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# Design of a Wide-Range Adjustable Linear Power Supply

Puxin LIU [a] , Xingwen Dong [b], and Chunsheng Zhu [c]

The college of Nuclear Technology and Automation Engineering, Chengdu University of Technology, Cambridge, Chengdu, 610059, China.

[a] liupuxin@stu.cdut.edu.cn, [b] dongxingwen@stu.cdut.edu.cn, [c] 305841371@qq.com

**Abstract.** Industrial adjustable DC power supplies are mostly analog power supplies that use hardware closed-loop control and rely on mechanical regulation, making it difficult to balance wide range adjustable output and low ripple, and having poor regulation accuracy. To solve this problem, a wide range adjustable and low ripple DC stabilized power supply was designed using TI TPS54360B synchronous Buck converter and MIC29502 low dropout linear regulator. Using STM32F103C8T6 microcontroller as the control core, we independently designed DC-DC feedback loop, LDO feedback loop, and ADC sampling loop to achieve closed-loop control of power system output and real-time monitoring of parameters. The test results show that the system can achieve adjustable output of 1.182V-24.2V, step accuracy of 7mV, ripple of 3mV, maximum output current of 3.3A, efficiency of 88%, with overcurrent and over temperature protection, fully meeting the precision power supply requirements of industrial low-power equipment.

**Keywords:** Two cascade modulation; regulated power supply; Power supply design.

## 1. Introduction

The development and widespread application of technologies such as industrial automation motion control have put forward higher requirements for the stability, accuracy, and anti-interference of power output. Compared to digital power supplies, analog power supplies are susceptible to external environmental interference, making it difficult to balance output regulation range and regulation accuracy. References [1-5] studied technologies such as UC3875 chip, FSL106MR chip, Boost converter, etc., and designed and applied switching power supplies for specific scenarios. References [6-11] conducted research on the design of linear regulated power supplies for specific application scenarios such as sensors and nuclear power plants. In industrial adjustable DC power supplies, linear power supplies have the characteristics of low ripple and low noise, but their efficiency is low and their adjustable range is narrow. Although switch mode power supplies have the characteristics of high efficiency, small size, and wide voltage input range, their electromagnetic interference is large, and the ripple and electromagnetic noise generated may affect precision instruments. Reference [12] designed a switch linear hybrid power supply to meet the operational requirements of particle accelerators, achieving power output stability at different temperatures, but did not focus on adjustable accuracy and adjustable range. This article proposes a two-stage voltage regulation and stabilization design scheme, which achieves stable power output under 30V input and adjustable 7mV wide range step, high output accuracy, and good dynamic response.

## 2. Circuit and Parameter Design

### 2.1 Overall Approach

Firstly, we should clarify the requirements for the power supply specifications, which include an input voltage of 30V, an output voltage adjustment range greater than 2.5-21.5V, a voltage ripple of less than 50mV, a full load greater than 3A, an efficiency greater than 75%, and a voltage step adjustable accuracy of less than 50mV. There have been numerous research results on the working principle and various device selection of synchronous Buck converters and low dropout linear regulators, which are technically mature and will not be repeated in this article. The following

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mainly elaborates on the design work that differs from traditional adjustable DC power supplies. The power supply in this article can be divided into two parts: the circuit part based on DC-DC and LDO, and the sampling control part based on MCU programming. The system diagram is shown in Figure 1.

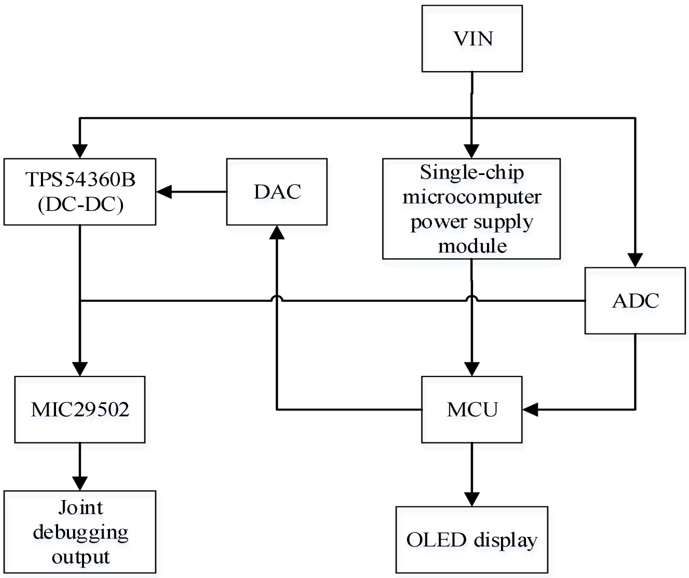

Fig. 1 Overall block diagram of system design

## 2.2 Power Topology Structure

The schematic diagram of the power supply is shown in Figure 2, where the front stage switching power supply, the rear stage linear power supply, and the load form a series stable current circuit.

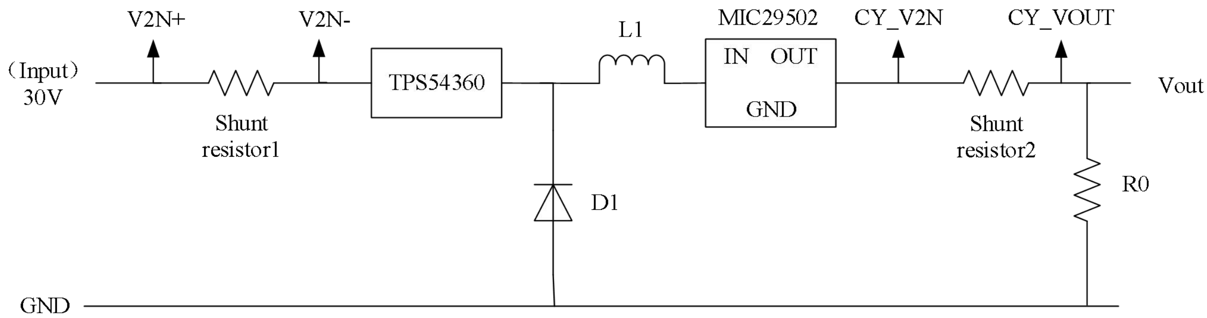

Fig. 2 Power topology diagram

To achieve power miniaturization, the front-end switching power supply adopts the mature TI TPS54360B synchronous Buck converter, replacing the bulky multi-stage filtering circuit in traditional adjustable linear power supplies, and achieving efficient conversion under 30V input. After DC-DC conversion and capacitor filtering, the 30V input can achieve pre stabilization and enter the later stage. The rear linear power supply adopts MIC29502 low voltage difference linear regulator. Compared with traditional LDO, it only has a voltage difference of 0.45V at 3A output, which can significantly reduce Buck losses from the root and improve the overall efficiency of the power supply. At the same time, the chip has graded overvoltage protection internally, which can achieve wide input and outstanding high-temperature stability, enabling the power supply to achieve a wider output range and stronger load capacity.

The core of the power supply lies in the feedback pin FB of the two chips. Compared with other power supply chips, this article designs a feedback loop by ourselves and uses MCU to program the DAC to perform closed-loop control on the output of the two chips, thereby greatly improving the

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adjustable accuracy and stability of the output. At the same time, in order to facilitate the ADC sampling loop to collect and calculate power parameters, a 100mΩ sampling resistor is connected to the input terminal of the switching power supply and the output terminal of the linear power supply.

### 2.3 ADC Sampling Loop

The ADC sampling loop is shown in Figure 3. This module uses the TI high-precision current detection chip INA240, which has a voltage gain of 20 times, an ultra-high common mode voltage range, and an extremely strong common mode suppression ratio. It can accurately amplify the weak current passing through the sampling resistor at the input terminal of the switching power supply and the output terminal of the linear power supply, and enter the 12 bit ADC inside the microcontroller for signal acquisition.

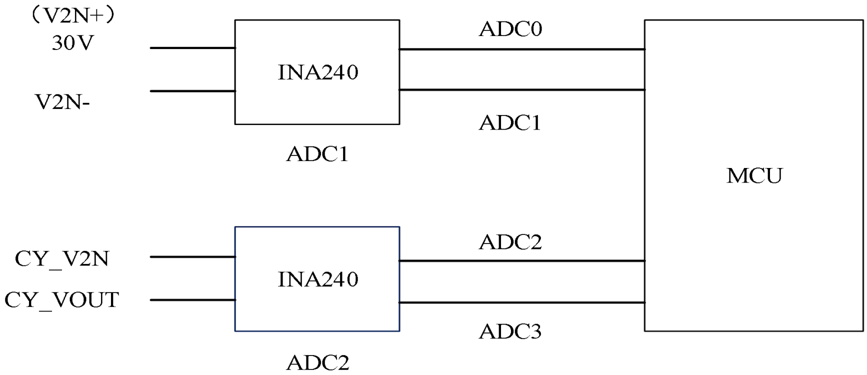


Fig. 3 ADC sampling loop diagram

### 2.4 Control Circuit

The control circuit structure is shown in Figure 4. This circuit achieves feedback control for both DC-DC and LDO chips using DAC8551. The hardware of this module consists of a differential structure consisting of DAC8551 chip, REF3025 voltage reference chip, and OP703. It is regulated using feedback voltage and reference voltage, and has good stability. Among them, DAC8551 provides 16 bit dynamic resolution and μs level response, while OP703 operational amplifier ensures signal purity through 1pA bias current and 90dB CMRR, laying the foundation for numerical control. The control core of this module lies in the use of a microcontroller, combined with the signal values sampled by the internal ADC, and through programming, outputting corresponding digital quantities to control DAC8551 according to the SPI protocol and button functions, thereby controlling the feedback terminals of the switching power supply and linear power supply, ensuring output stability and step accuracy, enabling the total output of the power system to be quickly adjusted to the output step value set by the button, and achieving extremely low ripple output.

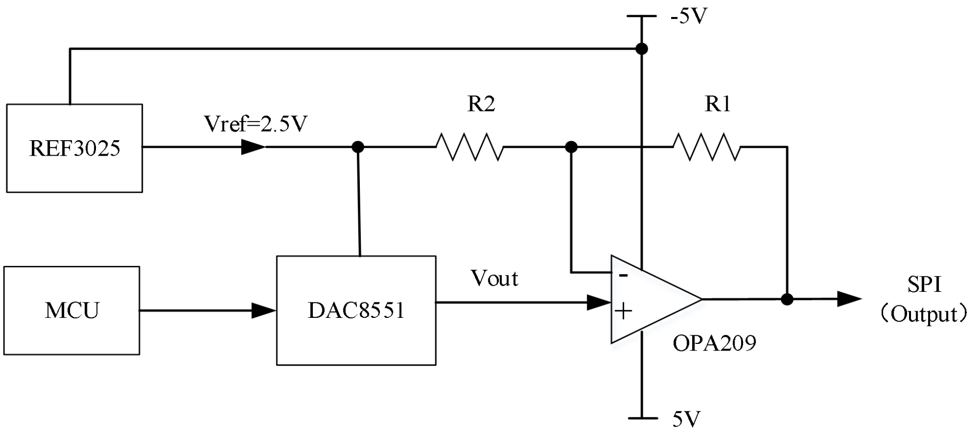


Fig. 4 Control circuit diagram

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### 2.5 Other Circuit Parameters

The selection and design of input rectifier filter circuits and output rectifier filters are technically mature. The selection and parameters of the relevant equipment used in this article are as follows:

(1) The filtering capacitors of the switching power supply and linear power supply module adopt a structure of 1 aluminum electrolytic capacitor in parallel with 3 ceramic capacitors, where the aluminum electrolytic capacitor is 220μF, and the 3 ceramic capacitors are 10μF, 0.1μF, and 10nF respectively. It has been tested that a large amount of switching noise can be filtered out.

(2) The common mode filter at the system input adopts UU9.8-5mH.

(3) The output inductance of the switching power supply is L=68μH.

(4) The filtering capacitors of the ADC sampling circuit and control circuit adopt a structure of 1 aluminum electrolytic capacitor in parallel with 2 ceramic capacitors, where the aluminum electrolytic capacitor is 47μF, and the 2 ceramic capacitors are 10μF and 0.1μF respectively.

### 2.6 Circuit Optimization

The key to optimization lies in PCB design. At high loads, the efficiency of TPS54360 decreases at the low voltage end with a wide input range, while the pressure drop loss of MIC29502 is significant, both of which may generate a large amount of heat. If the PCB layout heat dissipation design is improper, the chip temperature will be too high, triggering thermal shutdown or reducing lifespan.

To this end, provide a sufficiently large copper plated area for the heat dissipation pads of TPS54360, and drill enough heat dissipation vias to connect to the inner or bottom ground plane for heat dissipation. The GND pin of MIC29502 should also be connected to a good heat dissipation copper sheet; Disperse the heating devices to avoid heat concentration; Use heat sinks. At the same time, in order to ensure the stable operation of the entire system, thermistor and TL431 were used, and an over temperature protection circuit was constructed with LM393 comparator to prevent the temperature of the power chip from exceeding 70℃. As shown in Figure 5.

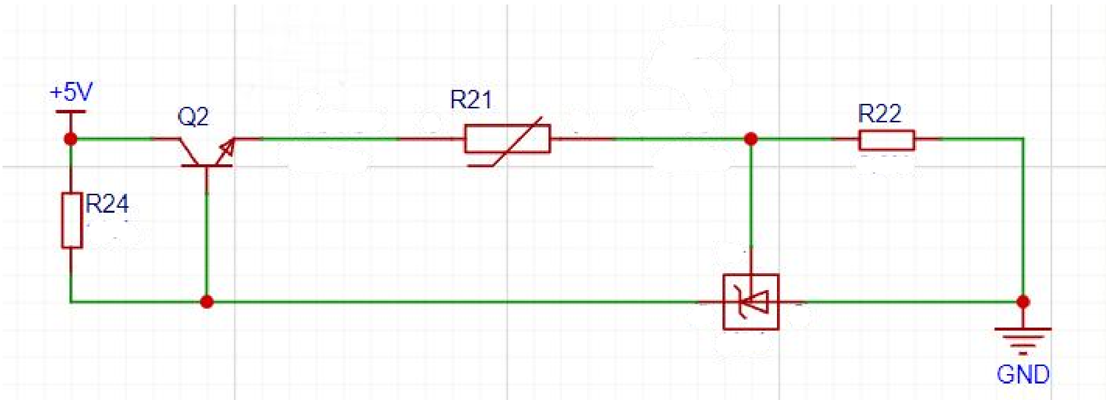


Fig. 5 Over temperature protection circuit

At the same time, in order to improve signal accuracy at the hardware level, the power loop of TPS54360 should be kept as small and compact as possible during PCB design. Minimize the copper coverage area of the SW node to avoid becoming an antenna, and place MIC29502 and its input/output capacitors as close as possible to its load.

## 3. Control Program Writing

During programming, a large amount of module resources from STM32F103C8T6 were utilized, and the key to control lies in timing accuracy and synchronous operation of different modules. Reasonable handling of the priority of different interrupts in programming: using external interrupt control buttons, using timer interrupts to control timing and ADC acquisition. At the same time,

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reasonable settings have been made for the timer, which can ensure sufficient corresponding speed and avoid conflicts between different module operations.

The main program is as follows:

Step 1: Scan the five independent control keys to determine their status.

Step 2: Obtain the key value by scanning the external interrupt of the microcontroller, determine which control key is pressed, and execute the corresponding function for the pressed key. The five keys have the functions of increment, decrement, left shift, right shift, and confirmation, respectively.

Step 3: Through programming, utilize the timer interrupt to activate the built-in ADC of the microcontroller for sampling the voltage across the DC-DC chip's feedback resistor. Convert the sampled values into corresponding DAC values in the code, then adjust the DC-DC chip's FB pin via the DAC. This controls the duty cycle of the switching power supply and linear power supply, enabling step-by-step adjustment within a 50mV range.

Step 4: Utilize the OLED screen to create a menu. Calculate the system's real-time efficiency based on the formula $\eta$ = output power / input power. Then, display the system efficiency, DAC step value, and button press count on the screen via the SPI protocol with sufficient response speed.

The process is shown in Figure 6.

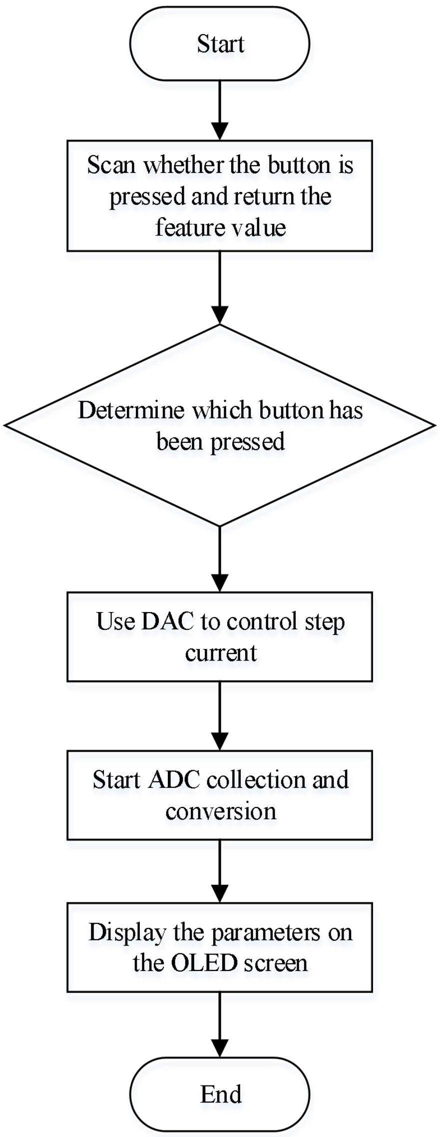


Fig. 6 Main program flow

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# 4. System Testing

In order to verify and validate the output adjustable range, output ripple, and adjustable accuracy of the wide range adjustable DC stabilized power supply designed, an experimental prototype was made, as shown in Figure 7.

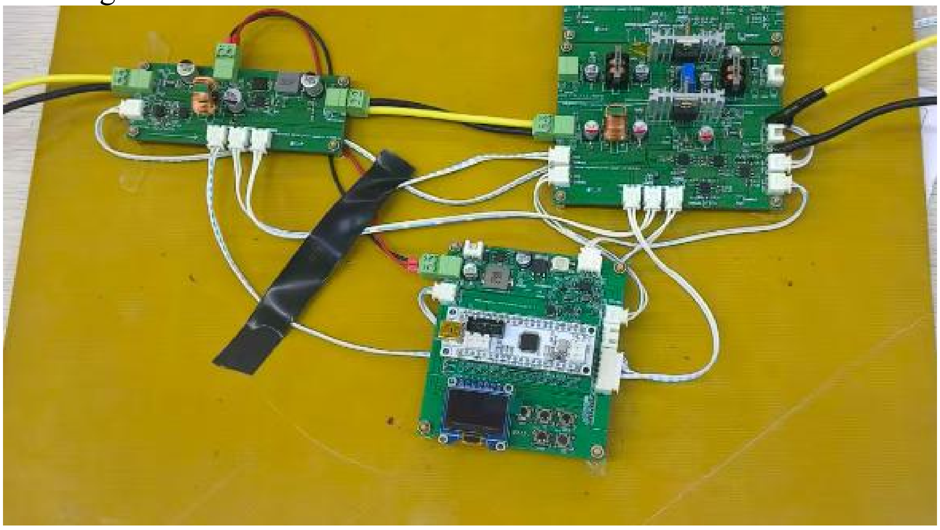

Fig. 7 Experimental prototype

## 4.1 Test Method

The test conditions are as follows: a DC voltage source is set to 30V, with the output connected to an electronic load. Measurements are taken using a multimeter and an oscilloscope.

Observe the ADC sampling values and the digital input of the DAC controlled by buttons through the OLED display, as well as the overall system efficiency. Adjust the load to determine whether the system output is stable. Simultaneously, measure various parameters of the power supply, pin voltages of key components, and test point voltages using a multimeter and oscilloscope. Compare the values displayed on the OLED with the actual measured values at the circuit sampling points to verify the accuracy of the sampling and the correctness of the display.

Software Debugging: After the program is debugged without errors, it is downloaded to the microcontroller. The DAC output value of the microcontroller is input into the feedback resistor to control the variation of the feedback voltage. A step-by-step voltage adjustment of 50mV is performed, followed by testing the AD sampling via the display program to ensure normal operation. By measuring the voltage across sampling resistor R7 with a multimeter, the stability of the circuit output, the working temperature of the circuit board, and the normality of the feedback can be determined. Additionally, during testing, the temperature of the LDO circuit is continuously monitored to prevent high temperatures from damaging the PCB.

After completing the unit testing of all system hardware and software components, conduct system joint debugging to verify the correctness of interactions between modules, interface compatibility, and the load-bearing capacity of wires, among other aspects. Perform overall function testing according to design requirements, adjust parameters, and complete the test documentation.

## 4.2 Testing Process and Results

(1) Adjustable range test of output voltage

Set the input of the DC voltage source to 30V, connect it to the load, adjust the DAC to -2.48V through the button, and then press the button in approximately 7mV steps. Test the data once for each DAC change, with 10 times as a group. The test results are shown in figure 8.

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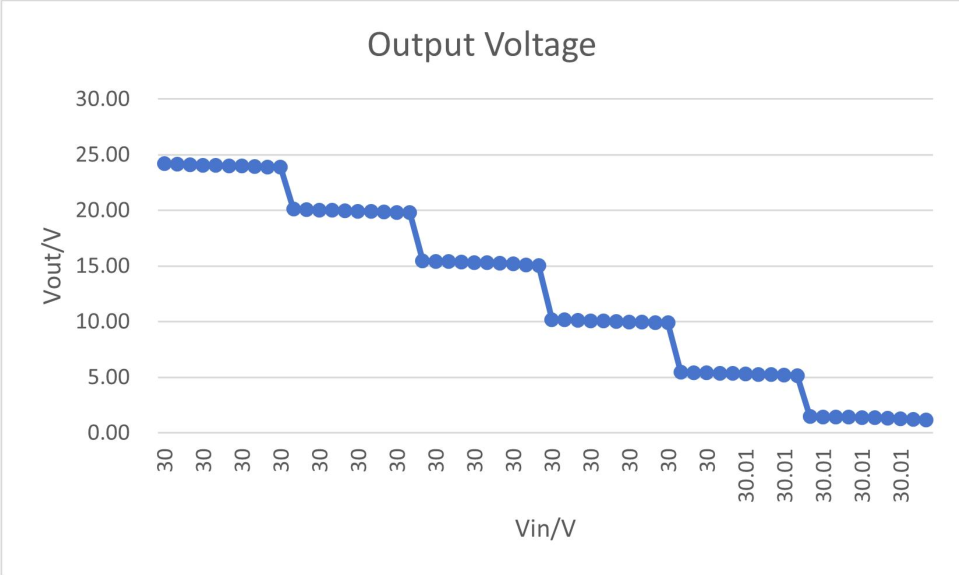


Fig. 8 Adjustable range of output voltage

It can be seen that the designed DC stabilized power supply can achieve a wide range adjustable output of 1.182-24.2V.

(2) Accuracy test

When testing according to the adjustable range of output voltage, a multimeter was also used to record the DAC voltage value after each button press. The step value was obtained by subtracting the voltage value obtained from each test, and the result is shown in Figure 9.

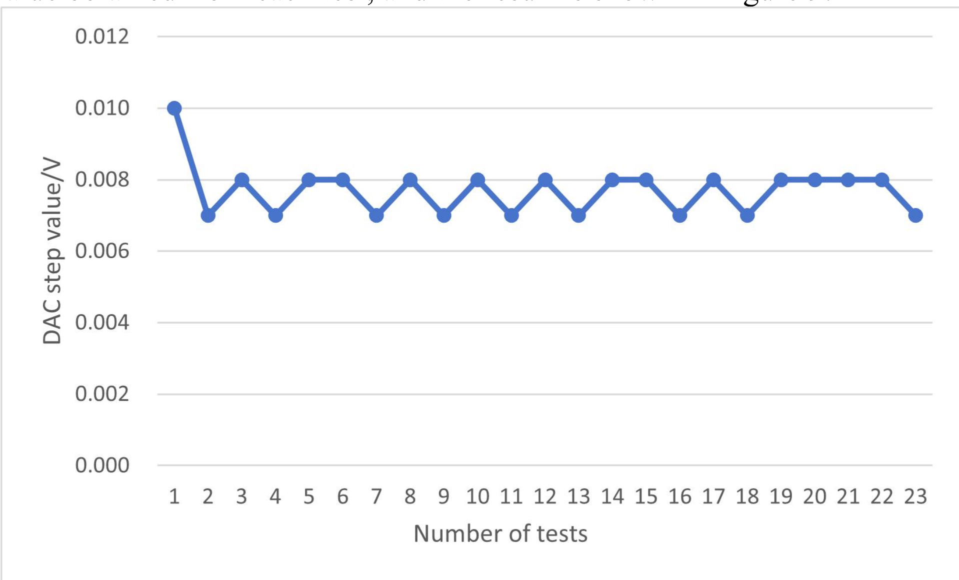


Fig. 9 DAC Step accuracy

(3) Output current test

Adjust the load to about 6 Ω and set the system to its maximum output state. The test data is shown in Table 1.

Table 1. Maximum output

| Vin/V | Iin/A | Vout/V | Iout/A | Vripple/mV | Efficiency/% |
|---|---|---|---|---|---|
| 24.19 | 2.50 | 21.02 | 3.30 | 20.00 | 75.11 |

(4)System efficiency test

The test results are shown in Figure 10.

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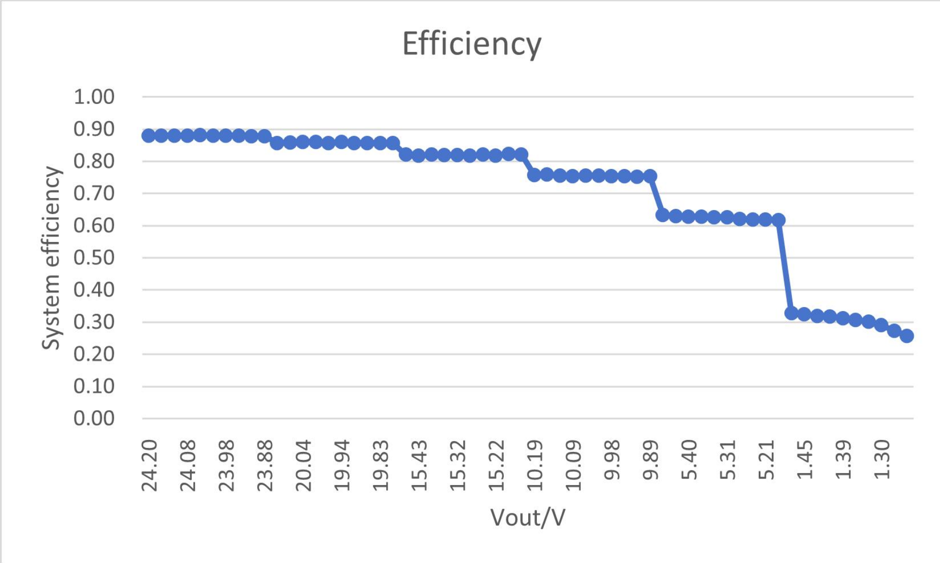


Fig. 10 System efficiency test

(5) Output ripple test

Adjust the load to enable system integration. When measuring the output ripple of the measurement system, use a grounding spring to measure at the testing point to improve accuracy. When the output voltage is 10V and the output current is 3A, the test ripple is 3mV, as shown in Figure 11.

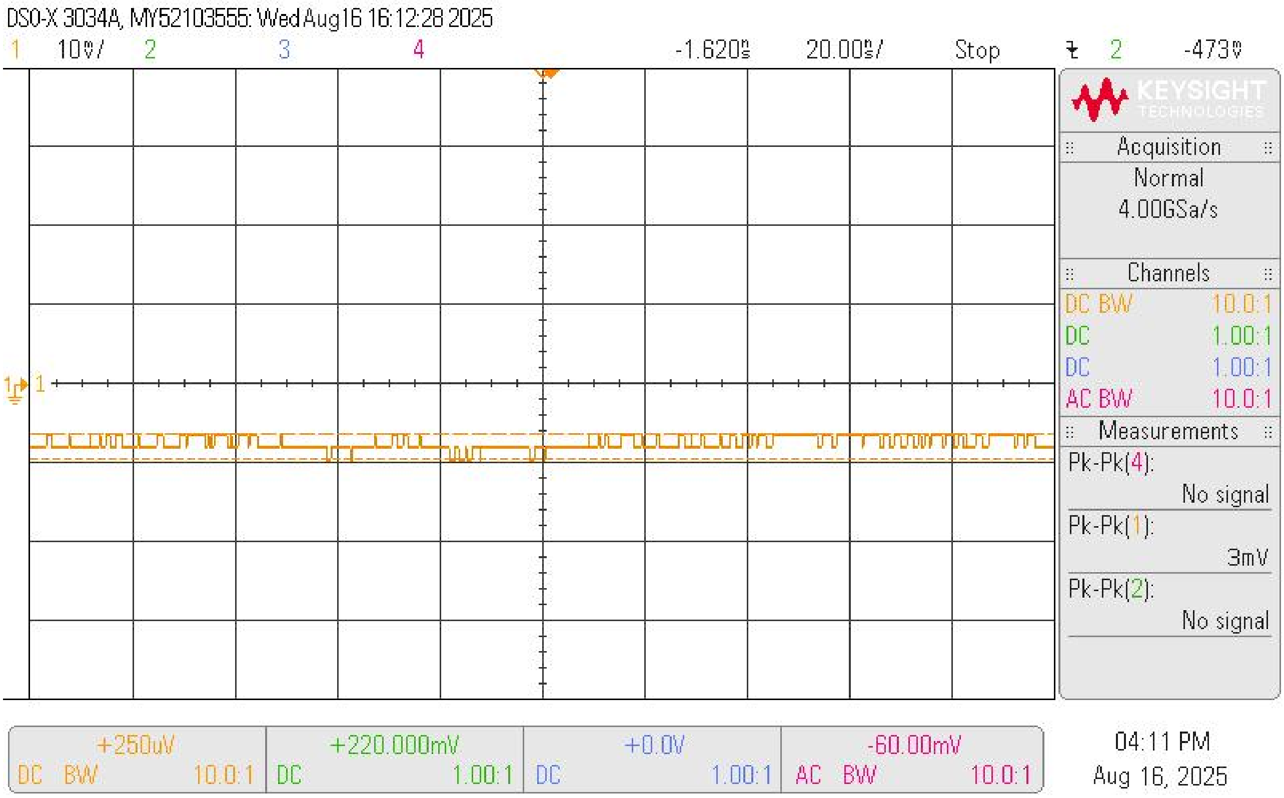


Fig. 11 Ripple test diagram

### 4.3 Analysis of Test Results

(1) The adjustable range of output voltage is 1.182V-24.2V;

(2) Maximum output current 3.3A;

(3) When the output voltage is 10V and the output current is 3A, the load ripple is 3mV;

(4) The maximum efficiency of the system is 88%;

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(5) Voltage step by 7mV;

(6) The system has functions such as over temperature protection and over current protection.

It can be seen that the output voltage of the designed power supply can be adjusted in 7mv steps, with very small output ripple and a wide adjustment range.

## 5. Summary

This article is based on a two-stage voltage regulation architecture, and successfully designs and implements a high-performance DC power supply system that combines high efficiency and ultra-low ripple characteristics. This design achieves high-efficiency voltage conversion with the previous stage TPS54360B synchronous Buck converter, and combines with the later stage MIC29502 low dropout linear regulator to achieve low ripple output. Using DAC8551 dynamic feedback network to achieve μV level dynamic response; Through the STM32F103C8T6 main control, 50mV step precise voltage regulation is achieved, and multiple protection mechanisms including overcurrent protection and NTC temperature protection are integrated. Actual testing shows that under 10V/3A full load conditions, the system efficiency reaches 76%, the output ripple is as low as 3mV, the voltage difference is less than 1V, and the ripple suppression ratio is over 60dB, fully meeting the power supply requirements of precision instruments.

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