Design of Single-Ended Forward Switching Power Supply Based on TOP246Y Chip

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Abstract. This paper is designed a single-ended forward switching power supply controlled by TOP246Y chip. The chip is high efficiency, small, low in cost, and can avoid damage caused by overvoltage of the switch tube caused by the feedback. Less peripheral components are advantageous for miniaturization of the forward power adapter. The output DC voltage by applying the PWM circuit is stable by using the Multisim simulation. The load can be stabilized from 50Ω~50KΩ. The output DC voltage is 11.85V (about 12V), the ripple coefficient is kept at 1.4%, and the voltage regulation rate is about 0.068%. The load regulation rate β is about 0.025%, which verifies that the power supply has excellent dynamic response characteristics and strong load capacity.

1. Switching Power Supply Working Principle

The TOP246Y chip is suitable for high efficiency, small size, low cost, fully sealed switching power supply modules or power adapters [1]. The basic structure of the switching power supply is shown in Figure 1. It consists of 220V AC input voltage, primary-side rectification, lowpass filter, electronic switch, high-frequency transformer, secondary-side rectification, and a smoothing filter. The output voltage is controlled by a comparator-controlled by a reference voltage, an error amplifier, and feedback to control the duty cycle of the pulse width modulation (PWM) to achieve an adjusted output [2].

This circuit is a forward-excited circuit. In work, the power source of the transformer core working on the hysteresis loop side can realize the one-way change of the magnetic flux. If the electronic switch is turned on, it enters the transformer through rectification and filtering. The core coupling is used to transfer the electrical energy of the primary coil to the secondary winding, and after secondary rectification into the output. If the electronic switch is turned off, the energy storage inductor can form a discharge loop with the diode to power the load. The excess inductor flows back to the power supply through the magnetic reset of winding to protect the chip [3].
2. Magnetic circuit design

2.1. Forward transformer design

The primary function of the transformer is to electrically isolate the output and output, increase or decrease the amplitude of the AC voltage after PWM, and protect the chip through the magnetic reset of winding [4].

2.2. Winding turns of the transformer

The number of winding turns can be determined by the following formula:

$$N_1 = \frac{V_{in}}{4fB_{max}A_c} \times 10^8$$  \hspace{1cm} (1)

where

- $A_c$: active cross-sectional area of the core in cm$^2$;
- $V_{in}$: input working voltage in V;
- $B_{max}$: maximum working flux density in G(wh/cm$^2$).

The voltage drop of the output rectifier cannot be ignored. The number of turns in the secondary winding of the transformer is determined by the following equation:

$$N_2 = \frac{1.1(V_{out} + V_f)}{N_1V_{in(min)}DC_{max}}$$  \hspace{1cm} (2)

where

- $V_f$: forward voltage drop of output rectifier;
- $DC_{max}$: maximum duty cycle;
- $V_{in(min)}$: minimum input voltage.

This formula is used to calculate the expected minimum input-voltage value of the secondary winding turns. (The regulator will lose its regulation if the input voltage is lower than this value) [5]

Since the core can only be around an integer number of turns, the number of turns calculated by the formula is generally not an integer, so the integer of an approximate value is usually taken. Therefore, this causes an error in the output voltage. It is required to calculate the range of the error, and then to compare the output voltage of each turn before and after the rounding. If the error is too large, it is necessary to replace the bridge rectifier with a higher or lower forward voltage drop. If the output voltage cannot meet the requirements, it is considered adding a coil to the primary output winding, or whether the secondary side needs isolation, and whether the type of autotransformer on the secondary side is used [6][4].

2.3. Winding method with low leakage inductance

The leakage inductance is that the magnetic lines of force generated by the coil cannot both generate leakage inductance through the secondary coil. The existence of leakage inductance,
when the switching device is turned off. It makes back electromotive force, which is easy to the over-voltage breakdown of the switching equipment. The leakage inductance can also form an oscillating circuit with the distributed capacitance in the loop and the distributed capacitance of the transformer coil, so that the circuit oscillates and radiates electromagnetic energy outward, causing electromagnetic interference [7].

The main factors affecting the leakage inductance of the winding are winding turns, winding width, and the insulation thickness of the winding. The wider the winding, the smaller the leakage inductance and the leakage inductance is also affected by the coupling effect [7].

3. Circuit design

3.1. Design of the input part
A resistor, a capacitor, a Zener diode, etc. are used to form a start-up circuit, so that the transformer is rectified and filtered using a diode, a capacitor, etc., to achieve a control power supply current limiting. The auxiliary winding control circuit of the transformer achieves low voltage start-up, and when the driving current is large, power consumption is reduced [11].

3.2. Design of control part
The TOP246Y chip is used as the core of the control part. The chip contains an error amplifier and a MOSFET. The alternating magnetic field is formed by the on and off of the MOSFET, and the secondary coil of the transformer generates a corresponding induced electromotive force [11].

3.3. Reset circuit
Using the residual current device (RCD) resets circuit [9] when the switch is disconnected, the transformer induces a tremendous electromotive force. If there is no reset circuit, the magnetizing inductance oscillates with the junction capacitance of the MOSFET, and the oscillating capacitance is caused the breakdown for the MOSFET [11].

3.4. Feedback part design
The TIL191 electrically isolates the input and output and uses the linear photocoupler to form an optocoupler feedback circuit. By adjusting the duty of the control terminal to change the duty cycle, the purpose of precision regulation is achieved, and signal reception and transfer are also achieved [11].

4. Analysis of experimental results

4.1. Verifying output voltage
As shown in Figure 3, the waveform of the output voltage during operation, the maximum output voltage +12V requires 0.006ms to stabilize the output. The time of stable operation for the transformer is 13ms, and the time from the start to the stable operation of the power supply is not exceeded 14ms [9], indicating that the power supply has good dynamic response characteristics [12-13].

4.2. Verifying output voltage ripple

The data for the output voltage is led to excel, and the waveform of the output voltage ripple is sampled as shown in Figure 4. The peak-to-peak ripple value of the output terminal is 11.853-11.860V, the ripple voltage is 17mV, and the ripple coefficient is $\gamma = \frac{0.017}{11.85} \times 100 = 0.14\%$. It is known that the power supply has good ripple characteristics and good stability [12-13].

4.3. Load capacity

The output voltage waveform of the simulation plus equivalent load 50kΩ-50Ω changes is shown in Figure 5. After the equivalent load, the output voltage changes to 11.854-11.862V, and the fluctuation is 8mV. The voltage regulation rate is $\alpha = \frac{0.008}{11.85} \times 100 = 0.068\%$, and load regulation rate is $\beta = \frac{(0.001 + 0.002)}{11.85} = 0.025\%$. It is fully indicating that the power supply has a strong load capacity [12-13].
5. Conclusion
The design of the single-ended forward switching power supply is mainly divided into two parts, namely circuit design, and magnetic circuit design. However, the design of the magnetic circuit is relatively complicated and difficult to grasp. The magnetic components of the high frequency switching power supply are mainly transformers and filter inductors. This paper fully introduces the calculation of the number of turns of the forward transformer, the method of winding, the low leakage inductance, and the core reset circuit, etc. The method of designing the magnetic circuit is clear, and the design of the high frequency switching power transformer and the design of the filter inductor achieve high efficiency, small size, low cost, and improved reliability.

Based on the single-ended forward switching power supply developed by TOP246Y, this paper introduces the characteristics of TOP246Y and the design of each part of the peripheral circuit. According to the simulation results by using National Instruments Multisim, the switching power supply can stably output the DC voltage of 11.85V (about 12V) when the load is changed from 50Ω to 50kΩ. The turn-on delay time is about 13ms, and the ripple coefficient is maintained at 1.4%. The voltage rate adjustment is about 0.068% as well as the load regulation β is about 0.025%, which verifies the excellent dynamic response characteristics of the power supply, unique ripple characteristics, and stable load carrying capacity. Through the analysis of the results, the feasibility of the theory was verified, and excellent results were obtained.

6. References
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