

Affordable Power Supply

DESIGN DOCUMENT

Team 47

Client/Advisor: Dr. Gary Tuttle

Adam Simodynes, Benjamin Almquist, Michael Neilson,

Mary Le, Chance Webster, and Krishan Sritharan

sdmay21-47@iastate.edu

Revised: 11/15/2020 Rev 3

Executive Summary

Development Standards & Practices Used

We will be using both passive and active components for this project, along with linear and switch-mode voltage regulators. The software practices we will use the programming language C to program the microcontroller for our project.

IEEE Recommended Practice for Powering and Grounding Electronic Equipment Standard

Summary of Requirements

- Input Voltage
 - $24 V_{RMS}$ AC wall supply
- 4 voltage outputs
 - 2 to 25 VDC
 - 1.5 A max current
 - Standard binding posts output connector
 - -2 to -25VDC
 - 1.5 A max current
 - Standard binding post output connector
 - 0 to 10VDC
 - 1 A max current
 - Standard binding post output connector
 - Fixed 5 VDC
 - 2 A max current
 - Standard USB type A output connector
- Box dimensions of 7 inches long, 4 inches wide, 2 inches deep
- Output display to display the voltage levels
- Cost of final product to be below a hundred dollars

Applicable Courses from Iowa State University Curriculum

EE201, EE230, EE333, EE330

New Skills/Knowledge acquired that was not taught in courses

Selecting a case for the PCB, using a CNC machine, laying out a PCB, designing hardware to support a microcontroller.

Table of Contents

1	Introduction	4
1.1	Acknowledgement	4
1.2	Problem and Project Statement	4
1.3	Operational Environment	4
1.4	Requirements	4
1.5	Intended Users and Uses	4
1.6	Assumptions and Limitations	5
1.7	Expected End Product and Deliverables	5
2	Project Plan	5
2.1	Task Decomposition	5
2.2	Risks And Risk Management/Mitigation	6
2.3	Project Proposed Milestones, Metrics, and Evaluation Criteria	6
2.4	Project Timeline/Schedule	6
2.5	Project Tracking Procedures	6
2.6	Personnel Effort Requirements	7
2.7	Other Resource Requirements	7
2.8	Financial Requirements	7
3	Design	7
3.1	Previous Work And Literature	7
3.2	Design Thinking	7
3.3	Proposed Design	7
3.4	Technology Considerations	8
3.5	Design Analysis	8
3.6	Development Process	8
3.7	Design Plan	8
4	Testing	9
4.1	Unit Testing	9
4.2	Interface Testing	9

4.3	Acceptance Testing	9
4.4	Results	9
5	Implementation	10
6	Closing Material	10
6.1	Conclusion	10
6.2	References	10
6.3	Appendices	10

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Figure 1: Schedule

Table 1: Estimated Time Per Task

Figure 2: Power Supply Block Diagram

1 Introduction

1.1 ACKNOWLEDGEMENT

Our team would like to say thank you to Professor Tuttle for advising and providing financial support in our project. We appreciate all the advice he has given and look forward to working with him more.

1.2 PROBLEM AND PROJECT STATEMENT

With Covid-19 limiting lab availability to students, it is difficult for electrical engineering students to work with any hardware because they do not have power supplies to test their circuits. It would be beneficial for students studying electrical engineering to have access to a power supply at home during this pandemic.

The solution for this problem is to design an affordable power supply with a small form factor that any electrical engineering student can easily build and operate from home. This will allow students to perform any hardware labs for their electrical engineering courses without requiring access to an on-campus lab.

1.3 OPERATIONAL ENVIRONMENT

The operational environment of the power supply will be a student's dorm or apartment. These locations may not be as clean and orderly as lab spaces, so the device should be rugged enough to survive being moved frequently. It may also be exposed to other hazards not found in labs such as food and liquids.

1.4 REQUIREMENTS

The power supply will have four voltage outputs: 1.5 to 25 VDC (1.5A max current), -1.5 to 25VDC (1.5A max current), 0 to 10VDC (1A max current), and 5VDC fixed output (2A max current). The three variable outputs will be accessible through binding posts. The fixed output will be a standard USB type A. The input for the power supply will be a 24- V_{RMS} AC wall supply, with at least 100W input power.

The power supply will have a microcontroller to display output voltage levels, which will be controlled using a rotary encoder. The unit will fit in a case approximately 7 inches long, 4 inches wide, and 2 inches deep. The final cost of the unit should be below 100 dollars.

1.5 INTENDED USERS AND USES

The intended users of the product are electrical and computer engineering students. The uses for the product are to test hardware for electrical and computer engineering courses, more specifically for the hardware laboratories within the courses.

1.6 ASSUMPTIONS AND LIMITATIONS

Assumptions:

- The students have some background knowledge on power supplies and how to properly operate them.
- The product will not be used outdoors.
- The end product will be assembled by the ETG, to avoid any malfunctions of the product.

Limitations:

- The end product will be no larger than 8"x5"x3"
 - Client requirement.
- The product cost will not exceed a hundred dollars.
 - Client requirements

1.7 EXPECTED END PRODUCT AND DELIVERABLES

The deliverables for our product are a working prototype of the product, an instruction manual for building the power supply and how to use it. The prototype will meet all the requirements specified previously. It will come with a PCB, complete set of parts, and a box.

The instruction manual will consist of the list of parts needed to build the power supply and where to purchase them. It will also include a list of instructions for building the power supply and how to operate it.

2 Project Plan

2.1 TASK DECOMPOSITION

The main tasks that need to be completed for the project are designing the circuitry for the power supply, designing the case for the PCB, setting up and coding the microcontroller, and writing the instruction manual.

The main parts of the circuitry that will need to be designed are the linear regulator circuitry, switch mode regulator circuitry, and microcontroller I/O circuitry.

For designing the case, we will need to design a heat dissipation module to keep our components temperature low, along with the user interface design and placement. Another task to complete on the case is the placement of the PCB and other components to fit into the case.

As for coding the microcontroller, we will need to include initialization, operational code, and fault detection

The instruction manual tasks will consist of creating a list of parts needed to build and operate the power supply. We will also need to create a procedure on how to put together the device, along with how to properly and safely operate it.

2.2 RISKS AND RISK MANAGEMENT/MITIGATION

For circuit design, the main risks are heat dissipation problems for the linear regulators and voltage accuracy and ripple problems for the switching regulators. The probability of these causing operational errors is low, probably around 0.2.

For designing the case, the risks are that the PCB will not fit inside the case with components, or that heat will not properly be dissipated out of the box. The probability of these causing functional errors is also low, around 0.1 if we design our PCB carefully.

For the microcontroller, the risks are that there will be bugs in the code that will not be found in standard testing. The probability of these errors is much higher, most likely around 0.7. In order to tackle this risk, we will need to complete thorough testing of our microcontroller code, including testing multiple inputs and outputs and edge cases.

For the instruction manual, the biggest risks are that our instructions will be hard to understand or misinterpreted, leading to a user error that damages the system. This risk is moderately high, at an estimated probability of 0.5. The best way we can combat this is by making our users manual as clear as possible, and by testing it on actual students in order to observe what common mistakes may be made and how to circumvent them.

2.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

The key milestones for our project will be completing each circuit design element and testing them to ensure accuracy, designing and buying a PCB for our project, coding and testing the microcontroller and display, completing the build of the prototype, and completing the instruction manual. For the circuit design completion, we expect the output voltages to be within a tenth of a volt of the expected output. As for the PCB, we expect it to be fully operational and expect it to fit inside the box.

For the microcontroller and its code we expect the display and rotary encoder to be functional and accurately displays the voltage. The prototype must meet all the requirements and be completely built. This includes the PCB, the user interface and accurate testing results. The instruction manual evaluation will be done by our advisor to verify the information is accurate and easy for the user to interpret.

2.4 PROJECT TIMELINE/SCHEDULE

For the project timeline, we utilized a tool called a gantt chart. The gantt chart will allow us to track the progress of each task and who is working on it. We plan to complete the project before May, 2021 to allow for extra time if needed. Each figure represents the tasks to be completed during each month of the semester.

January

* = an automatically calculated cell

TASK NAME	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
Parts Selection								
Linear regulator for 5v fixed output	1/25	25	1/31	6	6	0	Michael	100%
Case for PCB	1/25	25	1/31	6	6	0	Mary	100%
MCU IC	1/25	25	1/31	6	5.7	0.3	Adam	95%
24 VRMS Power Brick	1/25	25	1/31	6	1.8	4.2	Ben	30%
7v Buck Converter -- module or built ?	1/25	25	1/31	6	0.6	5.4	Michael	10%
Linear regulator for MCU	1/25	25	1/31	6	2	4	Mary	100%
Rotary Encoder(s)	1/25	25	1/31	6	0	6	Michael	0%
Switching Regulator	1/25	25	1/31	6	0	6	Ben	0%
Display	1/25	25	1/31	6	0	6	Chance	0%

February

* = an automatically calculated cell

TASK NAME	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
Schematic Design								
Fixed output linear regulator	2/1	1	2/7	6	0	6	Michael	0%
MCU Linear Regulator	2/1	1	2/7	6	0	6		0%
Switching Regulator	2/1	1	2/14	13	0	13		0%
MCU I/O	2/1	1	2/14	13	0	13		0%
Low voltage adjustable circuit	2/1	1	2/21	20	18	2		90%
Negative Voltage adjustable circuit	2/1	1	2/21	20	0	20		0%
Positive voltage adjustable circuit	2/1	1	2/21	20	0	20		0%
Fixed output circuit	2/1	1	2/21	20	0	20		0%
Testing								
Build and test fixed output linear regulator	2/14	14	2/28	14	0	14		0%
Build and test MCU linear regulator	2/14	14	2/28	14	0	14		0%
Build and test switching regulator #1	2/14	14	2/28	14	0	14		0%
Build and test switching regulator #2	2/14	14	2/28	14	0	14		0%

March

* = an automatically calculated cell

TASK NAME	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
Testing								
Build and test low voltage adjustable circuit	3/1	1	3/14	13	0	13		0%
Build and test negative voltage adjustable circuit	3/1	1	3/14	13	0	13		0%
Build and test positive voltage adjustable circuit	3/1	1	3/14	13	0	13		0%
Build and test fixed voltage output circuit	3/1	1	3/14	13	0	13		0%
		30						0%
PCB								
Design PCB	3/15	15	3/21	6	0	6		0%
Order PCB	3/21	21	4/4	14	0	14		0%
		30						0%
Coding microcontroller								
LCD Display Code	3/1	1	4/4	34	0	34		0%
Rotary Encoder Code	3/1	1	4/4	34	0	34		0%
Code for a button	3/1	1	4/4	34	0	34		0%

April

* = an automatically calculated cell

TASK NAME	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
Testing Code								
Testing User Interface code	4/5	5 30	4/11	6	0	6		0% 0%
Prototype								
Build and test prototype	4/12	12 30	4/25	13	0	13		0% 0%
Instruction Manual								
Write Instruction Manual	4/19	19	5/2	13	0	13		0

Figure 1: Project Schedule

2.5 PROJECT TRACKING PROCEDURES

The software used to communicate between group members has been google hangouts. To track our progress on each task, an excel spreadsheet was created in google drive to assign tasks to group members and track their progress. For our files, we have chosen to store them in google drive as well so all members have access to all files.

2.6 PERSONNEL EFFORT REQUIREMENTS

Include a detailed estimate in the form of a table accompanied by a textual reference and explanation. This estimate shall be done on a task-by-task basis and should be the projected effort in total number of person-hours required to perform the task.

List of tasks	Estimated hours to complete
Linear regulator schematic capture	2
Switching regulator schematic capture	5
Microcontroller schematic capture	3
PCB layout	10
Case selected and mechanical design completed	8

Microcontroller programmed	20
Build prototype	10
Test and debug prototype	15
Instruction manual written	10

Table 1: Estimated Time Per Task

2.7 OTHER RESOURCE REQUIREMENTS

Our project will require a power supply, a fabricated prototype PCB, all electrical components, a case, output connectors, soldering equipment, and electrical test equipment.

2.8 FINANCIAL REQUIREMENTS

The main financial requirement consists of purchasing the parts needed for the prototype, along with any parts needed for testing. This includes basic components (resistors, capacitors, and operational amplifiers), the case, microcontroller and other components needed for the project. Another cost will be purchasing a fabricated PCB for our prototype.

3 Design

3.1 PREVIOUS WORK AND LITERATURE

With our project being a low cost power supply, there are many different versions of our product already available. Therefore, there are other similar products in the market. Most of the other DC power supplies on the market have three outputs, 0 to 6 VDC, 0 to 25 VDC, and -25 to 0 VDC. The user interface of these power supplies are buttons to change the selected output and a dial to increase or decrease the voltage of that output. It also has an LCD display to view the output of the power supply. What differentiates our product from other competitors is the cost. Our product is designed to be affordable to students who would not be able to afford a regular power supply. Our power supply will also have a few changes to the selected outputs, such as a fixed 5 VDC output.

3.2 DESIGN THINKING

The details of the design thinking that has driven our design are the operational requirements of the product, and cost effectiveness. Our design is also driven by the need for ease of use and accessibility for students. These needs have determined several design choices from the “ideate” phase, including which parts to use and overall size and complexity. The cost was a large factor in determining which parts to order. To maintain the possibility of low overall cost, our team favored individual parts with low costs.

3.3 PROPOSED DESIGN

So far we have decided on a rough plan for the entire power supply. Part of this was deciding what types of IO we were going to use. The IO are going to use rotary encoders, a simple 2x16 LCD display, a few buttons, and 4 voltage outputs. The way in which we have decided to implement 2 of the 4 voltage outputs is via Buck converters which are controlled by a microcontroller. The adjustable, low voltage supply is done via a circuit with built-in current limiting that can be controlled via a variable voltage. The last of the 4 voltage outputs is done with a linear voltage regulator that has a current limit feature built in at 2A. For the higher voltage supplies (+25 and -25) the buck converters are meant to be efficient and cheaper to implement. For the low voltage supply, the variable voltage-variable current limit circuit that has been designed gives a cleaner output voltage than just using a buck converter alone. It also allows the user to have a current limit feature that can be adjusted if necessary. The fixed output is meant to

provide a 5V output, and using a regulator is an easy and cost effective solution to this. All of the design aspects have been chosen to minimize cost while maintaining as much quality as possible.

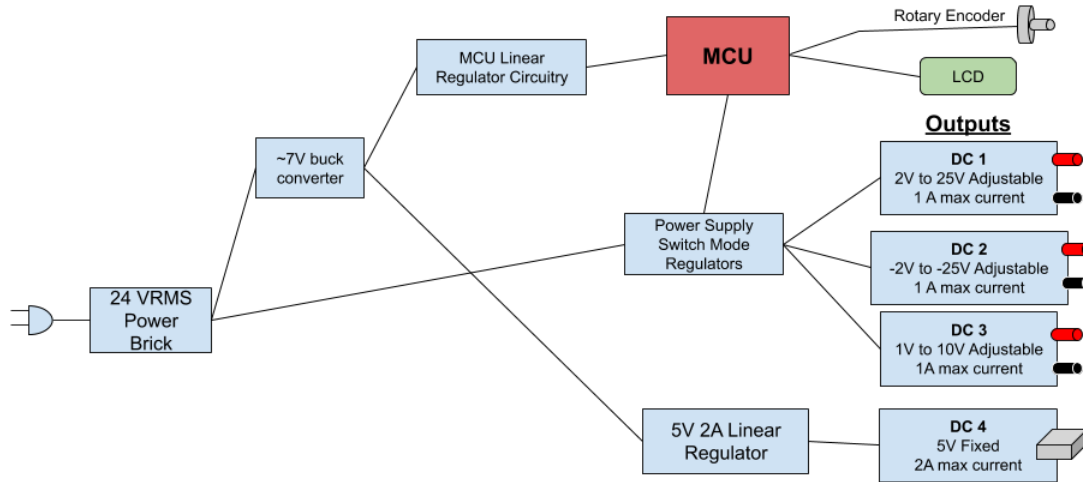


Figure 2: Power Supply Block Diagram

3.4 TECHNOLOGY CONSIDERATIONS

With our design being an affordable power supply, the main consideration to make is the cost of components cheaper than most components, which could affect the overall designs operations and longevity of the product. Another technical consideration to be made could be the size of the unit and the heat output of the unit. Since the case will most likely not be designed to dissipate heat, it will be something to consider when designing and testing our design.

3.5 DESIGN ANALYSIS

The only portion of the design that has been tested is the variable voltage-variable current limit portion. While this part of the circuit was tested successfully, it could still be better. What could be improved upon is making the steady state tracking of the circuit when fed a step response as an input would be able to track the output as expected. For example in this circuit we wanted the output to be exactly 2 times the input but the output would settle at 1.99 times the input. We can iterate on the design to make the output exactly 2 times the output. The way that we can modify the design to fit this would be to add an integrator in the feed forward path of the power supply.

3.6 DEVELOPMENT PROCESS

We have been using a waterfall development process so far in our project. For each part of our design, we have focused on requirements capture first, then moved to actual schematic capture and parts selection. Eventually, we will be able to design and test our PCB.

3.7 DESIGN PLAN

Our design is powered by an AC electrical outlet that goes to a 24 VRMS DC converter. This input then powers a microcontroller and several regulators that determine output voltage levels. The microcontroller interfaces with a rotary encoder, an LCD, and the switching regulators. The rotary encoder allows the user to adjust to their desired voltage level. The LCD prints the current output for the user. The currently active adjustable output can be determined through a push button. The variable outputs are accessed by the user through a binding post and the fixed output through a USB type A.

4 Testing

4.1 UNIT TESTING

We will be testing each switch-mode regulator circuit individually and measuring output parameters like voltage accuracy and ripple. We will also be testing an improved version of the low voltage supply with voltage accuracy, response time, and current limit accuracy. Next we will

4.2 INTERFACE TESTING

Our interface is designed to be an LCD display to display the output voltages, a button to select the output the user chooses to change, and a rotary encoder to modify the voltage level at the specified output. The tests that will need to be completed are verifying that the LCD displays the correct voltage, the button changes the selected output voltage on the LCD display, and the rotary encoder correctly changes the output voltage level. All in all, the three components of the user interface will be tested individually first, to verify they are operational, before testing the functionality of the components together.

4.3 ACCEPTANCE TESTING

We can show the client the power supply works by testing the output voltage with multimeters and a few test circuits. We can also show the client that we meet the cost requirement by showing the bill of materials for each of the parts required for the power supply.

4.4 RESULTS

So far we have not performed any testing beyond the variable voltage-variable current limit block meant of the output of the low voltage supply. When it was tested, the output was not exactly what was expected. For instance, the 5V output would actually output about 4.95V. This problem can be fixed with an iteration on the design that was discussed previously.

5 Implementation

During the first week back to school we plan to complete parts selection and begin to draw preliminary schematics for parts of the circuit. Once we have a rough circuit design drawn up and parts ordered, we will begin to build and test the various sections using breadboards. We will test each section individually before attempting to connect them. Next we will work on writing the code to be used in the microcontroller, and will test it on an Arduino to confirm functionality. We will then combine all of our components together and debug any problems we encounter. Once we have a working breadboard prototype, we will design a PCB layout for the entire circuit. Once this arrives, we will solder on our components and perform thorough testing on the entire system.

6 Closing Material

6.1 CONCLUSION

This design document for our power supply details our attempt for building a power supply in an at-home environment. With requirements such as having four total outputs, assembled all on a PCB board, and powered by a 24-VRMS AC or 36-V DC transformer, the inception of bringing a supply to life by next semester.

6.2 REFERENCES

Masoud Farhoodnea, Azah Mohamed, Hussain Shareef, "A comparative study on the performance of custom power devices for power quality improvement", *Innovative Smart Grid Technologies - Asia (ISGT Asia) 2014 IEEE*, pp. 153-157, 2014.

Ming Yang, Digvijay Deswal, Francisco de León, "Mitigation of Half-Cycle Saturation of Adjacent Transformers During HVDC Monopolar Operation—Part I: Mitigation Principle and Device Design", *Power Delivery IEEE Transactions on*, vol. 34, no. 6, pp. 2232-2239, 2019.

Tuttle, Gary. "EE 333 Labs." *EE 333 : Lab*, Iowa State University, 29 Oct. 2020, tuttle.merc.iastate.edu/ee333/lab.htm.

6.3 APPENDICES

Casing Data Sheet:

<https://www.budind.com/wp-content/uploads/2019/01/hb11553.pdf>

Voltage Regulator Data Sheet:

<https://www.st.com/content/ccc/resource/technical/document/datasheet/e9/be/53/a3/1f/6f/4f/75/C00000449.pdf/files/CD00000449.pdf/jcr:content/translations/en.CD00000449.pdf>

Microcontroller Data Sheet:

<https://ww1.microchip.com/downloads/en/DeviceDoc/ATmega48A-PA-88A-PA-168A-PA-328P-DS-DS40002061B.pdf>

Linear Regulator Data Sheet:

<https://www.ti.com/lit/ds/symlink/lp38842.pdf?HQS=TI-null-null-digikeymode-df-pf-null-ww&ts=1605505593553>