Design of DC Regulated Power Supply Based on Buck Circuit

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Abstract. DC stabilized power supplies are widely used in automotive, aviation and DC speed control fields. This article introduces the method of applying buck circuit design to realize 5V switching DC power supply. The designed switching power supply has the advantages of small ripple, continuously adjustable, good stability, etc, and can be used in low-voltage and high-power supply situations.

1. Introduction
The 5V DC power supply is a commonly used power supply for communication electronic equipment. There are many types of DC power supply circuit structures, which are mainly divided into two categories: single-ended converters (flyback, forward) and double-ended converters (push-pull, half-bridge, and full-bridge)[1]. This paper introduces a design method of 5V switching power supply based on buck converter. The designed switching power supply system has high efficiency and can be used as mobile phone charging power supply.

2. Design index requirements
Design and manufacture the switching power supply as shown in Figure 1.
Figure 1. Design task block diagram.

Under the condition of resistance load, the designed switching power supply meets the following requirements.

① Input AC voltage $U_1$ is: 180V~240V.
② Output DC voltage $U_0$ is: 4.5V~5.5V.
③ Output current $I_{OMAX}$: 2A.
④ With overcurrent protection function.
⑤ With output voltage measurement and digital display function.

3. Module circuit design

3.1 Rectifier filter circuit design
According to different rectification methods, the rectification circuit can be divided into full-wave rectification and half-wave rectification. In order to improve working efficiency, it is recommended to use a rectifier bridge to achieve it. The parameter selection should consider the maximum current limit and the reverse withstand voltage limit. The filter circuit is generally composed of capacitors, inductors and resistors. Taking into account that there are other conversion circuits after the rectifier filter circuit in this experiment, and the load capacity is small, it is recommended to use capacitor filtering to meet the requirements[2-3].

3.2 DC/DC topology circuit scheme
The DC-DC converter is the core of the entire system, which can control the output voltage and determine the efficiency of the entire system. The requirements of voltage regulation rate and load regulation rate are mainly reflected in the output voltage stability of the DC-DC converter and the accuracy of system closed-loop regulation. It has a step-down function according to the design requirements, and there are many circuit structures that meet the requirements. This project uses Buck circuit to achieve DC-DC conversion. Buck converter is also called step-down converter. The Buck circuit has a simple structure, no isolation transformer, and flexible and convenient control[4-5]. The principle and current waveform of the Buck converter are shown in Figure 2.

Figure 2. Buck converter circuit principle and current waveform diagram.
The working process of Buck circuit can be divided into two stages. When the switch is turned on, the input voltage is applied to the input of the LC filter, and the current on the inductor rises linearly with a fixed slope. When the switch is off, since the current on the inductor can not change suddenly, the inductor current flows through the diode VD. When the switch is turned on again, the diode VD is quickly turned off, and current flows from the input power supply and the switch tube. At the moment before the switch is turned on, the current \( I_{\text{min}} \) on the inductor is the initial current through the switch.

### 3.3 DC/DC Parameter calculation

#### 3.3.1 Calculation of inductance value

The determination of the inductance value is the key to inductance selection. In the switching power supply circuit in CCM mode, the determination of the inductance value is similar and can be derived from the inductance calculation formula. The current flowing through the inductor in a Buck circuit generally has only two states, rising and falling. The inductance value we choose should ensure that the change in the inductor current in the steady state does not exceed 0.3-0.5 times the average current\([6]\).

The formula is shown in (1).

\[
\Delta L = (0.3 - 0.5) \cdot I_o
\]

According to the relationship between inductor current and voltage (Volt-second rule), formula (2) is obtained.

\[
L = \frac{U_o(1 - D)}{(0.3 - 0.5)I_o f}
\]

#### 3.3.2 Freewheeling diode

When choosing a freewheeling diode, we should pay attention to the maximum current limit and the reverse withstand voltage limit. Under these two basic conditions, we hope that the diode's reverse recovery speed is as fast as possible. There are more diodes that meet these conditions, and FR101 (1A, 50V) can be used.

#### 3.3.3 Power switch tube

For power switching tubes, switching power supplies often use MOSFET field effect tubes with fast switching speeds. This project chooses IRFP150 (40A, 100V, 0.055Ω).

#### 3.3.4 Filter capacitor

The selection of filter capacitor must meet the requirements of output ripple. The filter capacitor \( C \) is calculated by the output ripple formula (3).

\[
\Delta U_o = \frac{DU_o}{RCf}
\]

### 3.4 PWM control circuit design

The most important function of the control circuit is to generate a PWM signal. The PWM signal can control the on and off of the main power switching device in the Buck circuit, and control the average value of the output voltage by adjusting the duty cycle. The main method to generate PWM signal is to integrate the control chip (TL494, SG3525, UC3842) and so on.

This project uses SG3525 control device. Compared with other control chips, SG3525's soft-start performance is superior, the peripheral circuit is also very simple, the duty cycle adjustment is more convenient, and the frequency is adjustable. Experiments show that the switching frequency of the Buck circuit is in the range of 25~50kHz, and the entire volume of the Buck regulator can be reduced as the frequency increases. But the frequency exceeds 50kHz, this advantage is very limited, because this not only increases the loss but also requires a large-volume radiator. The frequency of this project
is selected as 20kHz, and the specific parameter values can be obtained from the oscillation frequency formula (4) of SG3525.

\[ f' = \frac{1}{C_f(0.67R_f + 3R_D)} \]  

(4)

The capacitance and resistance of the peripheral circuit are: \( C_f = 0.01\mu F \), \( R_D = 10\Omega \), \( R_T = 8.2k\Omega \).

3.5 Design of output overcurrent protection circuit

Load overcurrent protection is mainly a protection set to protect the output current from being too high, to prevent the circuit current from being too large and causing safety problems. SG3525 has the function of over-current protection. We can use the 10-pin latch control terminal of the SG3525 chip to control the output of the circuit. When working, generally the non-inverting terminal of the comparator is connected to the load voltage terminal through constantan wire, the inverting terminal is connected to the reference voltage terminal, and the output terminal is connected to pin 10 of the chip through a resistor. When the voltage reaches a certain value, the potential of pin 10 will be raised by the output of the comparator. When the signal on pin 10 is high, the PWM petty register will act quickly, prohibiting the output of the SG3525 output. In addition, the soft-start capacitor also begins to discharge at this time. If the high level continues, the soft-start capacitor will be fully discharged until the end of the shutdown signal, and then re-enter the soft-start process to achieve over-current protection. The schematic diagram of the overcurrent protection circuit is shown in Figure 3.

![Figure 3. Schematic diagram of overcurrent protection circuit.](image)

4. Display circuit design

The display circuit is realized by Arduino microcontroller. Arduino UNO can accept 0–5V analog signals. The analog input pin has the ADC function, which can convert the externally input analog signal into a digital signal, thereby realizing the function of reading the analog value. An LCD1602 liquid crystal display is installed on the Arduino microcontroller to display the collected voltage signals. It requires not much code and is easy to implement.

5. Overall system design and experimental testing

The overall system design is shown in Figure 4, which mainly includes Buck circuit, PWM generating circuit, protection circuit and display circuit.
The switching power supply test waveform is shown in Figure 5.

6. Conclusion
The main circuit and control circuit of the DC stabilized power supply are relatively simple, the switch tube voltage stress is also small, and the efficiency is high. Experiments show that the power supply
has a low voltage regulation rate, good output waveform, reliable work, and can be applied in the field of small and medium power switching power supplies.

References
[1] Zhang, LT. (2010) Communication power. People Post Press, The Beijing.
[2] Sha, ZY. (2004) New type single chip switching power supply. Electronic Industry Press, People Post Press, The Beijing.
[3] Liu, SL. (2001) Practical technology of modern high frequency switching power supply. Electronic Industry Press, People Post Press, The Beijing.
[4] Li, HH., Yu, BZ., Qin, ZY., (2006) MOSFET Power Consumption Validation in Switching Converter Design. Power Electronics, 40: 107–108.
[5] Chen DL. (2005) Static converter. Harbin Institute of Technology Press, Harbin.
[6] Wang ZA. (2000) Power electronic technology. Machinery Industry Press, Beijing.