DUAL PLUG EV CHARGING POWER DISTRIBUTION DEVICE

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Final Report for ECE 445, Senior Design, spring 2022

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04 May 2022

Project No. 48

Abstract

Dual plug EV charging power distribution device is a supplementary device between electric vehicle charger and electric vehicles. It takes the current from EV charger as input, and outputs current in two individual output plugs. The device has two modes, even mode and priority mode. In even mode, two output plugs carry equal amount of current. In priority mode, the user set the priority output and output current level, and then the remaining current is allocated to the second output. In our final project, all subsystems and high-level requirements are achieved.

Contents

1 Introduction

1.1 Background

As increasing possession of EVs in families, many families own two or more EVs. However, the EV chargers nowadays have only one output plug (Homer, Octobor 2021), which means, EV owners need to manually connect EV charger to their second EV after their first EV finishes charging. This requires extra effort and time because the EV owners need to wait until their first EV being fully charged in order to charge their second EV. In addition, EV owners are unlikely to benefit from off-peak electricity hours because it is not realistic for them to charge all of their EVs during midnight with the one output plug EV charger.

1.2 Solution

Ideally, in order to solve this problem, we want to design a dual plug EV charging power distribution device as figure 1 shows, which includes a heat dissipation module, control subsystem, power subsystem, sensing subsystem, and user-interface subsystem. This device has two operation modes. One is the even mode, and the other is priority mode. In even mode, two output plugs carry equal amount of current. In priority mode, the user set the priority output and output current level, and then the remaining current is allocated to the second output. When one of the outputs finishes charging, the device allocates the excess power to the other output plug.

Because there is no EV charger and EVs for us to test for the project and testing under high level voltage and current is risky. We decide to simplify our device to a level that can be tested based on the lab device as figure 2 shows. We directly use a current generator as our design input.

1.3 Visual Aid

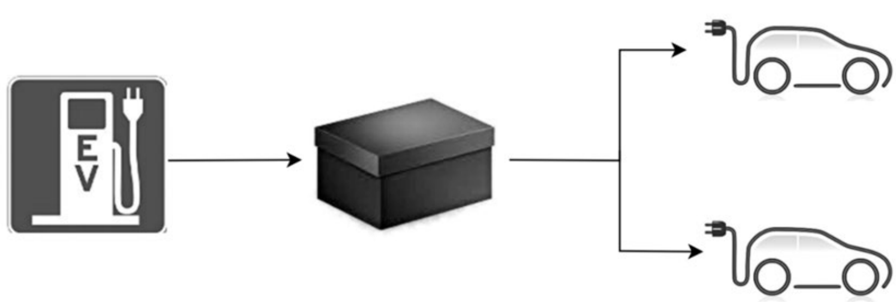

Figure 1 Original idea with EV charging station and electric vehicles

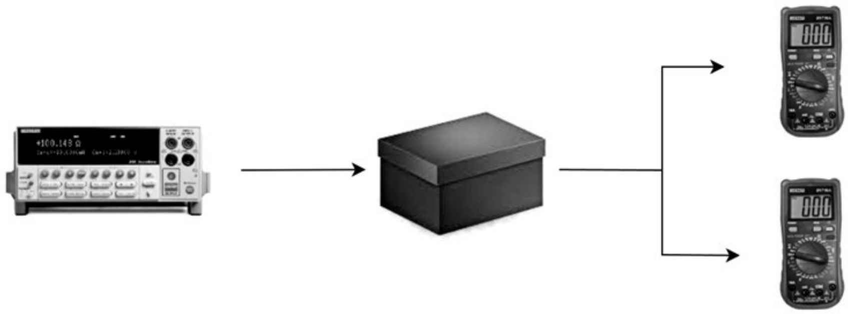

Figure 2 Simplified idea with current generator and Ammeters

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 90%, 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, control subsystem, user interface subsystem, and on-board micro-controller unit (MCU) is supplied by the power subsystem with 12V and 5V voltage generator. 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 two output plugs to charge two different targets with desired current. The heat dissipation module utilizes aluminum heat sink to cool the power distribution system, preventing resistor from overheating.

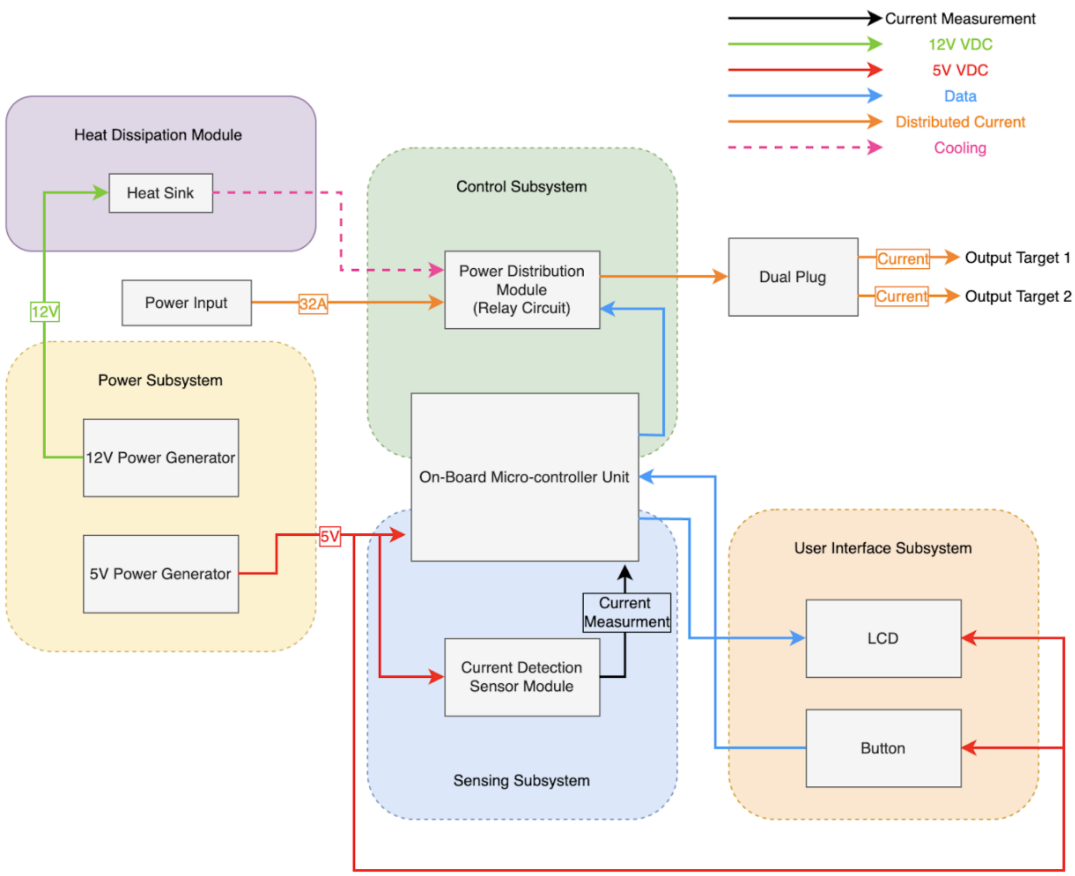

Figure 3 Block diagram of the dual plug EV charging conversion device

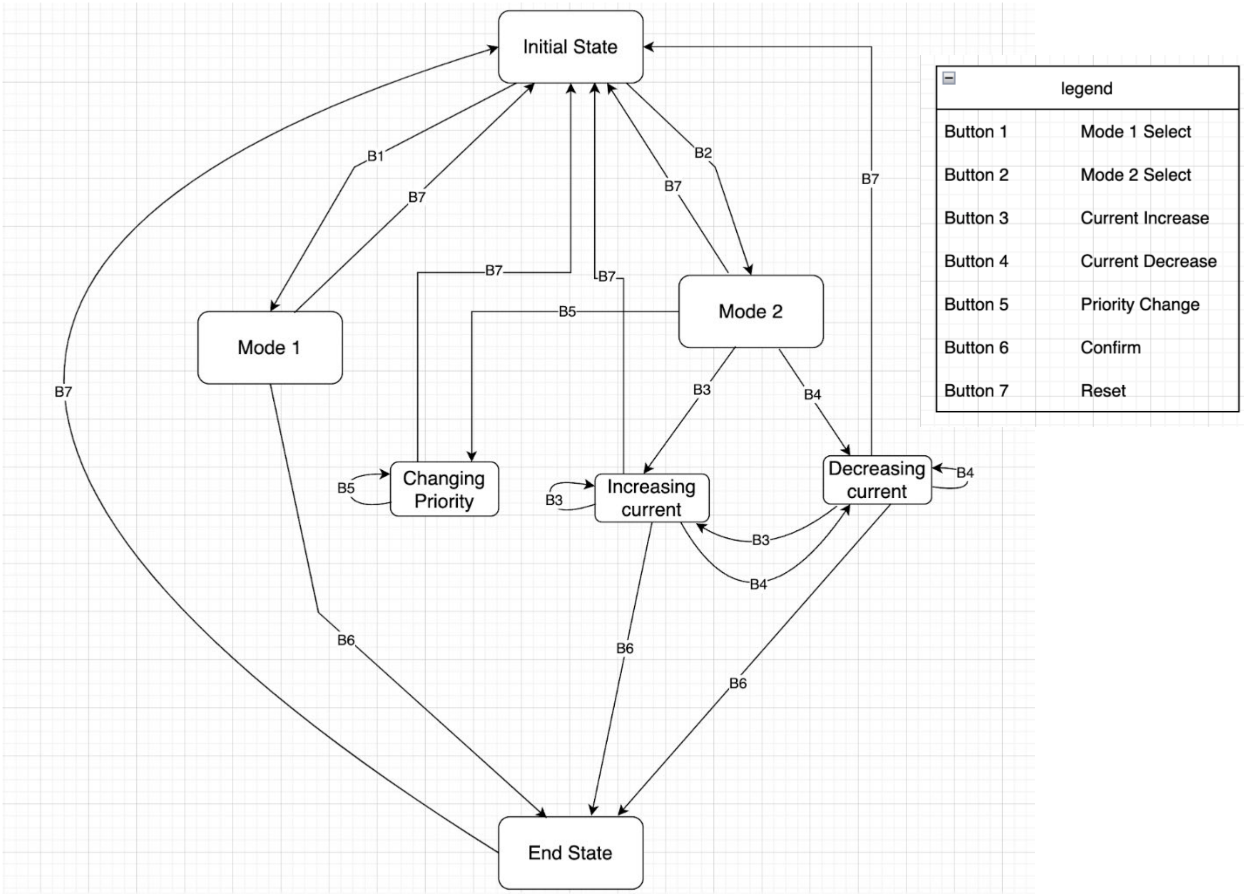

Figure 4 State diagram for operation mode control

2.2 Power Subsystem

2.2.1 12V Voltage Generator

A steady 12V voltage generator is used as part of the power subsystem. In original design document, 12V battery was used as 12V voltage supply. However, the 12V battery is not able to supply our device for more than 1 hour and the output voltage of the battery continually drops with respect to working time. Therefore, we eventually use 12V generator instead of 12V battery.

2.2.2 5V Voltage Generator

A steady 5V voltage generator is used as part of the power subsystem. The 12V to 5V DC converter was used first but the heat generation and unstable performance of the converter makes 5V voltage generator a better and more reliable choice.

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.

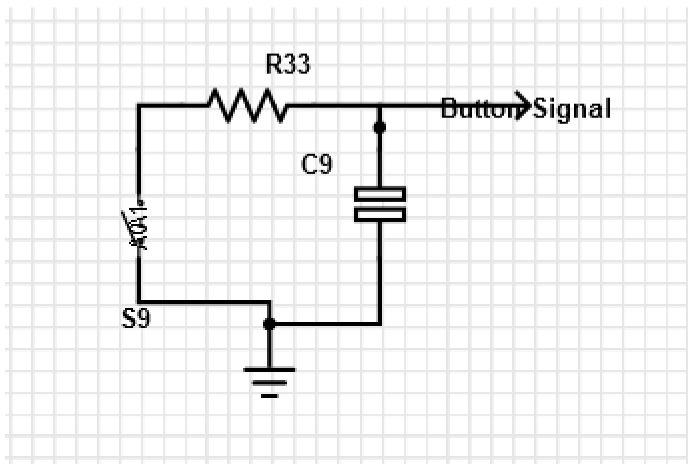

Figure 5 Debouncing Switch Circuit(Button Module)

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.

2.4.2 Relay Circuit Module

The relay circuit module would control the current output of two branches by taking the control signals from MCU module and control relays' on and off. The relay module circuit is made up of two parts, relay modules and the reversed amplifier. Since the highest output voltage of our MCU module could only go up to 5V while we need a 12V voltage to control the relay module, we designed a reversed amplifier to amplify the control signal of our MCU to be readable by our relay module.

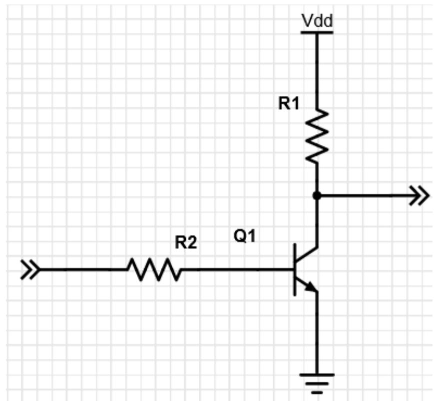

Figure 6 Reverse Amplifier

2.5 Sensing Subsystem

The current sensor will provide information regarding the current output of each output pug. The sensor, WCS1800 utilizes hall effect to measure the current.

$$I = \frac{V_{out} - V_0}{sensitivity}$$

Where I is current measurement, V_{out} is output voltage the WCS1800, V_0 is the voltage when current flow in WCS1800 is zero, and $sensitivity$ is calculated with the following formula:

$$sensitivity = \frac{V_{10} - V_0}{10}$$

Where V_{10} is the voltage when current flow in WCS1800 is 10A, and V_0 is the voltage when current flow in WCS1800 is zero.

2.6 Heat Dissipation Module

The heat dissipation module would make sure that the temperature of the whole device stays within the operational range of each component and cool the entire system down if the device gets overheated.

3 Design Verification

This section includes all the verification result of the subsystems and modules. More detailed information of the requirement and verification tables can be found in Appendix A.

3.1 Power Subsystem

Because our device eventually uses 5V and 12V voltage generators as power supplies, their output voltages are guaranteed to be stable.

3.2 User-Interface Subsystem

The user-interface subsystem can be verified easily through observing LCD display and relay module's behavior after button press. During both team self-examination and final demonstration, the functionality of user-interface subsystem is verified. As shown in the state diagram in figure, the LCD module is able to display the correct information when the MCU is in certain state. In addition, if valid button press is detected by the MCU, the text on LCD is updated correspondingly.

3.3 Control Subsystem

3.3.1 MCU Module

The MCU successfully controls the relay module according to mode operations, receives signal from button module and current sensing module, and display information through the LCD module.

3.3.2 Relay Module

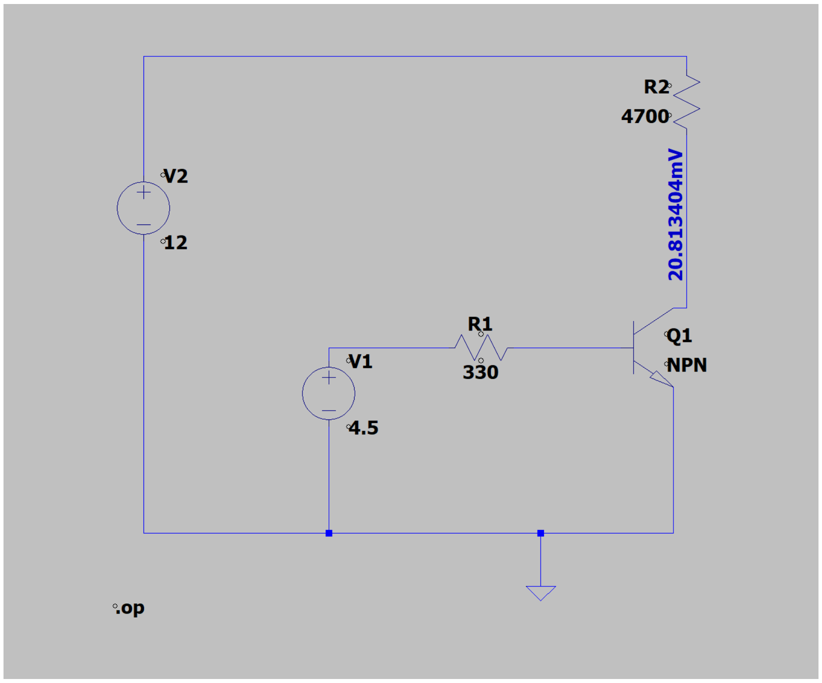

Figure 7 Reversed Amplifier Simulation 1

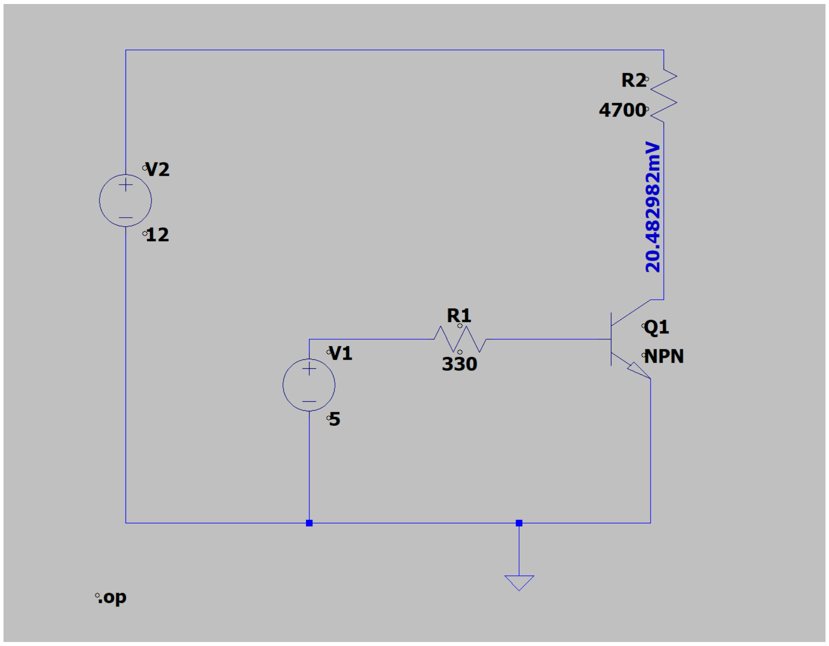

Figure 8 Reversed Amplifier Simulation 2

The Figure 7 and Figure 8 shows the simulation result of reversed amplifier. When the input of reversed amplifier is 5V, the output is around 20.483mV. When the input of reversed amplifier is 4.5V, the output of reversed amplifier is 20.813mV. Both values would be decoded as a low digital input for the relay circuit and relay circuit would connect NO pin to COM pin when receiving control signals in these ranges.

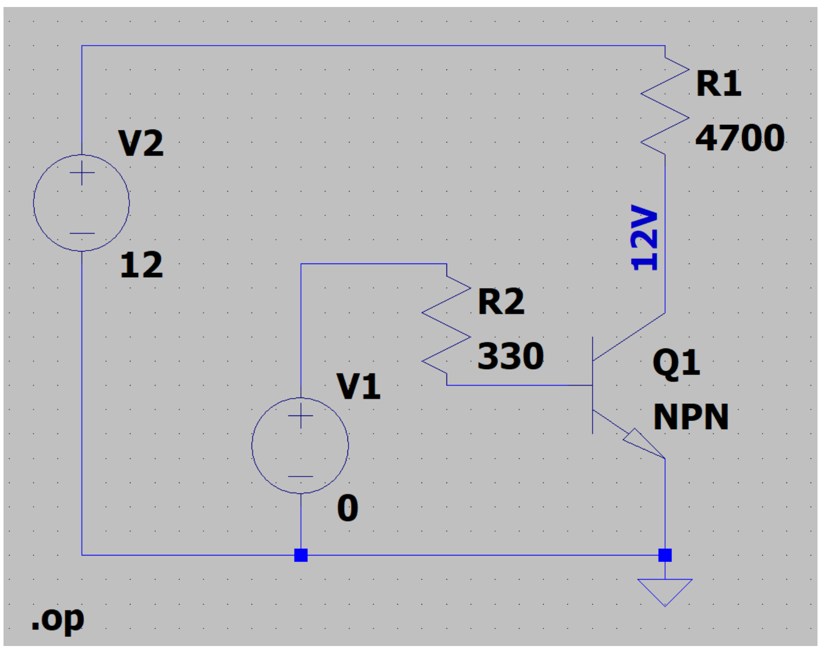

Figure 9 Reversed Amplifier Simulation 3

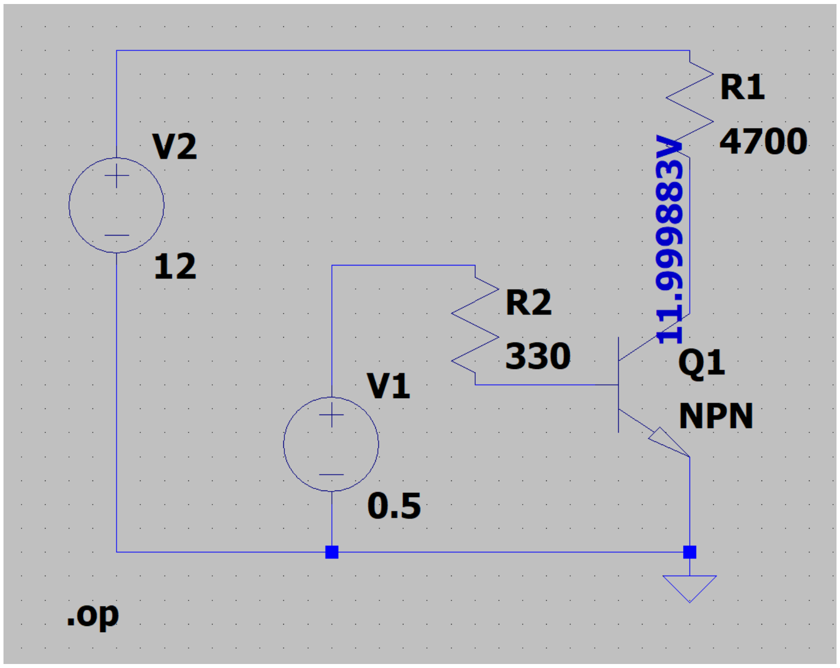

Figure 10 Reversed Amplifier Simulation 4

The Figure 9 and Figure 10 shows the simulation result of reversed amplifier. When the input of reversed amplifier is 0V, the output is around 12V. When the input of reversed amplifier is 0.5V, the output of reversed amplifier is 11.99988V. Both values would be decoded as a high digital input for the relay circuit and relay circuit would connect NC pin to COM pin when receiving control signals in these ranges.

Table 2 Reverse Amplifier Input and Output Results

Input (Low)	Output (High)	Input (High)	Output (Low)
10mV	11.976V	4.67V	15mV
15mV	11.972V	4.73V	14mV
11mV	11.978V	4.87V	13mV
12mV	11.966V	4.93V	15mV
11mV	11.975V	4.75V	14mV
10mV	11.978V	4.76V	14mV
10mV	11.973V	4.74V	15mV
11mV	11.969V	4.82V	11mV

The Table 2 shows the measured values of inputs and outputs of the reverse amplifiers. The inputs of the amplifier come from the output pins of the MCU. The measured values of outputs of the successfully verifies the functionality of reverse amplifiers. Given the fact that the MCU works as we designed, the relay module works as intended.

3.4 Sensing Subsystem

Table 3 Measurement from Current Sensor and Current Meter

WCS1800 current reading (A)	Current meter reading (A)	Error (%)
0.22	0.260	18.2

0.44	0.482	9.5
0.74	0.741	0.1
0.96	0.999	4.1

As shown in the table above, most cases' error is within the tolerance range except the first case, 18.2% error. The reason for this is due to the small current value. The WCS1800 outputs analog data when measuring current and its precision in measurement is approximately 0.0741A which means all current values will be multiple of that precision, and this will cause significant errors when the current value we read is relatively small. As a result, when the current being measured is not big enough compared to the precision current value, the error of the measurement becomes high. This error value also explains why the third measurement's error is 0.1%. The error disappears when the actual current value is around 10 times larger than the 0.0741A

3.5 Heat Dissipation Module

The device never experiences overheat issue during the development and demonstration of the project. So, the module is verified. However, if better cooling performance is needed, other features including fans and water-cooling system can be add to the module.

4 Costs

4.1 Labor

We estimate that each person's hour salary is 30$ per hour. Each team member has spent about 15 hours per week for 12 weeks. A multiplier of 2.5 accounts for overhead costs. Therefore, the total labor cost is, 30×15×12×3×2.5=40500$.

4.2 Parts

Table 4 Components' Cost

Part	Manufacturer	Unit Price ($)	Count	Actual Cost ($)
L7805ACV	STMicroelectronics	0.93	5	4.65
ATMEGA16A-PU	Microchip Technology	4.66	5	23.3
LCD1602	DFRobot	9.9	1	9.9
WCS1800 Current Sensor	Comimark	12.99	2	25.98
Relays	HiLetgo	6.79	8	54.32
4.7KΩ Resistor	Rohm Semiconductor	0.0348	100	3.48
330Ω Resistor	Rohm Semiconductor	0.0348	100	3.48
10KΩ Resistor	Rohm Semiconductor	0.0348	100	3.48
0.1μF Capacitor	Venkel	0.032	30	0.96
1μF Capacitor	Samsung Electro-Mechanics	0.04	60	2.33
22pF Capacitor	Stackpole Electronics Inc	0.073	10	0.73
LED	Harvatek Corporation	0.04	150	6
BJT	Solid State Inc.	0.5	40	20
Diode	Micro Commercial Co	0.264	10	2.64
PCA9555D	NXP USA Inc.	2.529	10	25.29
Power Resistor	LM YN	4.5	8	36
Button	Judco Manufacturing Inc.	1.567	10	15.67
12 Gauge 20 ft Wire	BNTECHGO	12.48	1	12.48
10 Gauge 20 ft Wire	BNTECHGO	16.98	1	16.98
Heat Sink	Awxlumv	11.99	1	11.99
Wire Connector	DZS Elec	0.7	10	7
100Amp Mini BusBar	Blue Sea Systems	16.38	2	32.76
150Amp Mini BusBar	Blue Sea Systems	20.18	1	20.18
Total				**339.6**

5. Conclusion

5.1 Accomplishments

In our project, we successfully finished all subsystems and modules as we designed in the design document, and all the high-level requirements proposed in the design document are achieved. Our device could successfully adjust the current output in two branches based on the control signal read of the button module. The LCD display could successfully show the real-time output current of each branch and other critical message to users as we expected. The MCU module could successfully decode the input message from the user input and generate the correct control signals to adjust the current output. The relay circuit module could successfully decode the control signals from MCU module and control the current output of two branches. Given the testing limitations in our lab, our device did not generate any detectable heat that requires extra heat dissipation module. Therefore, we were not able to test our heat dissipation module. However, we still used resistors with high power tolerance and with an aluminum cover as well as a heat sink placed under those power resistors to prevent overheating in actual cases. In short, our device is able to perform both the mode1 and mode2 operations based on the user inputs and the offset of the output currents are within the tolerance range as we designed.

5.2 Uncertainties

One of the biggest challenges and uncertainties we faced in the assembling and testing of our device was the contact resistance. The contact resistance between the power resistors and the relay modules, and the power resistors and the minibuses were actually larger than expected. Also, each individual route had different contact resistance which would affect the two current output branches. Luckily, the difference among eight different routes did not make a massive impact on the output current. We also chose to use the routes that have the most similar contact resistance at the same time to minimize the effect brought by the contact resistance.

In addition to contact resistance, another problem we discovered during the testing phase was that our voltage regulator was not that stable. After a long time of testing, LM7805 could be burned out and the 5V output of our regulator which was used as the voltage supply for the PCB was not that stable. To overcome this problem, a 5V voltage generator was used to replace the 12V to 5V regulator to provide the steady voltage supply for our PCB.

Other challenges appear at the PCB designing. Three pins of LCD module were not wired in our first version of PCB. The contrast adjustment pin and the backlight pins were not connected to the MCU module which resulted in the viewing angle of our LCD module being limited. This problem could be solved by some small modifications on our PCB design in the future.

In short, the most critical challenges we faced in our design was our misjudgment about the contact resistance which would affect the output of two branches. Other issues could be solved by redesigning PCB and replacing redundant parts on the PCB which would not affect the performance of our device.

5.3 Ethical considerations

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 strictly follows 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 substantial risk of electrical hazards. Thus, we utilized the generator with lower current output. During testing, team members wear 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 treat other teams and all course staff respectfully and kindly. We 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.

5.4 Future work

In the future, we will move foward to making our device compatible to real EVs and EV chargers. The communication among our device, EVs and EV chargers should be implemented. Specifically, MCU should summarize, process and the send the feedback signals from two EVs into one and transmit it to EV chargers. The MCU module should also process the feedback signal from EVs to adjust operation mode of the device. For example, when one of the EV is fully charged, the device should guide all the input current to the remaining EV based on those feedback signals and when both EVs are fully charged, the device should send a signal to the EV chargers which would notify the EV chargers to stop providing power to prevent overcharge. Another adjustment could occur at our relay circuit module. Instead of using power resistors to adjust the current output of two branches, we would use capacitors and inductors since as the current goes up, the heat generation and the power consumed by the power resistors could grow exponentially. For the power efficiency purpose, we would replace the power resistors in our future design. We are going to modify the PCB design and adjust the wire connection between MCU and LCD to make the LCD display more user friendly.

References

[1] T. Homer. "The Best Electric Vehicle Chargers for Your Car." October 2021 Available at: Accessed 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 May 2022

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

[3] United States Department of Labor. "OSHA 1926.404 - Wiring design and protection."osha.gov. Available at: https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.441 Accessed May 2022

Appendix A Requirement and Verification Table

Table 5 User-Interface Subsystem Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
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.	1. After the MCU, LCD, and Button Module are all powered. Check if content displayed on LCD changes with respect to button press.	Y
2. Each button's unique functionality is achieved, and corresponding operation is indicated through LCD.	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.	Y

Table 6 MCU Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
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.	Y
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.	Y
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.	Y
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	Y

	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 mentioned in mode 2's state machine in figure 4.	
5. The MCU must be able to interact with relay circuits and send control signals to relay circuits to control the current output.	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.	Y

Table 7 Current Sensor Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
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.	Y
2. The relay circuits must be able to change the current output based on the control signal.	2. The current level should decrease or increase with respect to the button press.	Y

Table 8 Current Sensor Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. The current sensor can measure current in output plugs with 90% accuracy.	1. Compare the measured value with current measure by multimeter.	Y