ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

TOUCH CONTROLLED PROGRAMMABLE DC POWER SUPPLY CIRCUIT

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1 Introduction

1.1 Problem and Solution Overview

1.1.1 Problem

The modern operation of electronic devices heavily relies on DC power sources at various voltage levels. This variability underscores the importance of voltage adaptation mechanisms for optimal functionality across consumer electronics. Take ubiquitous gadgets like cell phones, watches, and Kindles, which consistently require a standardized 5V supply. Mobile power, typically battery-operated, must meet diverse energy source demands, from 1.2V Nickel Metal Hydride to multiple Li-ion cells. Laptops, with nuanced power dynamics, often need 12V adapters for effective motherboard power.[2]

Our project aims to develop a user-friendly, touch-sensitive, and programmable DC power supply system, bypassing constraints of disparate units. By integrating intuitive controls and touch functionality, we enhance accessibility and ease of operation, allowing users to adjust settings effortlessly. Programmability enables customization, fostering versatility in diverse applications. Ultimately, we aim to provide a flexible solution, addressing challenges posed by conventional power supplies and promoting innovation in various fields.

1.1.2 Solution

To achieve this functionality, we have decided to divide the project into four modules, namely the AC-DC Converter, Variable Voltage Regulator, Touch Control Circuit, and Short Circuit Protection module.

The first part is to realize the transformation from AC to DC and DC to AC. AC-DC converters have been developed to a matured level with improved power quality in terms of power-factor correction, reduced total harmonic distortion at input AC mains, and regulated DC output in buck, boost, buck-boost, multilevel, and multipulse modes with unidirectional and bidirectional power flow. [1]Next, we will design a component to regulate different voltage levels. This component serves as a reliable source of DC output, capable of meeting various voltage requirements with stability and adjustability. We also need to deal with the touch control unit. We need to design a component that provides touch-sensitive controls for user interaction. It includes touch sensors (touch plate), digital integrated circuits, and other circuits to generate control signals for the variable voltage control circuits. We plan to apply The CTSs, which include the touch sensor, analog front-end (AFE) integrated circuit (IC), and micro-controller unit. [3]The short circuit protection part plays a critical role in safeguarding the circuit and the connected devices by detecting and mitigating short circuits. It incorporates specialized current sensors and overcurrent protection components to monitor the flow of electrical current within the circuit.

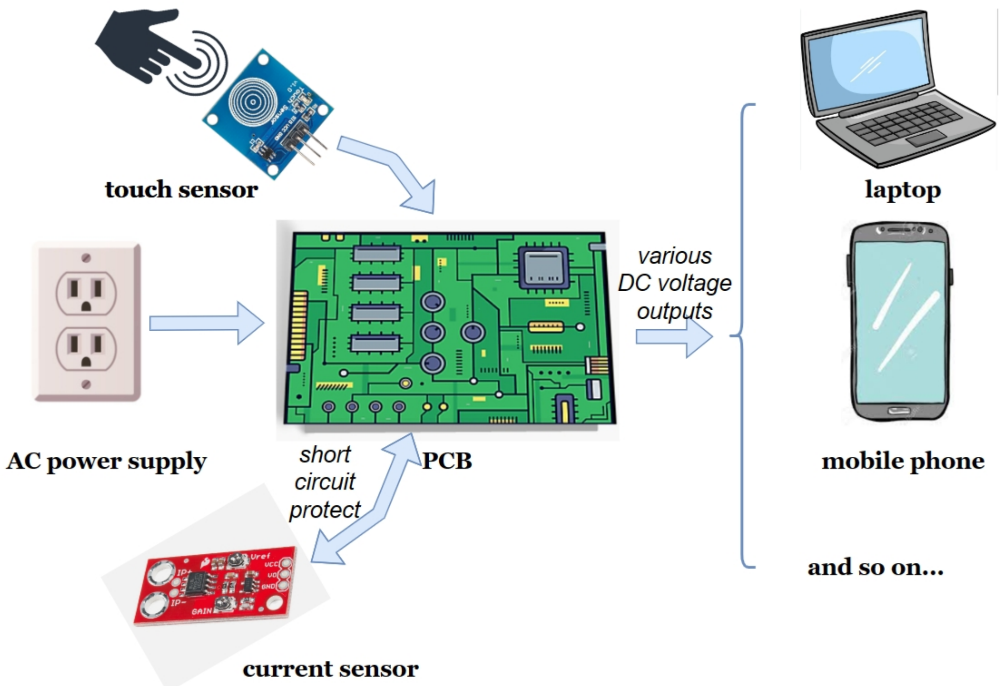

Figure 1: visual aid

1.2 Visual Aid

1.3 High-level Requirements List

- **The range of the spectrum of DC voltage levels from X volts to Y volts:** Our power supply circuit must be capable of providing a broad spectrum of DC voltage levels, specifying the range based on application requirements with an output voltage regulation accuracy of $\pm Z\%$ (where Z is the acceptable margin of error) to ensure compatibility with diverse applications.

- **Maximum response time of A milliseconds of the touch-controlled interface:** It helps to specify the maximum allowable time for a touch event to register and execute a command with a touch detection resolution of B mm (specify the smallest detectable touch movement or object size), ensuring that the system is both intuitive and responsive for users.

- **The time to detect a short circuit condition within X seconds:** The circuit design must incorporate a short circuit protection mechanism, specify the maximum allowable time to detect a short circuit and disconnect the power source or limit the current to a safe level within D seconds (specify the maximum allowable time to respond to a short circuit) to prevent damage to the circuit and components.

2 Design

2.1 Block Diagram

As shown below, our project integrates four subsystems to fulfill specific requirements. The AC-DC Converter ensures efficient conversion of AC to DC, providing a stable input for subsequent stages. The Variable Regulated Power Supply Circuit enables precise control over output voltage levels, meeting the requirements of charging voltage of diverse electronic applications. The Touch control circuit creates convenient user interaction, allowing users to easily adjust parameters with a simple touch interface. Additionally, the Short Circuit Protection Circuit enhances safety and reliability by swiftly detecting and mitigating short circuit events. This comprehensive design approach helps to ensure that the final product meets the high-level requirements.

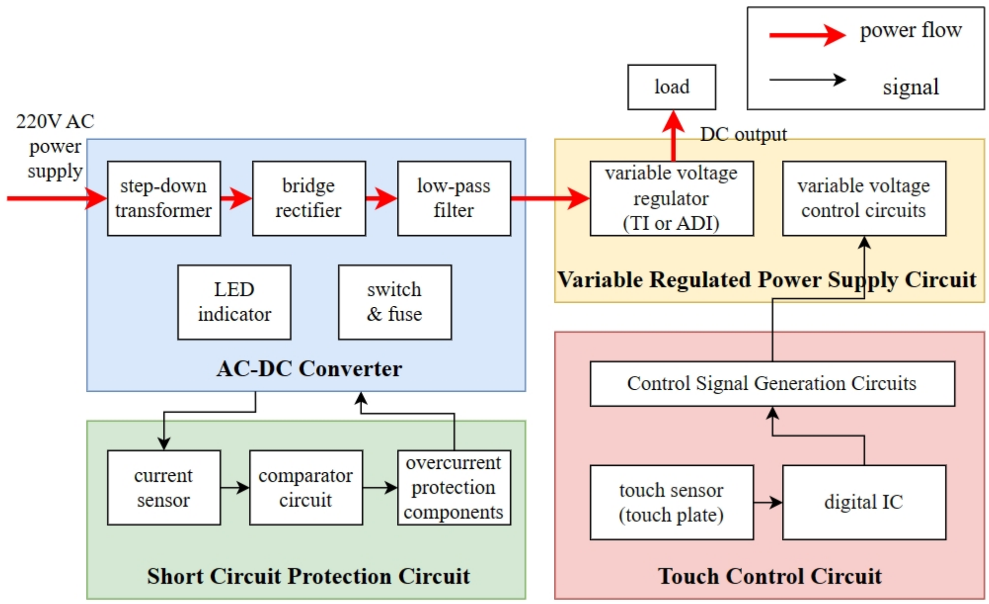

Figure 2: block diagram

2.2 Physical Design

Our entire design is integrated onto a single printed circuit board (PCB) for efficiency. To prioritize safety, the PCB is encapsulated within a protective enclosure. This enclosure shields the sensitive electronics from environmental factors and prevents accidental contact with live components. The only accessible elements for users are the touch sensor interface and a master switch. The touch sensor interface allows users to interact with the device intuitively, while the master switch enables easy control over the power supply operation.

2.3 Subsystem

2.3.1 AC-DC Conversion Subsystem

The AC-DC Converter Subsystem is a fundamental component within the project, responsible for converting AC from a mains power source into DC, suitable for powering electronic devices. The function of this subsystem includes efficient voltage conversion, noise reduction, and safety measures. It integrates several interconnected blocks, including the step-down transformer, the bridge rectifier, the low pass filter circuit, an LED indicator, switch and fuse.

- **Step-down transformer:** It reduces the input voltage from 220V AC to a lower AC voltage level, enabling efficient voltage reduction and ensuring compatibility and safety with subsequent stages.
- **Bridge Rectifier:** It converts the AC voltage into pulsating DC by rectifying the negative half cycles of the input waveform. It facilitates the conversion of AC to DC which is essential for creating a stable DC output.
- **Low Pass Filter Circuit:** It consists of capacitors and resistors arranged to filter out high-frequency components, reduces ripple and noise in the rectified output and smooth the rectified waveform, resulting in a more stable DC output.
- **LED Indicator:** It provides visual feedback on the operational status.
- **Switch and Fuse:** They offers control and protection against overcurrent or short circuit events. The switch enables easy on/off functionality, while the fuse prevents damage to components in case of unexpected faults or overload situations.

The interface of these components is shown below. The LED indicator is connected to the output of the low pass filter circuit to indicate the DC voltage. The switch and fuse are placed in series with the input power line before the step-down transformer to control and protect the entire AC-DC conversion subsystem.

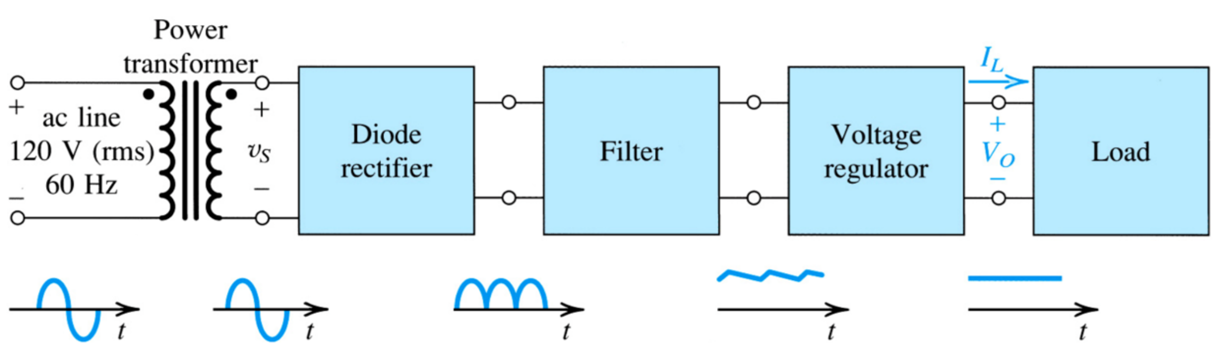

Figure 3: AC-DC power supply

The circuit schematics is shown below.

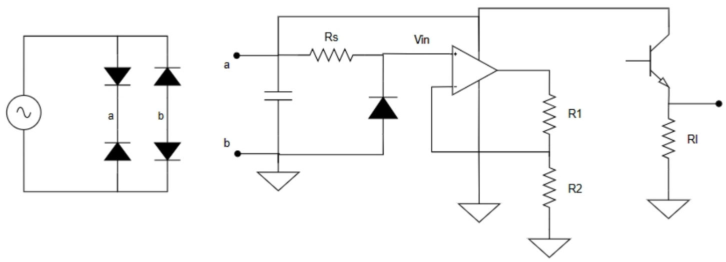

Figure 4: circuit schematics for AC-DC conversion

Requirement	Verification
1. The subsystem must be capable of accepting input voltages within the range of 205V to 242V AC, covering the possible voltage deviation. [6]	Apply voltages within this range (205V to 242V AC) and observe the subsystem's functionality.
2. The AC-DC conversion process must exhibit a minimum efficiency of 85% when operating at full load.	Measure the input and output power of the subsystem under full load conditions and calculate the efficiency: $$\text{Efficiency (\%)} = \left(\frac{\text{Output Power}}{\text{Input Power}}\right) \times 100\%.$$ Ensure it meets the specified minimum efficiency of 85%.
3. The output DC voltage must be regulated within a tight tolerance range of $\pm 1\%$ under all load conditions.	Apply varying loads to the subsystem and measure the output voltage at each load level. Ensure it remains within the tight tolerance range of $\pm 1\%$ under all load conditions.
4. The DC output voltage must exhibit a ripple voltage of no more than 50 mV peak-to-peak under full load conditions.	Measure the ripple voltage of the output DC voltage using an oscilloscope under full load conditions. Ensure it does not exceed 50 mV peak-to-peak.

Table 1: AC-DC Conversion Subsystem

2.3.2 Variable Regulated Power Subsystem

The Variable Regulated Power Subsystem serves as a stable and adjustable DC output to fulfill diverse voltage requirements. It includes a Variable voltage regulator from TI or ADI, and variable voltage control circuits for outputting different voltage levels. The role of this subsystem is to provide the main system with a stable direct current power supply with adjustable output voltage. By adjusting the set value, the output voltage can be flexibly changed within a certain range to meet the requirements of different functions of the overall system.

To meet the charging needs of various small electronic devices such as computers, mobile phones, and tablets, we have initially designed multiple levels of voltage, including 5V, 9V, 12V, and 15V. These levels can be easily and flexibly controlled and adjusted. Additionally, to minimize the impact of different loads on the output voltage and other environmental interference, we consider to design a feedback circuit that detects the input and provides regulated voltage to achieve higher precision.

- **Variable Voltage Regulator:** Integrated circuits designed to provide a regulated output voltage that can be adjusted or programmed to a desired level. These regulators typically accept an input voltage and deliver a regulated output voltage, which can be set within a specified range using external resistors or digital control interfaces.

- **Variable voltage control circuits:** Electronic circuits designed to control or adjust the output voltage of a power supply or voltage source.

- **Sampling circuit:** Reads the voltage and current information from the output port.

- **Feedback circuit:** Comparing the output voltage and current with the set value, and provides corresponding feedback information to the front-end circuit. This enables slight adjustments to be made in order to control the precision of the output.

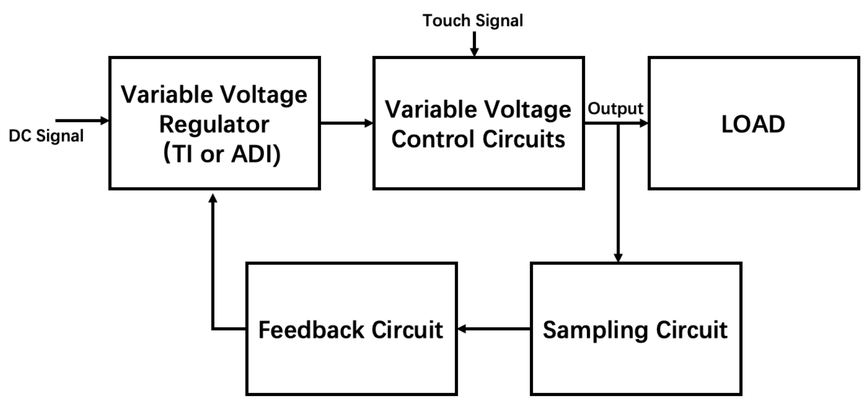

Figure 5: Regulated Power Subsystem block diagram

We need to find a variable voltage regulator with an appropriate working range to meet the requirements of our electronic devices. There are many aspects to consider, and we have not yet determined the specific chip. Below is the working diagram of LM2576 that we believe could be considered. Based on the analysis principle, we can achieve the desired output voltage by changing the ratio of R1 and R2.

In order to ensure accuracy and facilitate the reception of touch signals, we use relays to control the opening and closing of resistor branches instead of using adjustable resistors.

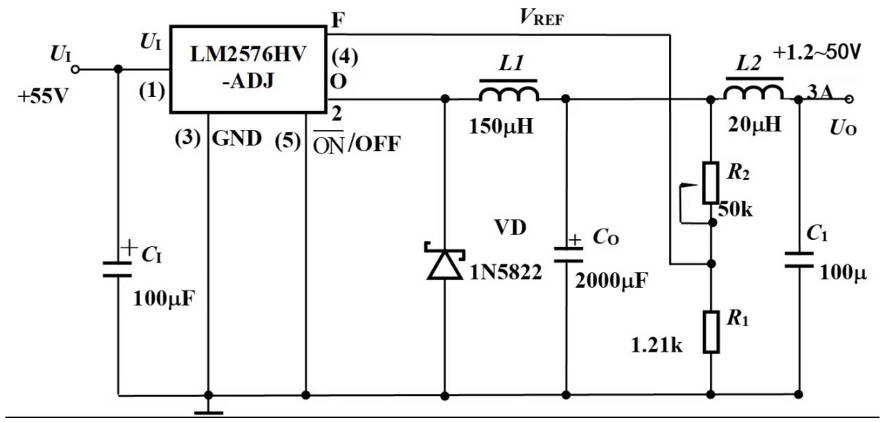

Figure 6: Typical Working Diagram of a Variable Voltage Regulator

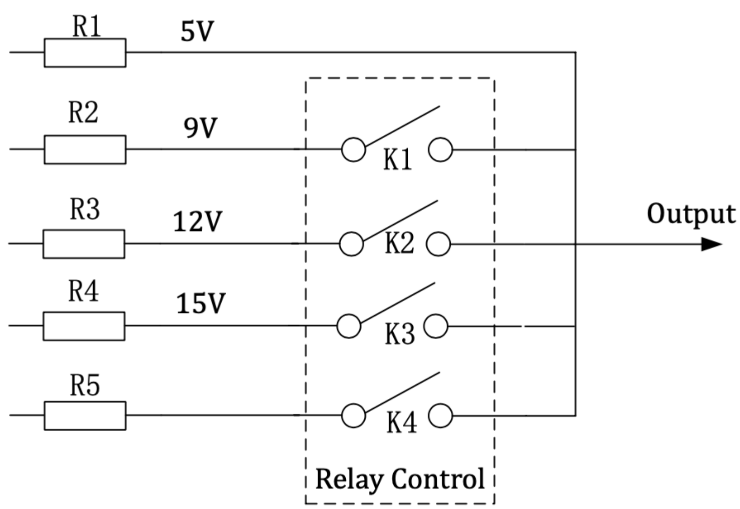

Figure 7: Relay Control

Requirement	Verification
1. Ensure the output voltage remains within an accurate range, without significant interference and fluctuations.	Connect different power-consuming devices at the output terminal and observe the changes in output voltage.
2. When the desired DC voltage value changes, the system needs to respond quickly, and the voltage conversion time must be controlled within a short period.	Measure the change in output voltage when the voltage is transformed through the touchscreen and observe the speed of the variation.
3. The feedback circuit can effectively regulate the voltage fluctuations at the output terminal.	Observe whether the system can automatically adjust to the appropriate voltage value in the case of over voltage or low voltage.

Table 2: Variable Regulated Power Subsystem

2.3.3 Touch Control Subsystem

The Touch Control Subsystem is intended to allow touch-sensitive controls for user interaction. It includes touch sensors (touch plate), digital IC, and other circuits to produce control signals for the variable voltage control circuits. This subsystem can achieve the transition between different states through programming and digital logic circuits. It recognizes input signals and processes them to provide corresponding outputs. The purpose of this subsystem is to create a simple interactive interface that allows users to control different states of the system through touch sensors, enabling the transition between various system states.

2.3.3.1 Principles of touch control circuit

From Figure above, it can be observed that when switch K is in the open state, the voltage across capacitor C is zero; when switch K is closed, voltage drop V1 charges capacitor C through resistor R. At the instant the circuit is closed, the voltage across capacitor C, Vt, is zero, and the maximum charging current is equal to V1/R. As charge accumulates on the terminals of capacitor C, Vt gradually increases, and the voltage across resistor R equals V1-Vt, with the charging current being (V1-Vt)/R. As time progresses, the current gradually decreases, Vt increases gradually until V1=Vt and i=0, marking the end of the charging process.[4]

Conductive objects exhibit capacitance between them. The size of this capacitance is influenced by the conductivity of the medium, the dimensions of the objects, and the presence of conductive materials in the surrounding environment. On printed circuit boards, large solder pads and adjacent ground form distributed capacitance C. When a finger touches the button, the capacitance of the human body interacts with the distributed capacitance, increasing the total capacitance and causing a change in capacitance.

A touch sensor and microcontroller pins form a continuously charging and discharging RC circuit. If the button is not touched, the RC circuit operates according to a fixed charging

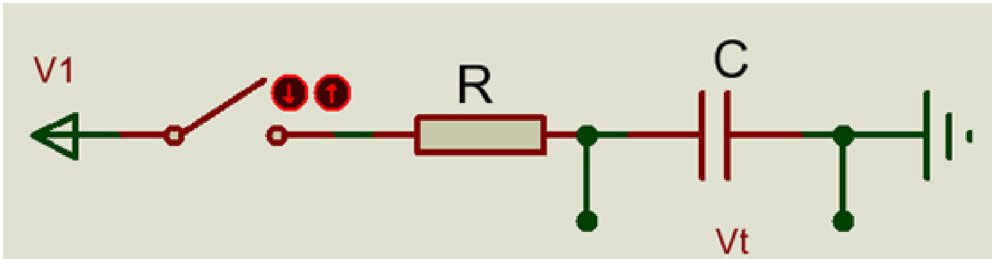

Figure 8: RC charge-discharge circuit

and discharging cycle. However, when the button is touched, the equivalent capacitance C increases, leading to an extension of the charging and discharging cycle, thus reducing the frequency. Typically, to determine whether the capacitive button is pressed, integrated circuits collect the number of pulses within a fixed time period, subtracting it from the number when the button is not pressed, and finally identifying the pressing and releasing of the button based on a defined threshold (such as the CH554 series).

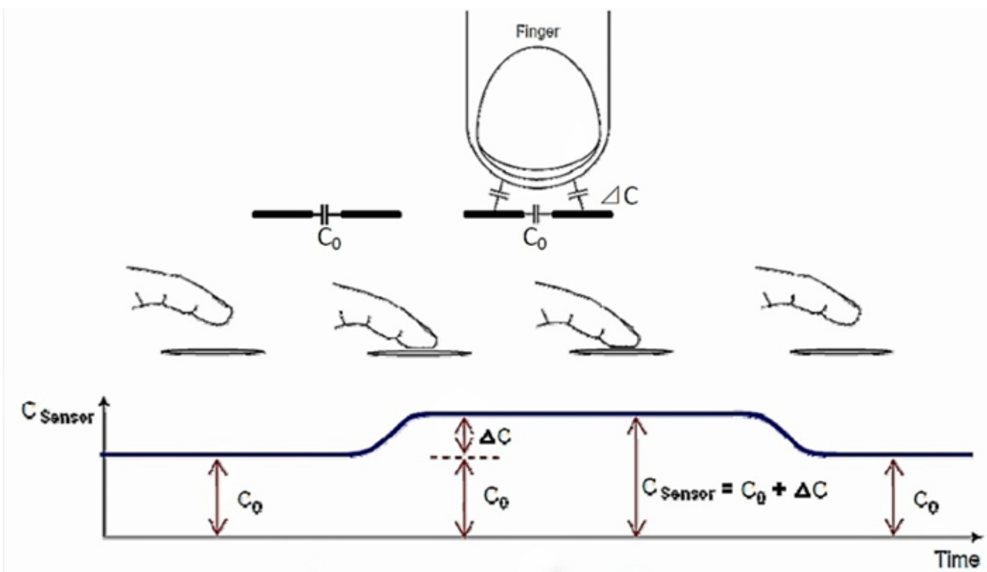

Figure 9: The principle of touch sensor

2.3.3.2 How it will contribute to the whole system

Firstly, it provides a modernized user interaction method. Users can directly control the power supply's parameters, such as voltage output and current limit, through a touchscreen or touch buttons, freeing them from traditional knob or switch operations. The touch control PCB module enhances the flexibility and programmability of the power supply. With the control module, users can easily set and adjust the power supply's output parameters, such as voltage and current settings, as well as operating modes and protection settings. What else, the touch control PCB module simplifies the power supply's control circuit. It integrates components like touch control chips, making the entire control circuit structure more concise, while also reducing hardware costs and layout complexity.

Overall, the touch control PCB module enhances the power supply's appearance design and user experience, making operations more convenient and comfortable, and bringing many advantages to the design of the Touch Controlled Programmable DC Power Supply Circuit.

2.3.3.3 Chip selection and circuit design

For the chip selection, after doing some research, TTP223 is decided to be chosen as the IC for the central of the touch control circuit. TTP223 is a single-channel capacitive touch chip, available in SOT-23-6L package. It operates at a voltage range of 2.0 5.5V and supports both momentary and latch output modes, controlled by the TOG pin. The default output level upon power-up is controlled by the AHLB pin. The chip defaults to a low-power mode (1.5uA), transitioning to normal operation mode upon detecting touch. After approximately 12 seconds of touch release, the chip returns to low-power mode. Pin 1 can sink current up to 8mA, and source current up to -4mA.[5]

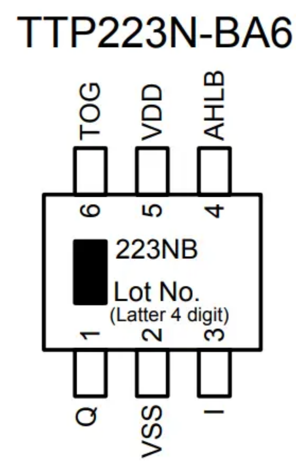

Figure 10: A figure of TTP223

Pad Number	Pad name	Pad description
1	Q	CMOS output
2	VSS	Negative power supply,ground
3	I	Input sensor port
4	AHLB	Ouput active or low selection,1 for active low,0 for active high
5	VDD	Positive power supply
6	TOG	Output type selection,1 for toggle mode,0 for direct mode.

Table 3: Pads description

With the Pads description above, we can see the application of the TTP223 IC chip, and we can then draw the application circuit as in Figure 10.

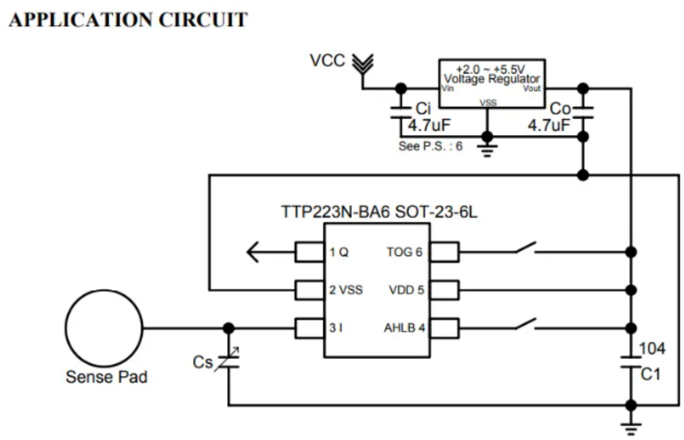

Figure 11: Application circuit

2.3.3.4 Requirements and Verfication

See Table : Touch Control subsystem.

Requirement	Verification
The touch control module needs to respond to light touches and accurately recognize different gestures and commands.	Perform touch tests using simulated fingers or specific testing tools with different pressures and speeds to confirm the response to various touch situations.
The touch control module should maintain stable performance under various environmental conditions such as temperature changes and humidity.	Test the touch control module under different environmental conditions, including temperature changes and humidity, to ensure it can function properly under various conditions..
The touch control module should accurately identify the user's touch position and translate it into corresponding commands or operations.	Use accurate testing tools to conduct positioning tests on the touch control module to confirm the accuracy of identifying and responding to the user's touch position.

Table 4: Touch Control Subsystem

2.3.4 Protection Subsystem

The Protection Subsystem is intended to ensure the safety of the circuit and the connected devices by detecting and preventing short circuits. It includes current sensors and over current protection components. This subsystem is an auxiliary protection device that promptly cuts off the circuit in the event of an unexpected situation, protecting both the circuit and the user.

When designing the PCB, we determine the appropriate current and voltage level according to the actual application needs, and take into account factors such as temperature rise and safety factor to ensure the reliability and long-term stability of the circuit. In terms of voltage, there is no unified maximum voltage standard for PCB boards, which depends more on the material, thickness, design and use environment of the PCB. The continuous operating current in common PCB designs generally does not exceed 10A or 5A, and in household and consumer electronics, the continuous operating current usually does not exceed 2A, which will be a reference for our circuit protection standards.

- **Current Sensors:** Used to measure or sense the electrical current flowing through a conductor.

  In industrial control systems, the voltage and current within printed circuit board (PCB) circuits must be meticulously monitored and protected. The project undertakes this task using conventional simulation acquisition techniques. Sensors are employed to measure the current and voltage levels, converting these analog signals into digital form for processing.

  The conversion is performed by an analog-to-digital converter (ADC), which samples, quantizes, and codes the continuous analog signal into a discrete digital one. Once digitized, the signal's transmission to the control unit follows, facilitated by the ModBus protocol. This versatile protocol is tailored for data exchange in electronic devices, supporting various physical layers including serial communication.

  To counteract potential electrical noise and interference inherent in industrial environments, the project includes an isolated RS485 interface. The RS485 standard enables differential signaling with robust anti-interference capabilities, allowing for high-speed data transfer over extended distances. Its isolation feature safeguards against damage from voltage surges and minimizes ground loop issues.

  By integrating ADC for signal conversion with ModBus and RS485 for data transmission, the control unit can ascertain precise current and voltage data. Such accuracy is essential for the circuit breaker protection system, enabling it to make prompt decisions and execute necessary actions like disconnecting the circuit to prevent hazards like overloads or short circuits. This ensures the safety of personnel and the equipment's proper functioning.

  The integration of accurate data acquisition, reliable transmission, and effective protection strategies guarantees the system's stable operation.

- **Overcurrent Protection Components:** Used to detect and interrupt or limit the current when it exceeds a certain threshold, preventing damage to the circuit or equipment and ensuring safety.

  We have three primary methods for implementing circuit overcurrent protection. The first method involves active monitoring by the control unit, which receives electrical signals and oversees the operation of the circuit breaker to protect against overcurrent conditions. This approach requires a sophisticated control system capable of interpreting incoming signals and executing the necessary actions to disconnect power if an anomaly is detected.

  The second method focuses on the physical design of the circuit itself, incorporated into the printed circuit board (PCB). By strategically designing the circuit layout with

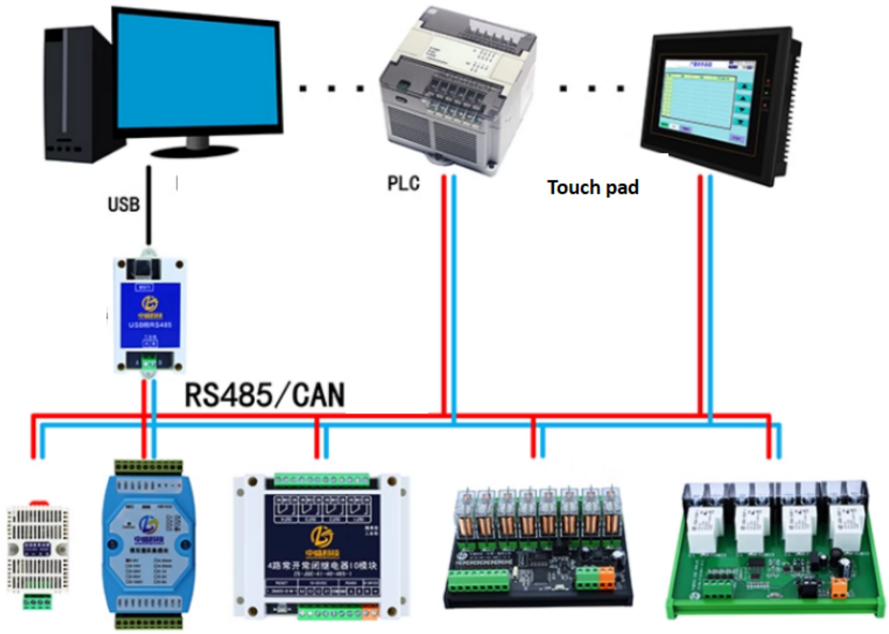

Figure 12: Application circuit

specific protection components such as current-limiting resistors, fuses, or polyfuses, we can provide a layer of safety that prevents overcurrent events from causing damage to the PCB or its associated components. This design-based approach ensures that the protection is inherent to the circuit's structure and does not rely solely on external monitoring systems.

The third and final method employs self-recovering fuses that are connected in series within the circuit. These devices act as a last line of defense, functioning as automatic resettable protection mechanisms. In the event of an overcurrent condition, they limit the current flow to safe levels and then reset themselves once the fault has been cleared, allowing for the continued operation of the circuit without manual intervention. This type of self-recovery fuse provides a reliable and convenient means of ensuring both the circuit's integrity and the user's safety from potential electrical hazards.

By utilizing these three strategies—active control unit monitoring, thoughtful PCB design, and self-recovery fuses—we create a robust and comprehensive framework for circuit overcurrent protection. Each approach serves as a critical layer in our multifaceted strategy to guard against electrical faults, thereby safeguarding both the functionality of the circuit and the well-being of the users.

2.4 Tolerance Analysis

The hardware of the touch control circuit itself may be difficult to choose, as a touch-controlled programmable touchpad is difficult for us to directly implement, so we may need

Requirement	Verification
1. The subsystem can detect the current and voltage signal from the circuit to the control system.	The current and voltage data can be get from the control system for the users.
2. The logic of the PCB itself acts as the part of the protection subsystem to avoid over current.	PCB will avoid and protect isself by the circuit logic.
3. By virtue of their physical properties, series self-restoring fuses provide minimal protection against voltage or current overload.	Series-capable self-restoring fuses will disconnect the circuit when overloading occurs.

Table 5: Protection Subsystem

to choose and purchase the appropriate one. This touch control circuit needs to meet our requirements for power regulation and detection, stably receive signals from the circuit, and be able to run the programming language we use to implement the functions.

To regulate the power supply, we need the filter block to reduce the ripple in the rectifier output. We plan to use a single capacitor connected from the output of the rectifier circuit to the ground to act as a filter section. The capacitor provides current to the load between peaks of rectified output. Between peaks of rectified voltage, the filter capacitor is discharging at a rate that depends upon the amount of current delivered to the regulator.

The ripple voltage, $V_{\text{ripple, C}}$ across the capacitor (C) can related to the value of the capacitance as follows,

$$V_{\text{ripple},C} = \frac{I_L}{f \cdot C} \tag{1}$$

where I_L is the DC component of the load current and f is the frequency of the filter output. To use the expression to compute C, the output ripple voltage must be converted to the ripple across the capacitor.

3 Cost and Schedule

3.1 Cost Analysis

Labor = $18/h * 7h * 12weeks * 4members$ =6480

Item	Number	Price(unit: $)
TTP223 chips	According to the level of voltage	0.5 for each
Printed Circuit Board	1	200-400
Capacitors	A few	0.05 for each
Resistors	A few	0.06 for each
IT/ADI regulator	A few	2.4 for each

Table 6: Cost Analysis

3.2 Schedule

Week	Weisong Shi	Chaoli Xia	Yiyi Wang	Sichen Wang
3/4	Learn PCB knowledge and work on the project proposal.	Learn PCB knowledge and work on the project proposal.	Learn PCB knowledge and work on the project proposal.	Learn PCB knowledge and work on the project proposal.
3/11	Learn about Touch control circuit.	Learn about the principle and some common approaches of circuit detection and protection.	Learn the principle under AC-DC conversion and the characteristics of the components.	Learn the working principles of Variable Regulated Power circuit.
3/18	Browse different chips and decide which to use.	Find and consult the corresponding circuit detection and protection components, compare the applicability of parameters.	Create the basic circuit diagram for the AC-DC converter. Do research on the property and requirements of each component.	Search and find feasible solutions that can achieve precise and stable regulation of the output DC voltage.

Week	Weisong Shi	Chaoli Xia	Yiyi Wang	Sichen Wang
3/25	Start to build the circuit.	, Analyze the feasibility of each program and discuss with the sponsor.	Continue doing research on the selection of components.	Verify the feasibility of precisely regulating the output voltage through feedback circuits.
4/1	Make the simulation of the circuit.	Make the simulation and logic analysis of the circuit.	Do simulation of the subsystem.	Design the Variable Regulated Power circuit.
4/8	Start to draw the CAD board.	Insert protection and monitoring parts into the PCB circuit.	Debug and Optimize	Do the simulation of the circuit.
4/15	Purchase item, draw the CAD board.	Purchase the components and integrate them.	Purchase the components. Design the PCB layout of the AC-DC converter.	Purchase item, draw the CAD board.
4/22	Print the PCB and test its functions.	Integrate the protection and detction components and adjust them.	Integrate the four subsystems together. Troubleshoot and debug. Complete the overall PCB layout design.	Integrate the subsystems.
4/29	Debug.	Adjust the components and solve the potential risk	Check whether it fulfills the high-level requirements. Do final optimization.	Debug.

Week	Weisong Shi	Chaoli Xia	Yiyi Wang	Sichen Wang
5/6	Write the essay.	Work on final report	Work on final report	Work on final report
5/13	Prepare for demo.	Prepare for demo.	Prepare for demo.	Prepare for demo.

Table 9: Schedule

4 Ethics and Safety

Undoubtedly, we need to learn many existing code structures and purchase some integrated hardware to implement our functions. So we should pay attention to avoiding plagiarism and large-scale technology appropriation, and ensuring that the core content of the project is implemented by ourselves.

To ensure safety,

In addition, there are several points based on the corresponding documents to note:

- **IEEE Code of Ethics:**
  8452 - Software Engineering Code of Ethics: Develop software that is reliable, and which meets the stated requirements.
  8460 - Sustainability of Software Engineering in an Evolving Global Population: The impact of technology on society should be considered to ensure it does not harm individuals or groups.

- **ACM Code of Ethics:**
  1.1 - Contribute to society and human well-being.
  1.3 - Honor property rights including copyrights and patents.
  1.4 - Give proper credit for intellectual property.

- **To avoid ethical breaches:**
  Ensure the DC power supply design is reliable and meets all stated requirements.
  Consider the societal impact of the technology, ensuring it does not cause harm.
  Respect property rights, including any copyrights or patents related to components used.
  Properly credit any third-party work or ideas incorporated into the project.

When designing and manufacturing PCB-based power converters, ensuring safety is essential:

- Isolation and encapsulation
  Ensure that all circuits are properly packaged to prevent accidental touching of exposed wires or components.
  Encapsulate the circuit board with an insulating material to prevent short circuits and electric shocks.

- Output voltage and current
  Ensure that the output voltage and current of the converter are within the design range and have sufficient stability.
  Use the appropriate feedback control mechanism in our solution to maintain stable output.

- Overload protection
  We incorporate overload protection circuits in the design to prevent the output current from exceeding the safe value, and use series-capable self-restoring fuses for thermal management.

We have included a short-circuit protection mechanism in the circuit design to prevent damage when the output is short-circuited.

- Electromagnetic Compatibility (EMC) :
  The isolated RS458 interface is used to ensure that the power converter complies with the relevant electromagnetic compatibility standards and reduces electromagnetic interference.

5 References

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