Dual Plug EV Charging Conversion Device

ECE 445 Design Document

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Spring 2022

1.Introduction

1.1 Background

At present, with the increasing need for electric vehicles(EVs), many families could have more than one electric vehicle. However, considering charging mostly happens during nighttime when electricity price is low and the majority of the existing home EV chargers have only one plug[1], it becomes inconvenient for families with multiple EVs to charge all EVs at night. Because when the electric vehicle is charged, the charging object can only be changed manually. In addition, in order to protect the battery cells from overheating, the output current of the EV charger decreases and causes a waste of energy.

1.2 Solution

Ideally, in order to solve this problem, we want to design a dual plug EV charging conversion device as figure 1 shows, which includes a power distribution subsystem, control subsystem, power subsystem, and user-interface subsystem. This device has two charging modes. One is the average charging mode, that is, each output plug allocates the same charging power. When one of the outputs finishes charging, the device allocates the excess power to the other output plug; The other one is the limit mode. The user can manually choose to set the output current with the priority. After the preferential output completes charging, the power will be allocated to the next priority output plug.

Because it is hard to test with an EV charger and Electric car. We decided to simplify our device to a level that can be tested based on the lab device as figure 2 shows. We want to directly use a voltage generator as our design input. For electric vehicles, it is hard to manipulate the EV battery's behavior, which is requesting lower power output from the device as the EV battery is filling. We decided to include loads like resistors in our design to control the output current amount, as mentioned previously in the limit mode of our design. In addition, in reality, the current's amplitude decreases as the battery charges, so to test the limit mode, we will decrease one of the outputs' current through a preloaded program in MCU.

1.3 Visual Aid

Figure 1. Original idea with EV charging station and electric vehicles

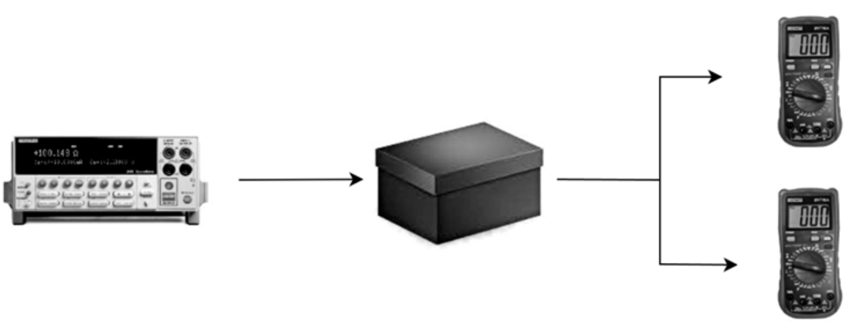

Figure 2. Simplified idea with current generator and Ammeters

1.4 High-level Requirements

- In mode 1, both output 1 and output 2 generate 0.4-0.5 times of the total input power in the corresponding output plug. In mode 2, the output with high priority generates the preset power while the rest of the power is allocated to the remaining output.
- The user is able to control mode selection and current setting through the button module. The mode information and output current information is displayed through the LCD module.
- The current sensor module can measure the current outputs of the plugs with the accuracy higher than 98%, compared with the current values measured directly from the output plugs.

2 Design

2.1 Block Diagram

In our design, the power of sensing subsystem, heat dissipation module, user interface subsystem and on-board micro-controller unit is supplied by the power subsystem with a 12V battery and a 12V to 5V DC converter to supply 12V and 5V VDC power accordingly. Then, the sensing subsystem with current detection sensor module will detect the current and feedback to on-board micro-controller unit, and the micro-controller unit will send the current measurement to the LCD of the user interface subsystem to display. The control subsystem will decide how the power distribution module distributes the power to two loads with the button input from the user interface subsystem which selects the operation mode. The control subsystem also takes current input of 32A to feed into the relay circuit. After power distribution, the current will be transmitted into a dual plug to be splitted into two outlets to feed two different targets with desired current. The heat dissipation module will use a fan to cool the power distribution system to prevent resistor overheating.

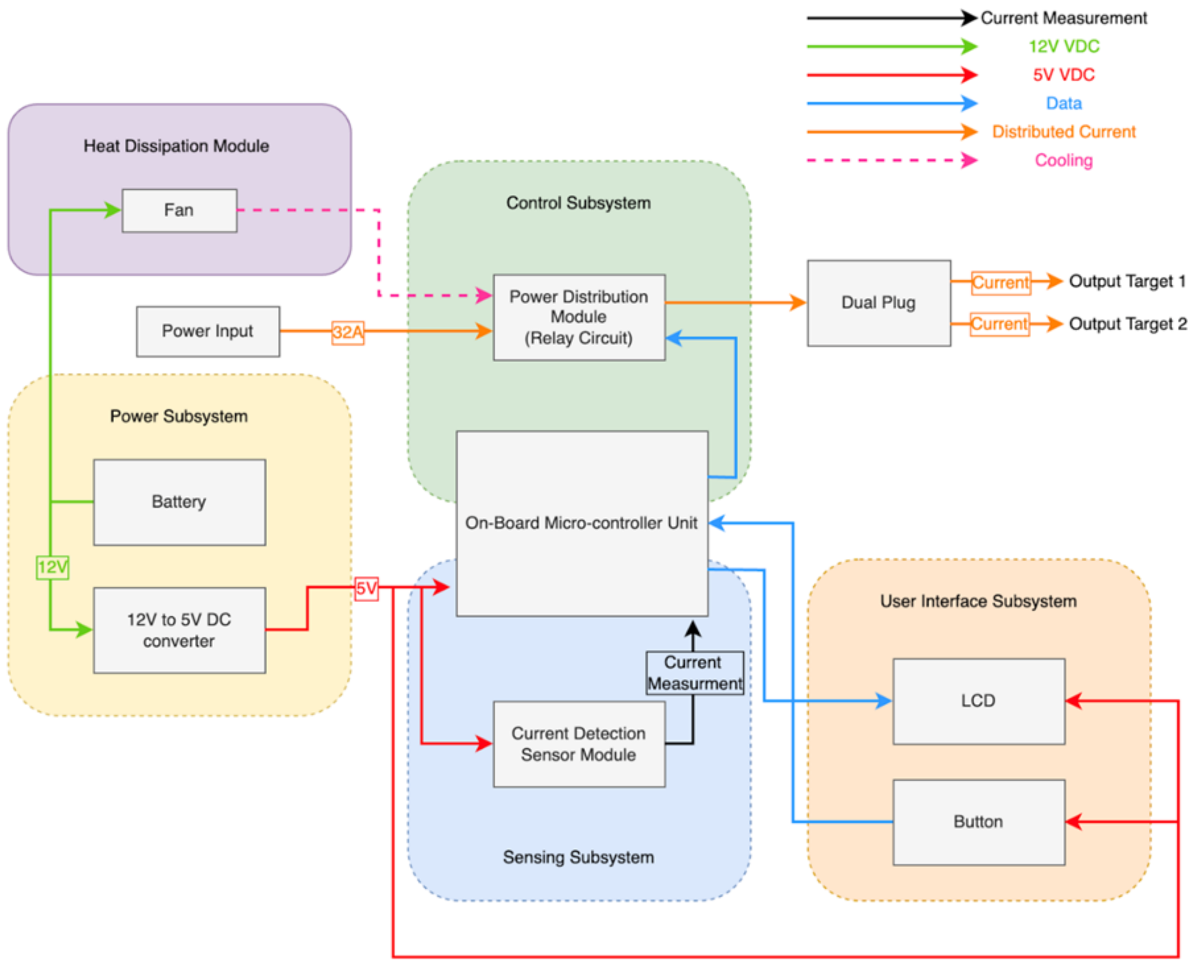

Figure 3. Block diagram of the dual plug EV charging conversion device

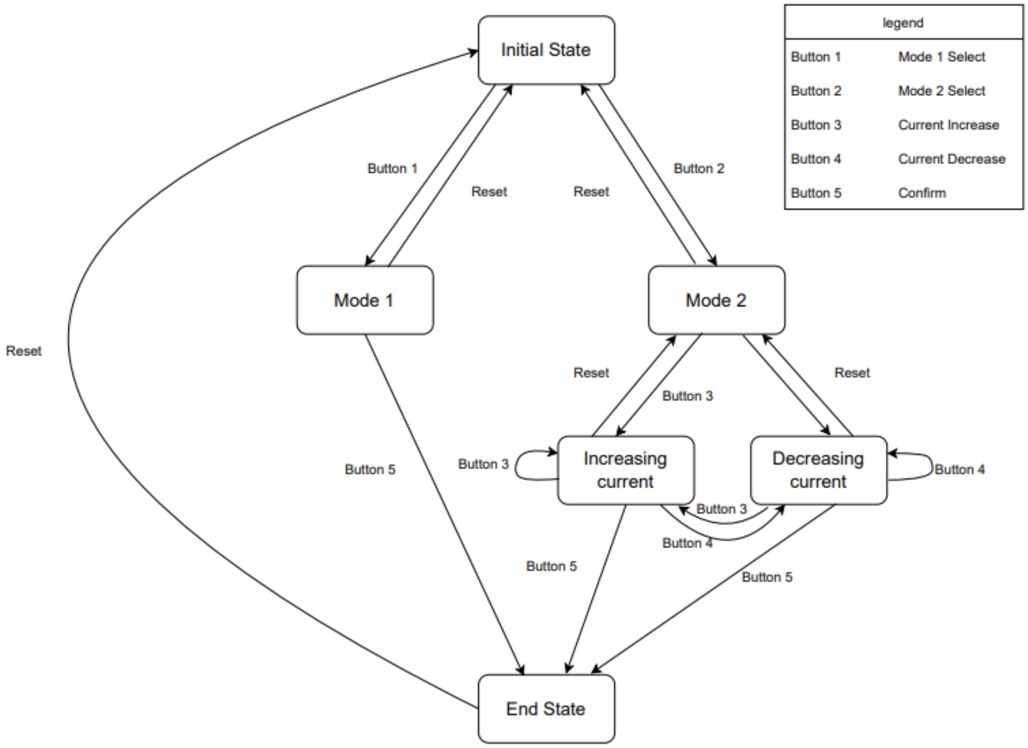

Figure 4. State diagram for operation mode control

2.2 Power Subsystem

2.2.1 12V Battery

The 12V battery should provide the power input for the electronics on the printed circuit board.

Requirement	Verification
1. It should be able to provide a steady 12V voltage supply.	1. Use a multimeter to measure the battery's voltage value. Make sure the output value is always in the range of 11.5-12V.

2.2.2 12V to 5V Converter

The 12V to 5V DC converter converts the 12V input from battery to a 5V output to match the VDD requirement of MCU.

Requirement	Verification
1. It should successfully convert the 12V input to a steady 5V output. 2. The output voltage should successfully power up the MCU and other electronics on the PCB.	1. Use a multimeter to measure the converter's output. Make sure the value is always in the range of 4.5-5V. 2. Use a multimeter to test the input pin of every other component on the PCB to guarantee their input voltages.

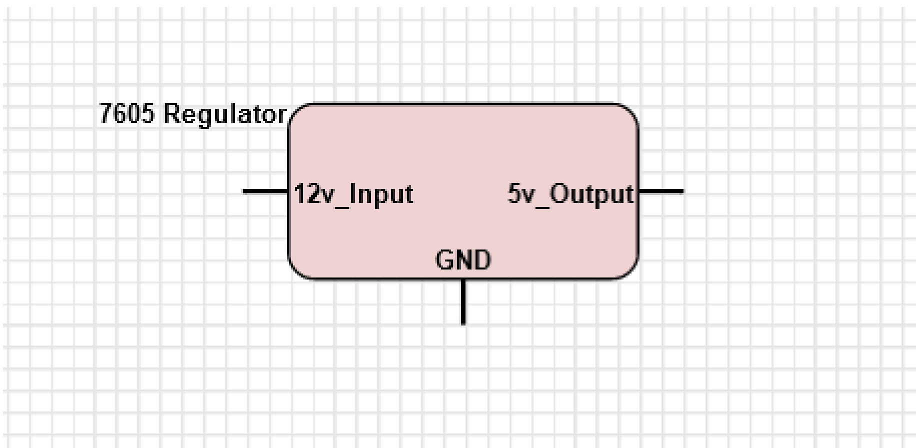

Figure 5. 12V to 5V 7605 Regulator

2.3 User-Interface Subsystem

2.3.1 LCD Display Module

The LCD monitor module would display the feedback from the control module which would provide a better user-device interaction.

2.3.2 Button Module

The button would allow users to set the working modes manually and control the power distribution as desired. The input signal would be delivered to the Control module which would be processed by the MCU.

Requirement	Verification

1. The buttons should successfully send feedback signals to the MCU when it is pressed. And the LCD display should be able to interact with the MCU. 2. Each button's unique functionality is achieved, and corresponding operation is indicated through LCD.	1. After the MCU, LCD, and Button Module are all powered. Check if content displayed on LCD changes with respect to button press. 2. The button module and LCD module have following functionality: A. After the Reset button is pressed, the LCD should display the default layout. B. After Mode 1 button is pressed, the LCD should indicate the mode is selected to 1 and display the measured output current. C. After the Mode 2 button is pressed, it should follow the state machine in figure 4 shown below.

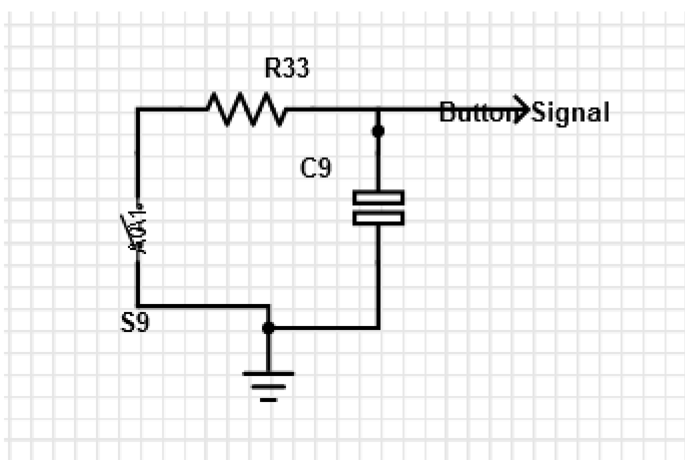

Figure 6. Debouncing Switch Circuit(Button Module)

2.4 Control Subsystem

2.4.1 MCU Module

The micro controller unit(MCU) would control most of the other components in our device to achieve the goal of user-device interaction, relays' control, and current measurement.

Requirement	Verification
1. The MCU must be able to send data to the LCD to display.	1. The LCD can display correct information, including mode selection and current output value.
2. The MCU must be able to receive data from buttons.	2. After the button is clicked, a certain operation mentioned in Button Module is performed in MCU. The result of the operation should be sent to the LCD module and indicated on LCD.
3. The MCU must be able to receive and interpret analog data from Current Sensor Module.	3. The value of measured output currents should be successfully shown on LCD and compare the value with the measured result from the multimeter.
4. The MCU must be able to perform the basic computation to decide the modes of operation.	4. After the mode is selected through the button, each mode's corresponding computation should be done. A. In mode 1, the MCU should send a signal to the LCD module so that the user is able to see mode selection and output current value. B. In mode 2, the MCU should send a signal to the LCD module so that the user is able to follow the operations

5. The MCU must be able to interact with relay circuits and send control signals to relay circuits to control the current output.	mentioned in mode 2's state machine in figure 4. 5. After the user changes and confirms the output currents in mode 2, the actual current outputs should be the same. The output currents can be measured and compared via multimeter.

2.4.2 Current Sensor Module

The current sensor will provide information regarding the current output of each port. It will check if the current output of each port is what we expected. It will send the feedback signal to MCU. Also, the sensor will be configured to recognize the positive jumps in current which would indicate that the device is plugged in.

Requirement	**Verification**
1. The sensor must be able to recognize the DC current values up to 32A and send the signal back to MCU module.	1. A. Directly use a current generator to output 32A current and read the measured value through the LCD. B. After the power distribution module can output 32A±5% current. Measure one current output with both multimeter and the current sensor. Compare the results.

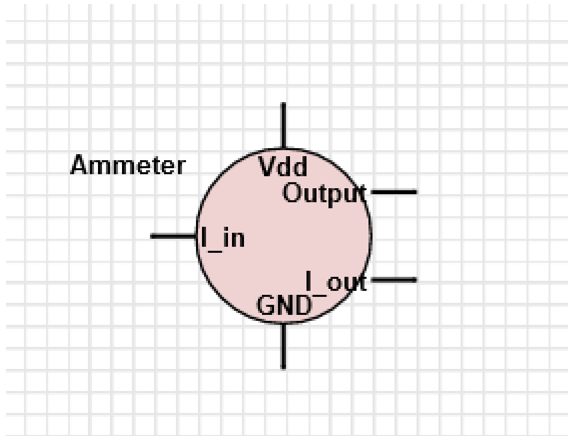

Figure 7. Current Sensor

2.5 Power Distribution Subsystem

2.5.1 Relay Circuit Module

The relay circuits should be able to control the amount of current output based on the control signal from the MCU.

Requirement	Verification
1. The relay circuits must successfully read and decode the control signal from MCU.	1. A. The output currents change as the current value is modified through the button module. B. The currents can be measured through a multimeter to check if the values match our design.
2. The relay circuits must be able to change the current output based on the control signal.	2. The current value should decrease or increase by 8A±5% every time the current control button is pressed.

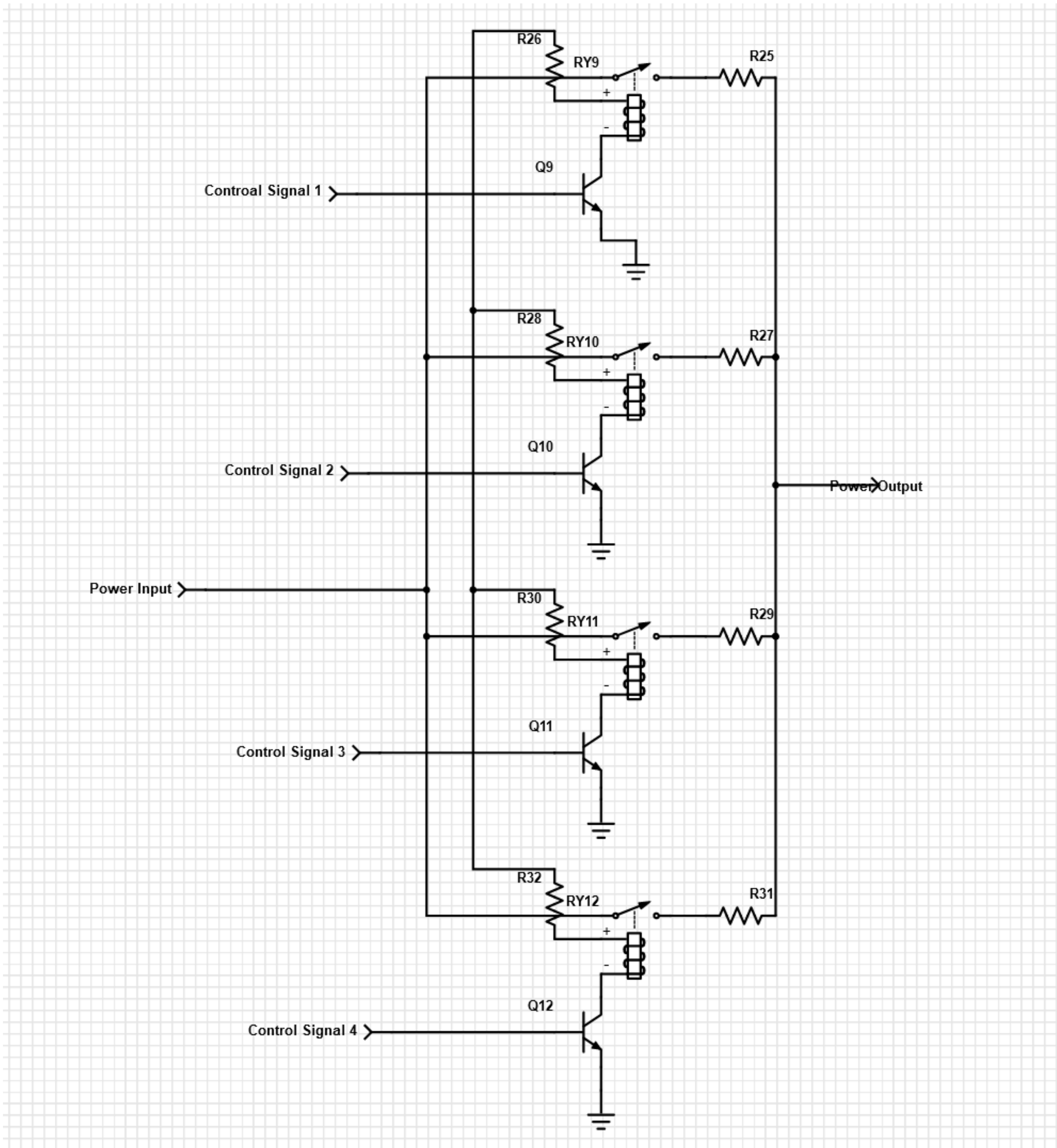

Figure 8. Power Distribution Subsystem

2.6 Heat Dissipation Module

The heat dissipation module would make sure that the temperature of the whole device stay within the operational range of each components and cool the whole system down if the device get overheated.

Requirement	Verification
1. The heat dissipation module should be able to ensure the temperature of the components in the device stay in the range of operating temperature (relay < 120°C, MCU < 85°C).	1. Using a thermometer to monitor the temperature around components in the device.

2.7 Circuit

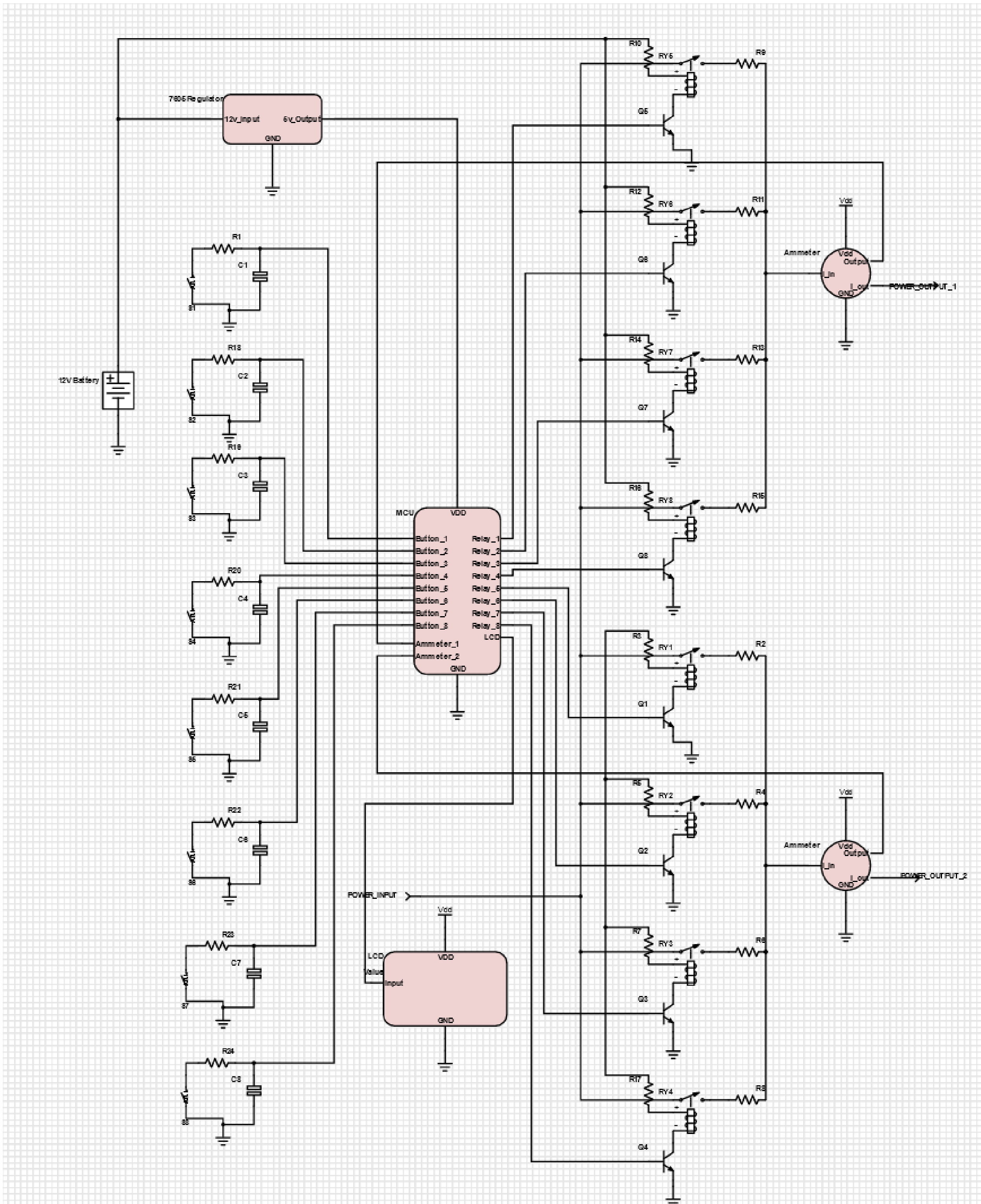

Figure 9. Device Circuit Overview

2.8 Tolerance Analysis

One factor that might affect the output power of our device is the contact resistance of the relay switches. In an ideal case, the contact resistance, R_c, of the relay would be 0 ohm, which means that when the switch is turned on, the contact end of the relay would just behave like a wire and consume no power. However, there would always be a small contact resistance of the relay. We want the output power to be at least 90% of the ideal case of our circuit. In an ideal case, the output power would be the output current, I_{out}, times the output voltage, V_{out}, where the output current equals to V_{out} divided by the resistor, R. In the worst case, the output current, $I_{out,w}$, would be

$$\frac{V_{out}}{R+R_c}$$

which is equal to

$$I_{out} \cdot \frac{R}{R+R_c}$$

and the output voltage would be

$$V_{out} \cdot \frac{R}{R+R_c}$$

In this case, the output power would be

$$V_{out} \cdot I_{out} \cdot \left(\frac{R}{R+R_c}\right)^2$$

To achieve 90% of ideal output, we need

$$\left(\frac{R}{R+R_c}\right)^2 > 0.9$$

$$\left(\frac{R}{R+R_c}\right) > 0.9487$$

$$R_c < 0.054R$$

According to our research, the maximum contact resistance of the relay would be less than 0.1 mOhm and the resistance of the resistor is around 10 mOhm which meets our requirement.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Hour salary = 30 $\$\cdot hr^{-1}\cdot person^{-1}$

Total number of Hours = 15 $hr\cdot week^{-1}$×12 *week* = 180 *hours*

Total Salary for one labor = 30 $\$\cdot hr^{-1}\cdot person^{-1}$×180 *hours*× 2.5= $13500

Total Salary for the team = 3 ×13500 = $40500

3.1.2 Parts Cost Estimation

Parts	Price[$]/Unit	Quantity	Total[$]
7805 Voltage Regulator	1.19	1	1.19
ATMEGA16 MCU	5.65	3	16.95
LCD1602 Module	8	1	8
Momentary Push Button Switch	0.55	6	3.3
WCS1800 Current Sensor	13	2	6
Power PCB Relay	5	8	40
Other	60	1	60
Total			135.44

3.1.3 Total Cost Estimation

The total cost of the whole project would be 40500 + 135.44 = 40635.44 dollars.

3.2 Schedule

Week	Taiyuan Hu	Shuchen Wu	Haochen Zhang
2.20.2022	Design PCB. Write design document.	Purchase components. Write design document	Software development for MCU
2.27.2022	Review PCB. Assisting Software development for MCU. Components' functionality test	Review PCB. Components' functionality testing. Assemble Power Distribution Module.	Software development for MCU
3.6.2022	Assisting Software testing for MCU. Control Module assembling.	Assemble power distribution module. Check requirements and verify power distribution module	Software Testing for MCU module
3.13.2022	Spring Break	Spring Break	Spring Break
3.20.2022	Assembling control module.	Assembling LCD module.	Software Testing of LCD
3.27.2022	Check requirements and verify control module	Check requirements and verify LCD module.	Assisting hardware assembling
4.3.2022	Developing cooling Module. Final testing and debugging.	Developing cooling Module. Final testing and debugging.	Assisting hardware testing
4.10.2022	Final testing and debugging	Final testing and debugging	Final testing and debugging

4.17.2022	Final testing and debugging	Final testing and debugging	Final testing and debugging
4.24.2022	Final Presentation	Final Presentation	Final Presentation
5.1.2022	Final Report	Final Report	Final Report

4 Ethics and Safety

Safety and ethics are two essential aspects in every modern design project. As stated in section 1.1 of the document, “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment,” every team member is going to strictly follow the criteria in IEEE Code of Ethics to operate our design[2]. Because the initial intent of the project is to operate the device in a high voltage and high current environment, team members are exposed to high risk of electrical hazards. Thus, we decided to utilize the generator with lower power output. In addition, the potential high-power consumption of the loads in the design may cause overheat, which can also lead to accidents. To address overheating, we add a heat dissipation module to cool the device, and, furthermore, numbers of loads would be reduced if heat dissipation module is not enough.

During testing, team members will be wearing insulating gloves to keep our personal safety. Also, according to requirements mentioned in the OSHA 1926.404[3], the device should be ensured being grounded where applicable and those components should be justified being well attached to the grounding conductor.

The team will treat other teams and all course staff respectfully and kindly. We will contribute to create an equal, safe, and respectful atmosphere in all ECE 445 working environments with our peers, professors, and TAs. All the communication within the team and between our TA and professor will be in an honest and polite manner. More importantly, our team has zero tolerance to any kind of plagiarism, and we will report the behavior when we notice it.

Reference

[1] T. Homer. “The Best Electric Vehicle Chargers for Your Car.” October 2021 [Online]. Available: https://www.popularmechanics.com/cars/g37789945/best-electric-vehicle-charger/?utm_source=google&utm_medium=cpc&utm_campaign=arb_ga_pop_d_bm_g37789945&gclid=CjwKCAiA6seQBhAfEiwAvPqu15zpV2U5Pgxjw49UTcce2VcZR51rHtspl1kNU5o_HXn3G8IDMW0NshoC8GQQAvD_BwE [Accessed Feb.20, 2022]

[2] IEEE Board of Directors. “IEEE Code of Ethics.” IEEE Code of Policies, Section 7 - Professional Activities (Part A - IEEE Policies). June 2020 [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed Feb. 20, 2022]

[3] United States Department of Labor. “OSHA 1926.404 - Wiring design and protection.”

osha.gov. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.441 [Accessd Feb. 24, 2022]