negative voltage regulator is the same as the positive one, except for all of the currents are flowing "backwards", from the "top of the circuit" in the schematic to the "bottom".

The output voltage is set by the voltage divider that is created by the resistors in my circuit. The output current doesn't affect the voltage across the load because the voltage is set by the voltage divider, so that when the "output voltage" drops, the feedback of it dropping then increases the current going into the base of the Darlington pair, which raises the voltage back to what it was supposed to be.

The potentiometer is able to change this output voltage by changing the characteristics of the voltage divider.

The current limiting also takes advantage of this feedback system, as when the voltage across the current limiting resistor is greater than Vbe(on) for the current limiting transistor, it's feedback reduces the voltage, and therefore the current that flows through the load.

6.5. Fan Controller

6.5.1. Fan Controller interface definition

Name	Type	Description
Positive Rectified Voltage	Input	Voltage Range: ~-16 volts to -18volts
GND (Reference)	Input	The reference voltage (GND)
Fan GND	Output	The negative size of the fan, assuming the positive is connected to the Positive Rectified Voltage

Table 5: Fan Controller Interface Definition

6.5.2. Fan Controller Schematic and Theory of Operation

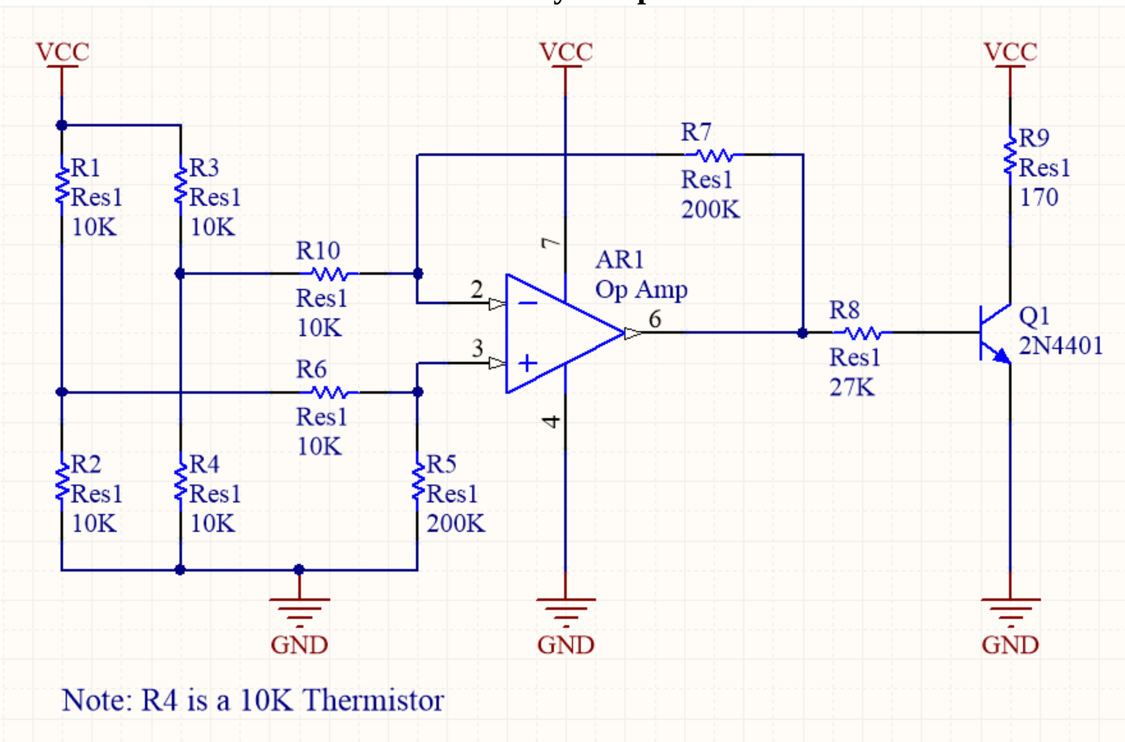

Figure 14: Fan Controller Schematic Diagram

NOTE: R9 is the fan, it is modeled as a resistor for simulation purposes.

This circuit used voltage dividers and an Operational Amplifier to use feedback from the OpAmp and the Thermistor in the circuit to control the output current through the Fan.

When the Thermistor in the above diagram lowers resistance as it gets hotter, than the OpAmp tries to compensate by outputting current, which biases the transistor and allows current to flows through the Fan.

6.6. Capacitor Discharge

This section was omitted due to time constraints.

6.7. Extra Credit Circuits

6.7.1. Extra Credit Circuits interface definition

Name	Type	Description
Positive Rectified Voltage	Input	Voltage Range: ~-16 volts to -18volts
GND (Reference)	Input	The reference voltage (GND)
Fan GND	Output	The negative size of the fan, assuming the positive is connected to the Positive Rectified Voltage

Table 6: Extra Credit Interface Definition

6.7.2. Extra Credit Circuits Schematic and Theory of Operation

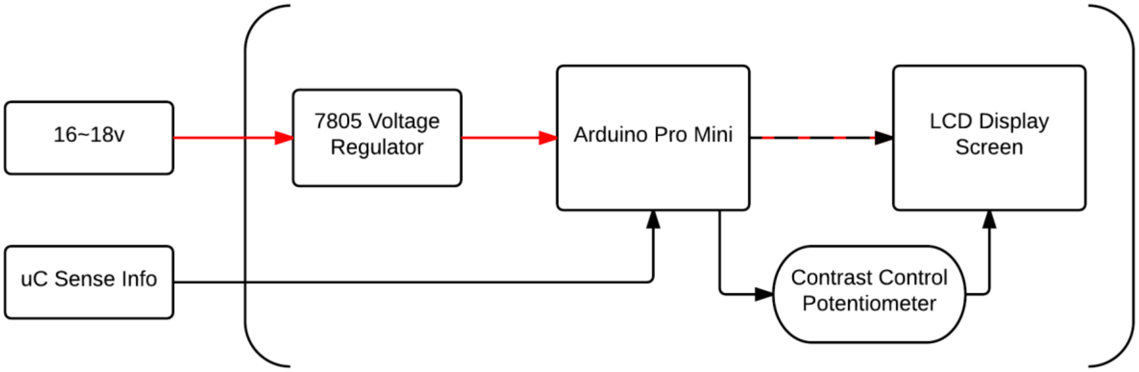

Figure 15: Block Diagram for Extra Credit LCD Display

For an extra credit, and to add to the usefulness of the final design, I added a Microcontroller that is programmed to output the output voltages of both the positive and negative values onto an LCD that was laser cut and mounted into the front panel. This allows the device to be used independently of an “voltage-setting” multi-meter.

The voltage sense lines needed to be regulated down to 5 volts so that they could be interpreted by the Microcontroller successfully, so voltage dividers were used, as they are linear regulators and therefore simple math can determine the output voltage on the microcontroller.

Figure 16: Picture of the Display measuring the voltage on the Power Supply

7. Testing

7.1. Block Tests

For this project Items that fall under functional tests are listed below along with recommended testing procedures**.**

7.1.1. AC Rectifier - Two channels, one positive and the other negative when referenced to ground

1. Power the AC rectifier with wall input.
2. Set the multimeter to measure DC voltage.
3. Connect the power supply's ground to the ground of the multimeter.
4. Connect one output of the AC rectifier to the voltage input of the multimeter.
5. Check the reading on the multimeter.
6. Connect the other output of the rectifier to the voltage input of the multimeter.
7. Check the reading on the multimeter.

PASS: One output reads positive value and the other one reads negative value when referenced to ground.

FAIL: Both outputs are positive, negative, or zero when referenced to ground.

7.1.2. AC Rectifier - Rectify 60Hz, 120 VAC_{rms} to DC

1. Power the AC rectifier with wall input.
2. Connect the power supply's ground to the ground of the multimeter.
3. Connect one output of the AC rectifier to the voltage input of the oscilloscope.
4. Check the oscilloscope output.
5. Connect the other output of the AC rectifier to the voltage input of the oscilloscope.
6. Check the oscilloscope output.

PASS: The oscilloscope reads DC voltage for both rectifier outputs.

FAIL: The oscilloscope reads AC voltage or no voltage for either output.

7.1.3.AC Rectifier - Capable of supplying at least 900mA amp per channel continuously

1. Follow the instruction on the ECE322 test station.
2. Connect the ECE322 test station to the AC rectifier outputs.
3. Connect the ECE322 test station to an ampmeter.
4. Switch the station to test channel 1.
5. Decrease the resistance of the test station until the ampmeter reads at least 900mA
6. Switch the station to test channel 2.
7. Decrease the resistance of the test station until the ampmeter reads at least 900mA

PASS: The ampmeter for both channels reads at least 900mA.

FAIL: The ampmeter does not read at least 900mA for either channel.

7.1.4. AC Rectifier - Voltage ripple out of the filter is less than 0.75V_{p-p} per channel with both channels fully loaded to 900mA

1. Follow the instruction on ECE322 test station.
2. Connect ECE322 test station to the AC rectifier outputs.
3. Connect the ECE322 test station to an ampmeter.
4. Switch the station to test channel 1.
5. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
6. Connect VOLT+ of the test station to the voltage input of the oscilloscope.
7. Check oscilloscope waveform.
8. Switch the station to test channel 2.
9. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
10. Connect VOLT+ of the test station to the voltage input of the oscilloscope.
11. Check oscilloscope waveform.

PASS: The oscilloscope waveform shows voltage ripples smaller than 0.75Vpp for both channels.

FAIL: The oscilloscope waveform shows voltage ripple larger than 0.75Vpp for either channel.

7.1.5. AC Rectifier - Easily accessible AC power switch

Visual inspection by the TA

PASS: The AC power switch is mounted on the front or back side of the power supply and can turn the system on and off

FAIL: The AC power switch is not mounted on the front or back side of the power supply or cannot turn the system on and off

7.1.6. AC Rectifier - A clearly visible power indication light

1. Flip the power switch to "on" mode.
2. Check the indication light.

PASS: The power indication light is mounted on the front or back side of the power supply and can turn on and off with the switch

FAIL: The power indication light is not mounted on the front or back side of the power supply or cannot turn on and off with the switch

7.1.7. AC Rectifier - Assembled safely and with no electrical hazards and utilizes a safety fuse

1. Make sure the power supply is not plugged into the wall.
2. Open the fuse socket.
3. Check if a fuse (at least 1 amp) is present.

PASS: The power supply is assembled safely without loose wire(s) and potential shortage, and a fuse is present in the fuse socket.

FAIL: The power supply is not assembled safely or has loose wire(s) or shorts, or a fuse is not present in the fuse socket.

7.1.8. Voltage Regulators - One positive channel when referenced to ground is capable of supplying at least 900mA continuously (2 ~ 12V)

1. Follow the instruction on ECE322 test station.
2. Connect channel 1 of the ECE322 test station to the power supply's ground and positive channel.
3. Connect the ECE322 test station to an ampmeter.
4. Connect the ECE322 test station to a voltmeter.
5. Switch the station to test channel 1.
6. Set the power supply to output 12V or higher.
7. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
8. Check both the voltmeter and the ampmeter.
9. Set the power supply to output 2V or lower.
10. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
11. Check both the voltmeter and the ampmeter.

PASS: ±10% of 12V and ±10% of 900mA can be displayed at same time on the voltmeter and ampmeter AND ±10% of 2V and ±10% of 900mA can be displayed at same time on the voltmeter and ampmeter.

FAIL: ±10% of 12V and ±10% of 900mA cannot be displayed at same time on the voltmeter and ampmeter OR ±10% of 2V and ±10% of 900mA cannot be displayed at same time on the voltmeter and ampmeter.

7.1.9. Voltage Regulators - One negative channel when referenced to ground is capable of supplying at least -900mA continuously (-2 ~ -12V)

1. Follow the instruction on ECE322 test station.
2. Connect channel 2 of the ECE322 test station to the power supply's ground and negative channel.
3. Connect the ECE322 test station to an ampmeter.
4. Connect the ECE322 test station to a voltmeter.
5. Switch the station to test channel 2.
6. Set the power supply to output -12V or higher magnitude.
7. Decrease the resistance of the test station until the ampmeter reads at least -900mA.
8. Check both the voltmeter and the ampmeter.
9. Set the power supply to output -2V or lower magnitude.
10. Decrease the resistance of the test station until the ampmeter reads at least -900mA.
11. Check both the voltmeter and the ampmeter.

PASS: ±10% of -12V and ±10% of -900mA can be displayed at same time on the voltmeter and ampmeter AND ±10% of -2V and ±10% of -900mA can be displayed at same time on the voltmeter and ampmeter.

FAIL: ±10% of -12V and ±10% of -900mA cannot be displayed at same time on the voltmeter and ampmeter OR ±10% of -2V and ±10% of -900mA cannot be displayed at same time on the voltmeter and ampmeter.

7.1.10. Voltage Regulators - Must supply a range of at least 2 ~ 12V under all load conditions

1. Make sure the power supply does not have a load.
2. Using a voltmeter and measure the positive channel of the power supply with reference to its ground.
3. Adjust the positive channel control knob of the power supply to output the highest voltage.
4. Check the voltmeter.
5. Adjust the positive channel control knob of the power supply to output the lowest voltage.
6. Check the voltmeter.
7. Adjust the negative channel control knob of the power supply to output the highest magnitude of voltage.
8. Check the voltmeter.
9. Adjust the negative channel control knob of the power supply to output the lowest magnitude of voltage.
10. Check the voltmeter.

PASS: The power supply have passed the previous two tests, AND can supply a range of at least 2 ~ 12V with no load.

FAIL: The power supply did not pass one or both of the previous two tests, OR cannot supply a range of at least 2 ~ 12V with no load.

7.1.11. Voltage Regulators - Positive Channel has overload protection to limit current to 1A ±10%

1. Follow the instruction on ECE322 test station.
2. Connect channel 1 of the ECE322 test station to the power supply's ground and positive channel.
3. Connect the ECE322 test station to an ampmeter.
4. Switch the station to test channel 1.
5. Decrease the resistance of the test station until the ampmeter reads at least 1A.
6. Check the ampmeter.
7. Slowly keep on decreasing the resistance until minimum resistance is reached.
8. Check the ampmeter.

PASS: 1A ±10% was observed for positive channel.

FAIL: 1A ±10% was not observed for positive channel.

7.1.12. Voltage Regulators – Negative Channel has overload protection to limit current to -1A ±10%

1. Follow the instruction on ECE322 test station.
2. Connect channel 2 of the ECE322 test station to the power supply's ground and negative channel.
3. Connect the ECE322 test station to an ampmeter.
4. Switch the station to test channel 2.
5. Decrease the resistance of the test station until the ampmeter reads at least 1A.
6. Check the ampmeter.
7. Slowly keep on decreasing the resistance until minimum resistance is reached.
8. Check the ampmeter.

PASS: -1A ±10% was observed for negative channel.

FAIL: -1A ±10% was not observed for negative channel.

7.1.13. Voltage Regulators - Power supply assembled safely and with no electrical hazards

1. Open the black cover of the power supply.
2. Examine the inside.

PASS: The power supply is assembled safely without loose wire(s), loose board(s), and potential shortage.
FAIL: The power supply is not assembled safely with loose wire(s), or loose board(s), or potential shortage.

7.1.14. Voltage Regulators - BJT Usage

1. Visually verify components used. All semiconductor components used in construction of voltage regulator blocks must BJT components.

PASS: All silicon components are BJTs
FAIL All silicon components are not BJTs

7.1.15. Thermal Protection Block - Functional cooling fan

1. Turn on the power supply and wait for 30 seconds.
2. Observe the fan.
3. Touch the thermistor with two fingers.
4. Observe the fan.

PASS: The fan is not running at 70^o F (room temperature) AND the fan starts to run at around 95^o F (when touched with fingers).
Fail: The fan is running at below 70^o F AND/OR the fan does not start to run at above 95^o F.

7.1.16. Thermal Protection Block - Design should use an OPAMP and a BJT or MOSFET to control the fan.

1. Check the fan circuit with the designed schematic.

PASS: The fan circuit was designed using an OPAMP and a BJT or MOSFET.
FAIL: The fan circuit was designed without using an OPAMP or a BJT or MOSFET.

7.1.17. Thermal Protection Block - The fan and its control circuit are assembled safely and with no electrical hazards.

1. Short the power supply's positive channel to ground.
2. Wait for about 20 ~ 30 seconds.
3. Check the fan.

PASS: The fan turns on after shorting the positive output to ground, AND is assembled without any loose wire(s), loose board(s), and no potential shortage.
FAIL: The fan does not turn on within 30 seconds after shorting the positive output to ground, OR is assembled with loose wire(s), loose board(s), or has potential shortage, OR the power supply is damaged due to shortage.

7.1.18. Capacitor Discharge Block - The filter capacitor for the positive channel discharges to under 3 volts in 5 seconds or less when the main power switch is turned to off AND no load presents on the output of the supply.

1. Connect a voltmeter to the power supply's positive channel and ground.
2. Turn on the power supply and wait for 30 seconds.
3. Turn off the power supply and wait for 5 seconds.
4. Check the voltmeter.

PASS: The voltmeter displays less than 3 volts after 5 seconds. **.**
FAIL: The voltmeter displays more than 3 volts after 5 seconds.

7.1.19. Capacitor Discharge Block - The filter capacitor for the negative channel discharges to under magnitude of -3 volts in 5 seconds or less when the main power switch is turned to off AND no load presents on the output of the supply.

1. Connect a voltmeter to the power supply's negative channel and ground.
2. Turn on the power supply and wait for 30 seconds.
3. Turn off the power supply and wait for 5 seconds.
4. Check the voltmeter.

PASS: The voltmeter displays less than magnitude of -3 volts after 5 seconds. **.**

FAIL: The voltmeter displays more than magnitude of -3 volts after 5 seconds.

7.1.20. Capacitor Discharge Block - Design used one (or more) MOSFETS

1. Check the discharge circuit with the designed schematic.

PASS: The discharge circuit was designed using at least one MOSFET.

FAIL: The discharge circuit was designed without at least one MOSFET.

7.1.21. Capacitor Discharge Block - Capacitor ripple voltage still meets spec outlined in earlier sections.

1. Connect the power supply ground to the oscilloscope ground.
2. Connect the power supply positive channel to the oscilloscope
3. Check oscilloscope waveform.
4. Connect the power supply ground to the oscilloscope ground.
5. Connect the power supply negative channel to the oscilloscope
6. Check oscilloscope waveform.

PASS: The oscilloscope waveform shows voltage ripples smaller than 0.75Vpp for both channels.

FAIL: The oscilloscope waveform shows voltage ripple larger than 0.75Vpp for either channel.

7.2. System Tests

7.2.1. Each channel must be capable of supplying at least 900mA per channel continuously

1. Follow the instruction on ECE322 test station.
2. Connect the ECE322 test station to the power supply's ground.
3. Connect channel 1 of the ECE322 test station to the power supply's positive channel.
4. Connect channel 2 of the ECE322 test station to the power supply's negative channel.
5. Connect the ECE322 test station to an ampmeter.
6. Switch the station to test channel 1.
7. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
8. Switch the station to test channel 2.
9. Decrease the resistance of the test station until the ampmeter reads at least 900mA.

PASS: 900mA ±10% can be outputted for both channels.

FAIL: 900mA ±10% cannot be outputted for both channels.

7.2.2. Voltage output between ±2 and ±12 volts under 900mA load

1. Follow the instruction on ECE322 test station.
2. Connect the ECE322 test station to the power supply's ground.
3. Connect channel 1 of the ECE322 test station to the power supply's positive channel.
4. Connect channel 2 of the ECE322 test station to the power supply's negative channel.
5. Connect the ECE322 test station to an ampmeter.
6. Connect the ECE322 test station to a voltmeter.
7. Switch the station to test channel 1.
8. Set the power supply to output 12V or higher.
9. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
10. Check both the voltmeter and the ampmeter.
11. Switch the station to test channel 2.
12. Set the power supply to output magnitude of -12V or higher.
13. Decrease the resistance of the test station until the ampmeter reads at least magnitude of -900mA.
14. Check both the voltmeter and the ampmeter.
15. Set the power supply to output magnitude of -2V or lower.
16. Decrease the resistance of the test station until the ampmeter reads at least magnitude of -900mA.
17. Check both the voltmeter and the ampmeter.
18. Switch the station to test channel 1.
19. Set the power supply to output 2V or lower.
20. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
21. Check both the voltmeter and the ampmeter.

PASS: ±10% of 12V and ±10% of 900mA can be displayed at same time on the voltmeter and ampmeter AND ±10% of 2V and ±10% of 900mA can be displayed at same time on the voltmeter and ampmeter.

FAIL: ±10% of 12V and ±10% of 900mA cannot be displayed at same time on the voltmeter and ampmeter OR ±10% of 2V and ±10% of 900mA cannot be displayed at same time on the voltmeter and ampmeter.

7.2.3. An overload to limit current to ±1A ±10%

1. Follow the instruction on ECE322 test station.
2. Connect channel 1 of the ECE322 test station to the power supply's ground and positive channel.
3. Connect channel 2 of the ECE322 test station to the power supply's ground and negative channel.
4. Connect the ECE322 test station to an ampmeter.
5. Switch the station to test channel 1.
6. Decrease the resistance of the test station until the ampmeter reads at least 1A.
7. Check the ampmeter.
8. Slowly keep on decreasing the resistance until minimum resistance is reached.
9. Check the ampmeter.
10. Switch the station to test channel 2.
11. Decrease the resistance of the test station until the ampmeter reads at least -1A.
12. Check the ampmeter.
13. Slowly keep on decreasing the resistance until minimum resistance is reached.
14. Check the ampmeter.

PASS: ±1A ±10% was observed for both positive and negative channels.

FAIL: ±1A ±10% was not observed for either channel.

7.2.4. Safely equipped with a cooling fan that should not normally be running at 70ºF, but should reach rated speed around 95ºF

1. Turn on the power supply and wait for 30 seconds.
2. Observe the fan.
3. Touch the thermistor with two fingers.
4. Observe the fan.
5. Short the power supply's positive channel to ground.
6. Wait for about 20 ~ 30 seconds.
7. Check the fan.

PASS: The fan is not running at 70º F (room temperature) AND the fan starts to run at around 95º F (when touched with fingers), AND The fan turns on after shorting the positive output to ground, AND is assembled without any loose wire(s), loose board(s), and no potential shortage.

Fail: The fan is running at below 70º F AND/OR the fan does not start to run at above 95º F, AND The fan does not turn on within 30 seconds after shorting the positive output to ground, OR is assembled with loose wire(s), loose board(s), or has potential shortage, OR the power supply is damaged due to shortage.

7.2.5. Discharges the filter capacitor on each channel to under 3 volts in 5 seconds or less when the main power switch is turned to off and there is no load present on the output of the supply.

1. Connect a voltmeter to the power supply's positive channel and ground.
2. Turn on the power supply and wait for 30 seconds.
3. Turn off the power supply and wait for 5 seconds.
4. Check the voltmeter.
5. Connect a voltmeter to the power supply's negative channel and ground.
6. Turn on the power supply and wait for 30 seconds.
7. Turn off the power supply and wait for 5 seconds.
8. Check the voltmeter.

PASS: The voltmeter displays less than 3 volts after 5 seconds for both channels.

FAIL: The voltmeter displays more than 3 volts after 5 seconds for either channel.

7.2.6. External connections for leads and voltage adjustment

Visual inspection by the TA

PASS: The power supply has at least three external connections and two voltage adjustments.

FAIL: The power supply does not have at least three external connections and two voltage adjustments.

7.2.7. Assembled safely and with no electrical hazards

1. Open the black cover of the power supply.
2. Examine the inside.

PASS: The power supply is assembled safely without loose wire(s), loose board(s), and potential shortage.

FAIL: The power supply is not assembled safely with loose wire(s), or loose board(s), or potential shortage.

7.2.8. Voltage ripple out of each channel less than 0.75V per channel with both channels fully loaded to 900mA

1. Follow the instruction on ECE322 test station.
2. Connect ECE322 test station to the power supply outputs.
3. Connect the ECE322 test station to an ampmeter.
4. Switch the station to test channel 1.
5. Set the output voltage to 12VDC and -12VDC as appropriate.
6. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
7. Connect VOLT+ of the test station to the voltage input of the oscilloscope.
8. Check oscilloscope waveform.
9. Switch the station to test channel 2.
10. Decrease the resistance of the test station until the ampmeter reads at least 900mA.
11. Connect VOLT+ of the test station to the voltage input of the oscilloscope.
12. Check oscilloscope waveform.

PASS: The oscilloscope waveform shows voltage ripples smaller than 0.75Vpp for both channels.

FAIL: The oscilloscope waveform shows voltage ripple larger than 0.75Vpp for either channel.

7.2.9. Utilizes a safety fuse

1. Make sure the power supply is not plugged into the wall.
2. Open the fuse socket.
3. Check if a fuse (at least 1 amp) is present.

PASS: A fuse is present in the fuse socket.

FAIL: A fuse is not present in the fuse socket.

7.2.10. Easily accessible AC power switch

Visual inspection by the TA

PASS: The AC power switch is mounted on the front or back side of the power supply and can turn the system on and off

FAIL: The AC power switch is not mounted on the front or back side of the power supply or cannot turn the system on and off.

7.2.11. A clearly visible power indication light

1. Flip the power switch to “on” mode.
2. Check the indication light.

PASS: The power indication light is mounted on the front or back side of the power supply and can turn on and off with the switch

FAIL: The power indication light is not mounted on the front or back side of the power supply or cannot turn on and off with the switch

8. Parts List and Cost Analysis

Item Name	Link	Part Designato	Vendor	Vender No	Price	Quantity	Total	Notes	Grand Total:	$80.62
Transformer	[link]	T1	Jameco	221373	$13.95	1	$13.95			
AC Switch	[link]	SW1	Jameco	76523	$1.49	1	$1.49			
Fuse Holder	[link]		Jameco	108792	$2.49	1	$2.49			
Fuse	[link]	F1	Jameco	103908	$0.29	1	$0.29			
Filter Caps	[link]	C1, C2	DigiKey	565-2633-ND	$3.32	2	$6.64			
Indicator LED	[link]	D1	Jameco	253690	$0.06	1	$0.06			
Mounting Hardware	N/A		OSURC	Unknown	$4.00	1	$4.00	Estimate		
Rectifier Diodes	[link]	D2,D3,D4,D5	DigiKey	1N4004DICT-N	$0.13	4	$0.52			
Misc Wire	N/A	N/A	OSURC	N/A	$4.00	1	$4.00			
Misc Resistors	N/A	N/A	OSU IEEE Store	N/A	$0.05	30	$1.50			
100K Pot	[link]	R4, R8	Jameco	29103	$1.25	2	$2.50			
Plastic Case	N/A	N/A	TekBots	Unknown	$8.95	1	$8.95	Estimate		
2N4401 NPN BJT	[link]	Q1, Q2, Q7	Mouser	512-2N4401BU	$0.22	3	$0.66			
2N4403 PNP BJT	[link]	Q5, Q6, Q8	Jameco	38447	$0.10	3	$0.30			
TIP29 NPN	[link]	Q3	DigiKey	TIP29CFS-ND	$0.56	1	$0.56			
TIP30 BJT	[link]	Q4	Jameco	179346	$0.35	1	$0.35			
Misc Heatshrink	N/A	N/A	OSURC	N/A	$0.50	1	$0.50	Estimate		
Power Cord	[link]	N/A	Jameco	38050	$4.95	1	$4.95	Alternate Part Used		
Power Resistor (.68 Ohm	[link]	R5, R9	DigiKey	P0.68W-1BK-N	$0.34	2	$0.68			
Custom Vreg PCB	[link]	N/A	DFRobot	PCB0001	$10.00	0.1	$1.00	1/10 recieved used		
Thermistor	[link]	Fan: R4	Jameco	207037	$0.59	1	$0.59			
Operational Amplifier	[link]	Fan: U1	Jameco	24539	$0.29	1	$0.29			
LCD Screen	[link]	N/A	EBay	370800705767	$23.28	0.1	$2.33	1/10 recieved used		
7805 Voltage Regulator	[link]	N/A	DigiKey	LM7805-ND	$0.62	1	$0.62			
Arduino Pro Mini	[link]		SparkFun	DEV-11113	$9.95	1	$9.95			
Fan - 12VDC	[link]		Jameco	139601	$3.95	1	$3.95			
Misc Tekbots Protoboard	N/A		TekBots	N/A	$7.50	1	$7.50			

Note: Used custom, propriety BOM format, the original can be found online at https://goo.gl/6XqXrh