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Research on High Voltage Power Supply for Plasma Lightning Ball

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Abstract

The lightning ball is highly loved by people for its beautiful glow. This project delves into the power system of the lightning ball, using STM32 as the main control chip to generate high-frequency and high-voltage pulsating DC power to supply the lightning ball. Using TFT display screen as a human-computer interaction medium, with multi-level menu interface, supporting TF card reading and touch control. This design has powerful functions, good stability, and high accuracy, making it suitable for small power, high-frequency, high-voltage pulse DC sources.

Keywords

High-frequency and high-voltage power supply; STM32; Plasma Lightning Ball.

1. Introduction

1.1. Principles of Plasma Lightning Balls

In the plasma lightning ball, it is filled with inert gas, and 12V DC is converted into high-frequency high-voltage pulse electricity through circuit transformation. It is then passed through the wire core to the steel wire pile, and the steel wires in the center steel wire pile are twisted and bent, forming a pointed outer tip. After the lightning ball is electrified, gas discharge phenomenon occurs between the steel wire pile in the center and the glass ball shell, piercing the inert gas inside the ball, causing it to form a plasma and emit brilliant arc light, The high-end plasma lightning ball also has a voice control mode [1]. When adjusted to this mode, the voice control circuit can cause gas discharge to undergo intermittent changes based on the presence or absence of sound.

When the gas inside the ball experiences discharge, the color of the light emitted by the magic ball is actually the atomic characteristic spectrum of the gas filled inside the ball. The gas filled is generally a mixture of krypton or xenon and neon. Krypton and xenon make the light inside the sphere appear more like lightning rather than airflow. The color relationship of gas luminescence is shown in Table 1. Of course, in addition to the type of gas, the magnitude of the current and the pressure inside the ball also affect the color emitted by the ball[2].

Table 1 Inert Gas Discharge Colors

Gas element name	He	Ne	Ar	Kr	Xe
Atomic number	two	ten	eighteen	thirty-six	fifty-four
The color of light emitted during discharge	yellow	red	Red or blue	Chartreuse	Blue-green

1.2. Main research content of the project

Small power digital high-frequency high-voltage pulsating DC power supply has been applied in the medical and home decoration industries, and has broad market prospects.The main research content of this project is to use the STM32F103VCT6 as the control chip to design a digital switching power supply for plasma lightning balls, which outputs a low-power high-frequency high-voltage pulsating DC power supply for plasma lightning balls and has a complete human-computer interaction interface. Using a 2.8 inch TFT LCD touch screen as a human-computer interaction medium, with a multi-level menu interface that allows for switching between optional functions; Supports TF card storage, writing, and reading, capable of displaying color images and fonts; Supports point-to-point touch control, allowing you to directly click on the screen for system settings and operations. In normal mode, it supports touch control for multi-level brightness adjustment, while in voice mode, the brightness can be changed according to the surrounding volume changes. Finally, after applying 220V AC power, the system can achieve the above functions, and the lightning ball can emit a brilliant arc light.

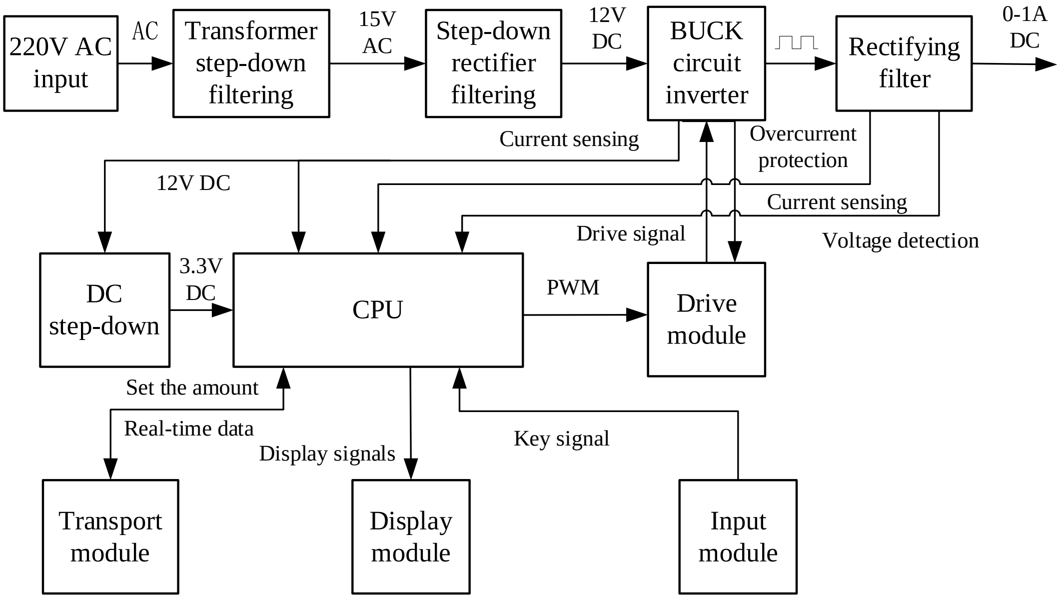

Figure 1: Schematic Diagram of Plasma Lightning Ball

2. The working principle of high-frequency and high-voltage pulsating DC source

2.1. High-voltage DC power supply

With the progress of new technology, switching power supply has now been widely used in the development of high-voltage power supply, making it possible to use smaller volume and weight of high-voltage isolation transformer, high-voltage capacitor and high-voltage rectifier diode.

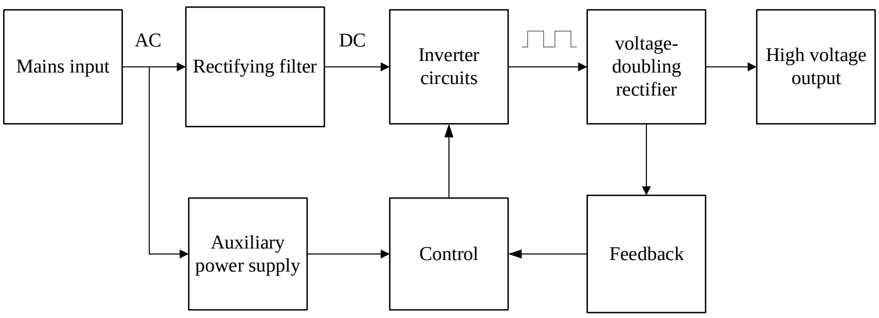

Figure 2: Schematic Block Diagram of High Voltage Switching Power Supply

The workflow of a general high-voltage switching power supply is as follows: input AC power, convert it into DC power after being rectified and filtered by a unit. High frequency square wave

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pulses are generated through various forms of inverter circuits such as half bridge and full bridge, forming an inverter unit. The high-frequency square wave pulse enters the high-frequency isolation step-up transformer for boosting, increasing the DC voltage to the output high-voltage indicator range. Send the output high-voltage feedback signal to the control and detection unit of the high-voltage power supply. The feedback signal is processed by the control and detection unit of the high-voltage power supply, the frequency or pulse width of the driving signal pulse is adjusted, and the conduction time of the power switch in the inverter unit is changed to achieve the adjustment of the output voltage amplitude [3].

2.2. Working principle of flyback power supply

Based on the power level and usage requirements, this project selects a flyback circuit with simple circuit, low cost, high reliability, and simple driving circuit as the topology circuit.

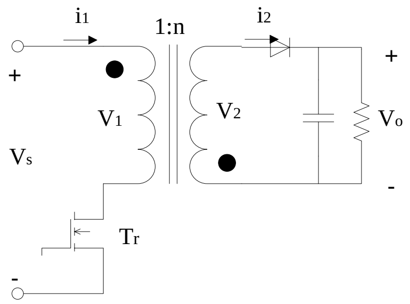

Figure 3: Flyback circuit topology diagram

Connect switch tubes in series in the primary circuit of the transformer, and control the time of energy transmission through the disconnection of the switch tubes. The working process is as follows: when T_r is on, the power current flows through the primary side of the transformer, $i_1$increases, and its change is $di_1/dt = V_s/L_1$. However, due to the action of diode, i_2 is zero, and the magnetic induction intensity of the transformer core increases, resulting in energy storage in the transformer; When T_r is turned off, the primary current rapidly decreases to 0, and the secondary current i_2 rapidly increases to its maximum value under the action of flyback, then begins to linearly decrease, with a change of $di_2/dt = V_o/L_2$. Due to the switching off of the switch tube, the current of the primary side is 0, and the magnetic induction intensity of the transformer core decreases, resulting in transformer energy release[2].

3. Hardware circuit design of high-frequency and high-voltage pulsating DC source

3.1. Topology circuit design

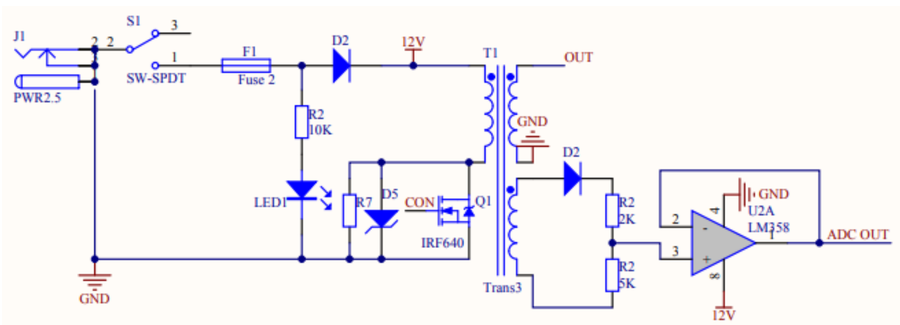

Figure 4: Main Circuit Topology Circuit Design

As shown in Figure 4, the main circuit adopts the basic principle of a flyback circuit, but due to the output requirement of pulsating DC, the rectifier diode and filter capacitor of the main circuit can be directly omitted, and the ground on both sides can be short circuited. After passing through fuses and diodes, the power supply passes through the primary coil of the transformer. Selecting MOSFET tubes as switching devices, when the MOSFET tubes are turned on, the power supply charges the transformer, and when turned off, the transformer transfers energy to the secondary side.

MOSFET generally performs well in lower power applications and higher frequency applications, while IGBT performs excellently in lower frequency and higher power designs. As needed, the switch tube needs to withstand a current of about 1A. Considering the characteristics and safety margin of MOSFET, IRF640 is selected [5].

3.2. Power supply circuit design

Power supply is a necessary condition for the normal operation of a system, and the stability of power supply has a significant impact on the overall performance of the system. Unstable power supply can cause significant fluctuations and deviations in the A/D sampling of microprocessors, affecting the working state of the system, and even leading to system paralysis in severe cases.

According to the needs of system operation, the power output voltage of the main control circuit should include 5V and 3.3V. To ensure the stability of the system, the main control selects linear power chips 7805 and LM1117-3.3 for voltage conversion.

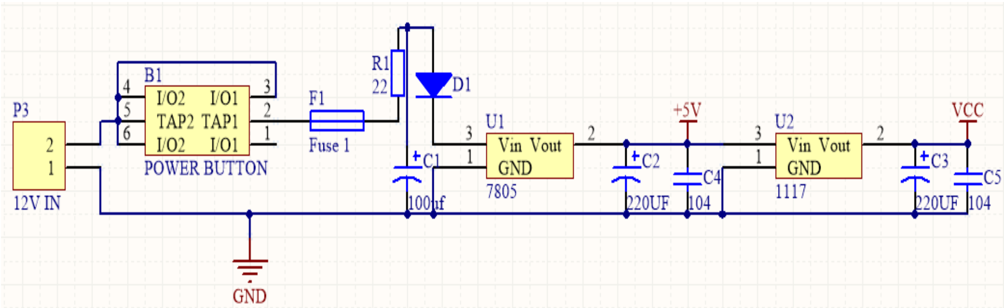

Figure 5 Voltage Conversion Circuit

3.3. Minimum System Circuit Design

STM32F103VCT6 chip with a frequency of up to 72MHz was selected as the main control chip. The STM32 series microcontroller is a 32-bit microprocessor based on the embedded ARM CortexM3 core, with a working frequency of 72 MHz, built-in high-speed memory, eighty I/O ports, 32 bit data bus width, 16 A/D sampling channels, capable of 12 bit A/D sampling, and includes four universal 16 bit timers and two PWM timers, with high sampling accuracy [6]. Equipped with DMA function, capable of data transmission without occupying system resources. It has 8 specialized timers, among which the TIM1 timer supports three sets of bidirectional and six PWM wave outputs, and also has a Break IN function, which can turn off PWM wave output through hardware to achieve the purpose of protecting the system. Equipped with 5 sets of USART serial communication capabilities, capable of real-time communication with the upper computer [6]. The minimum system should include: control chip, crystal oscillator circuit and reset circuit. The specific model of the selected control chip is STM32F103VCT6, packaged as LQFP100, with 100 pins and an external crystal oscillator of 8MHz. According to the chip manual, the minimum control circuit system can be designed, as shown in Figure 6.

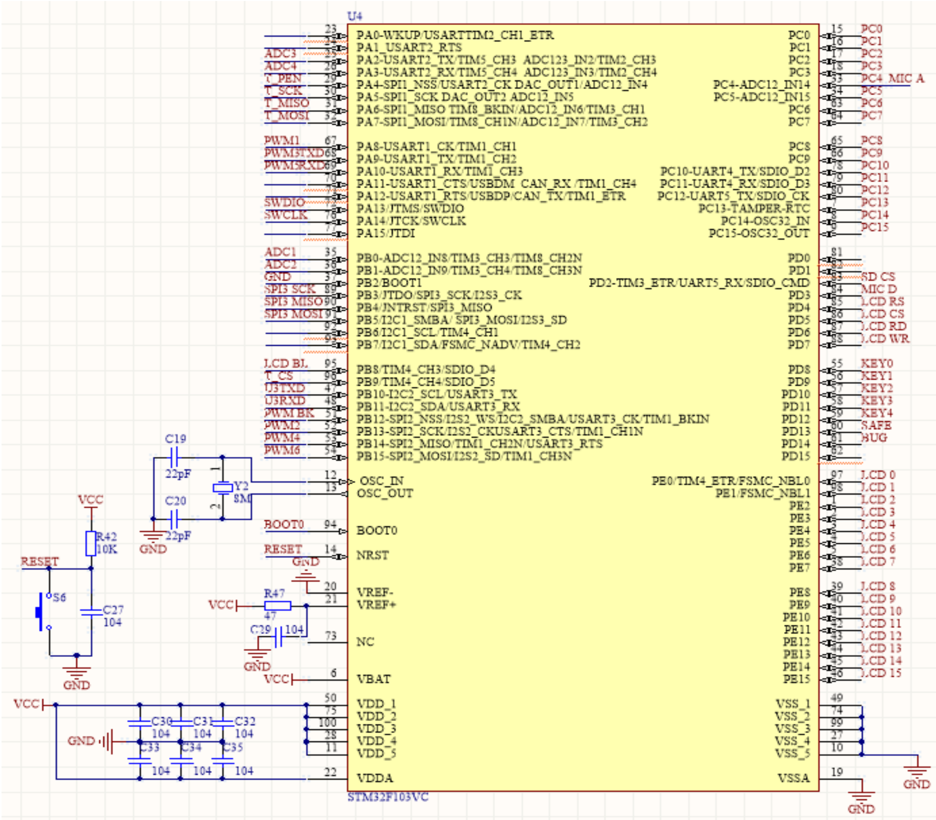

Figure 6: Minimum System Circuit

3.4. ADC sampling circuit design

STM32F103VCT6 has 3 sets of ADC with a total of 18 channels, including 16 external channels and 2 internal channels. The A/D conversion of each channel can be performed in single, continuous, scan, or intermittent modes. The control board has designed a total of 4 sets of AD sampling circuits, which can effectively complete closed-loop operations. In the sampling circuit of the power supply, diode rectifier bridge sampling is usually used. The control board is designed with MMBD4148SE dual diodes as clamping. Once the potential is higher than 3.3V, the diode at the VCC conducts, and the excess potential is absorbed by the VCC. Therefore, the actual input voltage to the AD pin is 0-3.3V, which effectively achieves clamping effect and protects the pin.

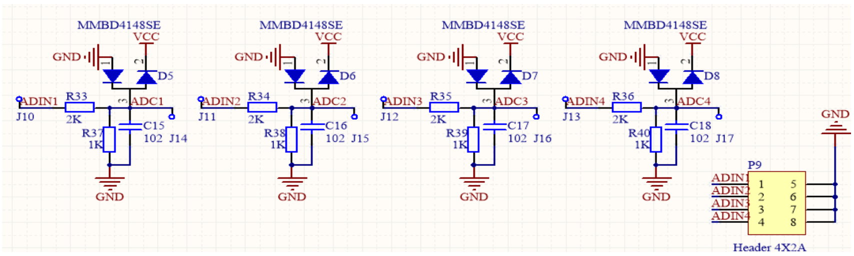

Figure 7: ADC sampling circuit

3.5. Voice Control Circuit Design

The plasma lightning ball has voice control function, so a voice control module needs to be added, which uses LM386.

Audio integrated power amplifier, output as AC signal. In practical use, it is necessary to raise the power supply circuit, raise the negative bit, and then perform AD sampling. At this time, the signal is a time-domain signal, which needs to be converted into a frequency domain signal through FFT transformation to calculate the volume.

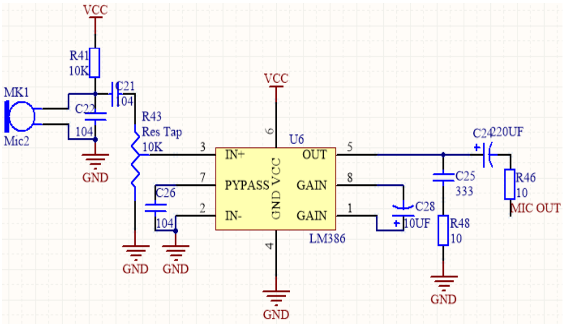

Figure 8: Voice Control Circuit Design

4. Software Design

4.1. Main program design

This project has designed a comprehensive interactive interface, including the main menu, four first level sub functions, and five second level sub functions. For this reason, the program running status flag was used in the design. Taking MODE as an example, when MODE is 0-9, it corresponds to different subroutines. The specific process is shown in Figure 9.

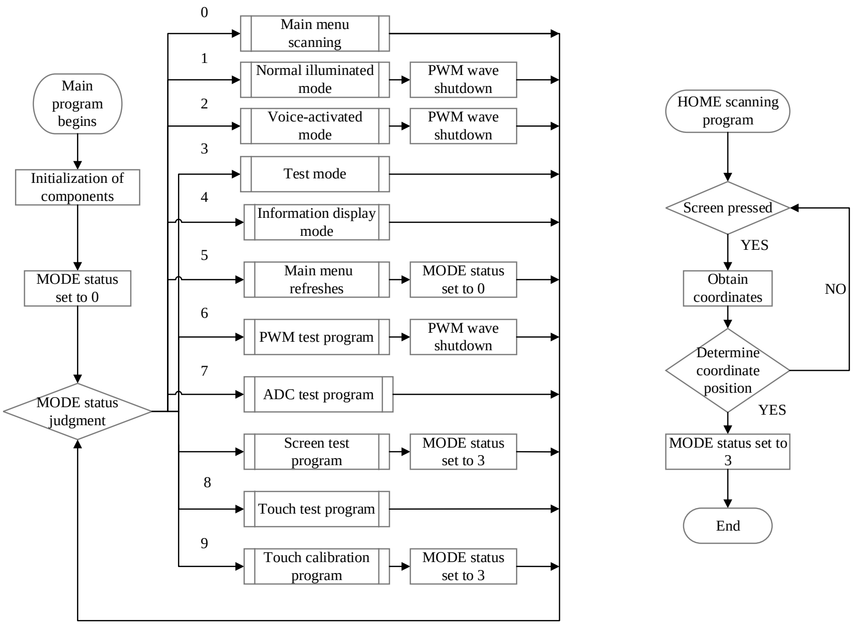

Figure 9： Main program flowchart EEPROM module workflow

4.2. System initialization principle

System initialization mainly involves initializing and configuring the GPIO, IIC, SPI, DMA, serial ports, timer interrupts, etc. used to achieve the system's functions[7].

GPIO initialization: GPIO initialization is the starting point for all functions. In STM32, if a pin function is enabled, its GPIO must be initialized first. The process includes: GPIO clock enable, pin output mode setting, output speed setting, etc. The I/O port of STM32 has 8 modes, namely analog input, floating input, pull-down input, pull-up input, open drain output, push pull output, multiplexed open drain output, and multiplexed push pull output. Generally speaking, push-pull output mode can be used, which can either inject current into the load or extract current from the load. Therefore, when configuring communication modules, PWM outputs, and other pins, LED, button, and other functions, push-pull output mode can be used. For ADC sampling pins, analog input mode must be used.

IIC initialization: IIC is mainly used to communicate with the off chip memory AT24C256 to store and read important system parameters. The initialization of IIC is relatively simple. After

GPIO configuration, set the two pins SCL and SDA of IIC to corresponding levels according to their timing. The IIC reading and writing flowchart is shown in Figures 10 and 11.

SPI initialization: SPI is a synchronous, full duplex, master-slave interface where data from the master or slave is synchronized on the rising or falling edge of the clock, allowing both the master and slave to transmit data simultaneously. The SPI interface can be 3-wire or 4-wire. [8] In this system, SPI is mainly used for communication with TF cards and transmission of touch data. Touch data is transmitted through the SPI1 bus, while TF cards are transmitted through the SPI3 bus. The initialization of SPI requires configuring SDO as input and SDI, SCKL, and CS as output.

Serial port initialization: The serial port is mainly used for communication with the upper computer. The serial port channel introduced in this project is USART3. During initialization, the USART3 pin needs to be configured, TX is configured as output, and RX is configured as input in order to transmit data.

DMA initialization: When configuring DMA, it is necessary to accurately configure its access address, working mode, total data amount, address increase or decrease, and other parameters. The ADC testing mode of this project uses 4 channels of ADC simultaneously, so it needs to be combined with DMA.

PWM initialization: In this project, only one output needs to be used, that is, one output needs to be configured. The configuration includes triggering pins, timer cycle, frequency division coefficient, output mode, alignment mode, duty cycle setting, etc.

Voice control module initialization: The initialization of the voice control module only requires the configuration of an ADC converter to read values through changes in level, but its AD value is not a level signal of sound size. During processing, a set of collected AD data is FFT transformed to convert the time-domain signal into a frequency-domain signal, obtaining the energy height of each frequency band, and calculating the overall volume size by calculating the root mean square value.

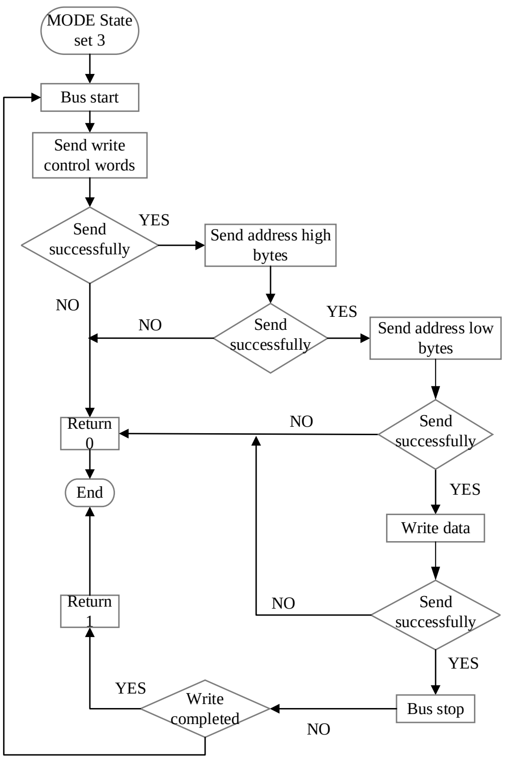

Figure 10: IIC Writing Process Flowchart

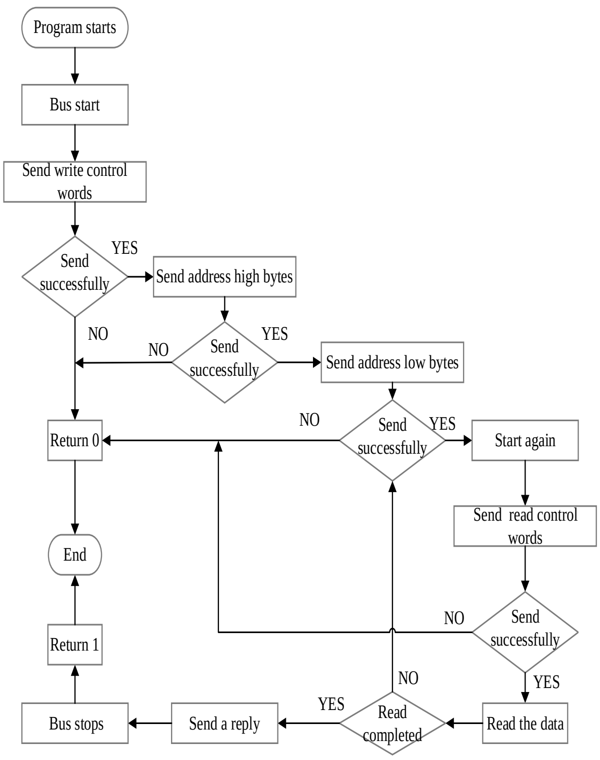

Figure 11: IIC Reading Process Flowchart

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5. System debugging

Figure 12: System standby diagram

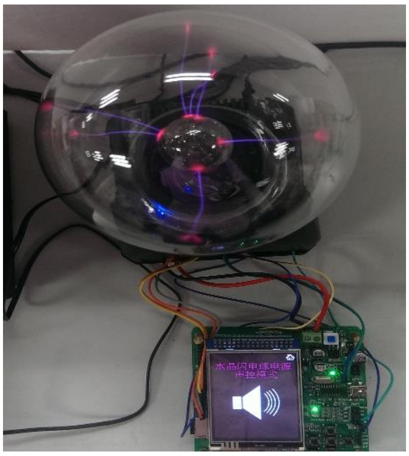

Figure 13: System operation diagram

Figure 14: Project Information Interface

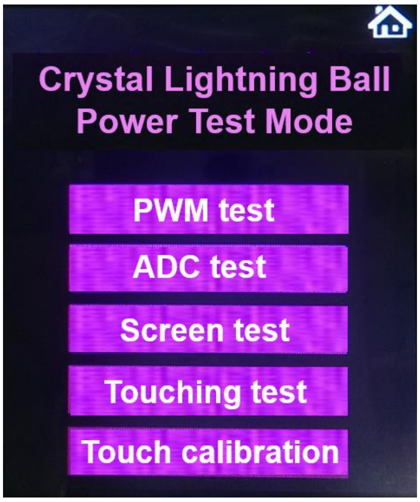

Figure 15: System Test Interface

Figure 16: System ADC Test Interface

Figure 17: System PWM Test Interface

As shown in the above picture, the main control board has been completed with a reasonable layout and normal functions. The main circuit welding has been completed, and the installation reservation position is accurate. The plasma lightning ball system has a complete structure and can operate stably for a long time. Moreover, this system has a good human-machine interaction interface, which is complete and the control logic is rigorous. The switching between various interfaces is normal, which can effectively meet the needs of human-computer interaction.

6. Conclusion

Through the above research, this project has achieved the following design goals:

1. Ensure multi-level brightness adjustment under the premise of normal operation of the plasma lightning ball.
2. Realized closed-loop operation of lightning ball output voltage.
3. The voice control function of the plasma lightning ball can adjust the brightness based on the size of the sound.
4. Implemented TFT LCD display and touch control.
5. The human-computer interaction interface has been improved, and the control is simple, clear, and convenient.

In the future, it can be further upgraded to improve luminous efficiency, high brightness, long lifespan, and reliability. It can also optimize the production of upper computer software for real-time control. Based on the above conclusions, this project has achieved all established goals.

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