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Design of a single-stage Flyback LED Constant current Driving Power Supply

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Abstract: In order to solve the problems of high cost and low efficiency of current LED driving power supply, a single-stage flyback LED constant current driving circuit is designed. The power supply adoptes OZ8027 as the main control chip in the critical conduction mode,which uses the peak current control method. A wide range of input voltage of 85~265V is designed, the output current is 200mA, and the actual output power target value is 13W.It is suitable for an AC input type for flyback constant current driving circuit whose light source board owns LEDs for 2-series and 5-parallel.This research describes the working principle of a single-stage flyback LED constant current drive circuit. The detailed design and analysis of the various components of the driving power supply circuit. The test shows that the circuit works normally, and the output current can be obtained after testing. The current is stable at 200mA, output power is 12.7W, output ripple ratio is 1.65%, and the conversion efficiency is as high as 92.33%. The experimental results show that the designed LED driving power supply is stable and reliable, low cost, high efficiency and meets the design standards of LED driving power supply.

1. Introduction

Nowadays, LEDs have been widely used in light sources. LEDs produce less pollution and waste than traditional fluorescent lamps, high luminous efficiency, good color temperature for better color rendering and long life. The continuous improvement of performance and the continuous decline of prices have made LED lighting an environmentally friendly alternative to indoor lighting equipments, traffic lighting, street lighting and other fields [1-2].

The light-emitting diode (LED) belongs to the semiconductor material,so the semiconductor material is sensitive to temperature, and the I-V nonlinear characteristic of the LED determines that the LED power supply needs to adopt the constant current driving method[3]. In order to meet the requirements of the US Energy Star for the LED products, the power factor of the LED driver must be higher than 0.7. At the same time, the current harmonic content must meet the requirements of the standard IEC61000-3-2C lighting equipment[4]. This research mainly designs a driving power supply circuit based on peak current control of flyback transformer, which can meet the requirements of high conversion efficiency, high power factor and low cost.

Wang Li[5]proposed a single-stage flyback constant current LED driving power supply that uses a continous conduction mode (CCM), which mainly uses the control technology of the multiplier, the output voltage of the power supply and The input current ripple will be relatively reduced, but the CCM needs to use dual-loop control so as to build the circuit more complicated. Because the switch

tube is not in the zero current conduction state when it is turned on, the switching loss of the switch tube is increased, thereby reducing the driving power efficiency; Meanwhile, the diode has a reverse recovery problem. Because the driving frequency of the flyback converter is fixed when the driving power supply is operating in CCM mode. The total harmonic distortion of the circuit is small, so the EMI filter circuit is also relatively easy to design.

Pan Feng[6] proposed a DC flyback driving power supply based on discontinuous conduction mode (DCM).The driving power supply mainly works in zero voltage conduction state,and uses quasi-resonant technology to reduce the Switching loss of MOSFET.This design not only makes the EMI of the circuit simple, but also improves the energy conversion efficiency of the driving power supply.

According to the condition whether the freewheeling diode is continuously turned on during the off time of the MOSFET, the operation mode can be divided into three types: current continuous (CCM) and current interrupted (DCM) and critical conduction mode (BCM)[7]. Compared with the other two modes of operation, the critical continuous mode (BCM) has more outstanding advantages in terms of performance and cost of the LED driving power supply. Compared with the current interrupt mode (DCM), the critical circuit mode (BCM) has less stress on the driver circuit components and higher power conversion efficiency. Compared with the current interrupt mode (CCM), the MOSFET has a soft-start characteristic in the critical conduction mode (BCM), and there is no reverse recovery problem of the freewheeling diode. At the same time, the control driving circuit is simple, the production cost is low and the conversion efficiency is high [8].

The working mode of the flyback driving power supply is different from that of other driving power supply. When the switch is in the conducting state, the current flowing through the high-frequency transformer gradually increases, and at this time, the secondary winding does not output the energy, but high-frequency transformer stores energy; when the main switch is in the off state, the primary winding is in an off state.The energy stored in the high-frequency transformer is released to the load of the driving power source through the secondary winding.

2. System Working Principle

The chip of OZ8027 is a primary side control AC/DC conversion controller with high power factor and constant current output. The chip has a high-voltage startup circuit and provides various protection functional circuits, such as a VDD overvoltage and undervoltage protection, a LED open and short circuit protection,a primary side cycle-by-cycle current limit, a maximum gate drive output clamp, and an overtemperature protection etc. .
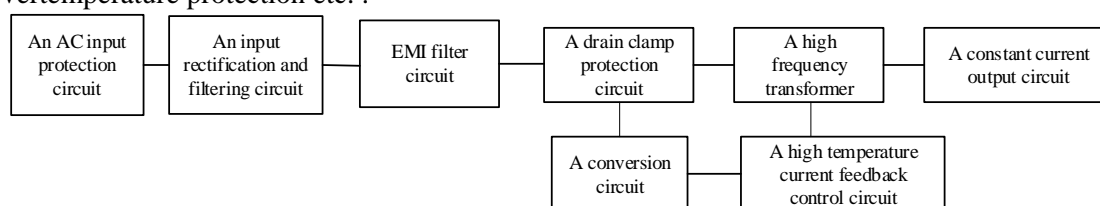

Figure 1.LED constant current drive circuit.

As shown in Figure 1, the driving power supply is mainly composed of an AC input protection circuit, an input rectification and filtering circuit, an EMI filter circuit, a drain clamp protection circuit, a conversion circuit, a high-frequency transformer, a constant current output circuit, and a high temperature current feedback control circuit. The specific implementation circuit is shown in Figure 1.
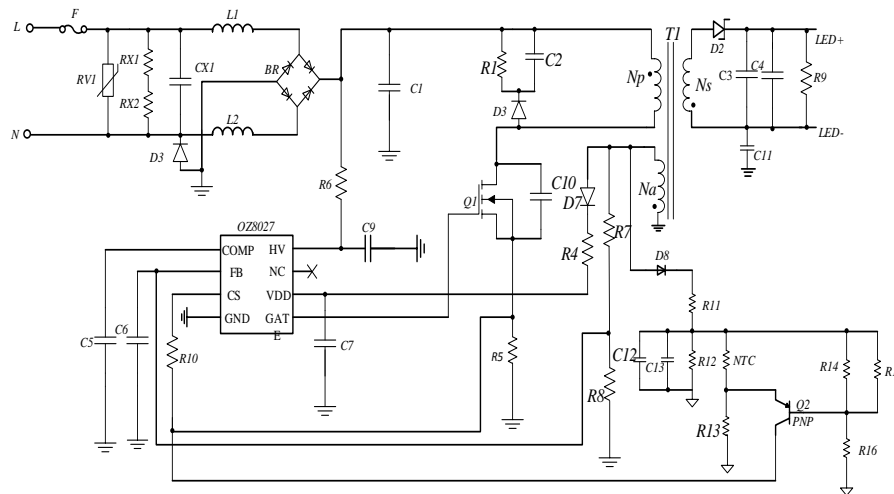
Figure 2. A single-stage flyback constant current LED drive power supply circuit.

The input AC power is first applied to the rectifier to provide initial operation.The chip's turn-on and turn-off thresholds are 15 V and 10 V.When the chip is turned on, the capacitor C7 is charged to 15 V by the chip's internal startup circuit. When the pin of VDD voltage of the chip reaches 15 V, all internal circuits start to run. The chip starts running to provide the driving pulse for the driving power circuit, and its pin of GATE outputs the signal to drive the MOSFET Q1 to work.At this time ,the feedback winding provides the working voltage for the chip.When the MOSFET is on, the input voltage is mainly applied to the primary winding Np. At this time, the voltage sensed by the secondary winding N_s is the lower voltage for the　up side and higher voltage for the down side. The rectifier diode D2 is turned off due to the reverse bias state. At this time, the high-frequency transformer is turned off. There is no current for the secondary transformer and the storage capacitor discharges for the load to work normally; when the MOSFET is off, the induced voltage for the N_s is the lower voltage for the down side and higher voltage for the up side.The rectifier diode D2 is on positively biased, and the high-frequency transformer stored energy by the rectifier diode.The high frequency transformer charges for the aluminum electrolytic capacitor and provides an output current for the load. The driving circuit diagram is as shown in 2.

In conjunction with Figure 2, the operation of a single-stage flyback converter operating in a critical conduction mode is analyzed. Firstly, the input of AC voltage is filtered by a surge protection circuit and an EMI circuit.And then it is subjected to a rectifier circuit to obtain a half-sinusoidal signal voltage $V_{m(t)}$

$$V_m(t) = V_{PK} \left| \sin(\omega t) \right| \tag{1}$$

The input voltage peak is named by V_{PK} in equation 1.

When the power supply is stable, the output of the chip's internal error amplifier can be considered to be a constant value in a half of the power frequency cycle.The output of the analog multiplier provides a reference waveform with a full-wave rectified voltage shaped as the PWM signal.The input of the generator is at the same phase. And the sampling signal of current from the switch through R7 is used as the input signal of the inverting terminal of the comparator. When the amplitude of the signal at the inverting terminal exceeds the non-inverting terminal, the driving circuit turns off the MOSFET Q1 to make the current of the primary winding zero.The energy is transferred to the secondary winding, and the current of the secondary diode VD2 begins to drop. When the zero-crossing detection circuit detects that the primary winding voltage U_a has dropped to zero,the MOSFET Q1 is turned on by the driving circuit, and the primary winding current start to rise. Therefore, the envelope of the primary current peak ip(t) can be expressed in equation 2.

$$i_p(t) = I_p \left| \sin \omega t \right| \tag{2}$$

In equation 2, I_p is named by the peak value of the current of the primary winding of the high frequency transformer in half a power frequency cycle. ω is the angular frequency of the input voltage. When the chip of OZ8027 operates in the critical continuous mode, the conduction time for MOSFET can be expressed as equation (3)

$$t_{on} = \frac{L \, I_p \, \left| \sin \omega t \right|}{U_{in} \left| \sin \omega t \right|} = \frac{L_p I_p}{U_{in}} \tag{3}$$

In equation (3), L_p is the primary inductance of the high-frequency transformer; U_{in} is the peak value of the input sine wave voltage. It can be seen from equation (3) that t_{on} is a constant value, when the driving power supply is stably operated. Since the driving power supply operates in the critical continuous mode, the time when the MOSFET Q1 is turned off is equal to the time when the current flowing through the output diode VD2 is reduced from the peak value to zero, so turn-off time t_{off} can be expressed as equation (4)

$$t_{off} = \frac{L_s i_s(t)}{U_0 + U_f} = \frac{L_p I_p \left| \sin \omega t \right|}{n(U_0 + U_f)} \tag{4}$$

In equation (4), L_s is the secondary side inductance of the transformer; $i_s(t)$ is the envelope of secondary current peak; n is the turns ratio for the primary winding and the secondary winding; U_0 is the output voltage and U_f is the forward voltage drop of the output diode VD2. The switching period of MOSFET Q1 can be got by equations (2) and (3).

$$T = t_{on} + t_{off} = \frac{L_p I_p}{U_{in}} (1 + K \left| \sin \omega t \right|) \tag{5}$$

It can be seen from equation (5) that the switching frequency of the MOSFET Q1 is varied during a power frequency cycle. When the input voltage of the power supply is low, which means the value of $|\sin\omega t|$ is low, the switching frequency of the MOSFET Q1 is high; When the power input voltage is high, which means the value of $|\sin\omega t|$ is high, the switching frequency of the MOSFET Q1 is low. Therefore, the average value ip(t) of the primary current of the high frequency transformer can be expressed as in equation (6)

$$i_p(t) = \frac{1}{2} i_p(t) D = \frac{1}{2} i_p(t) \frac{t_{on}}{T} = \frac{1}{2} I_p \frac{\left| \sin \omega t \right|}{1 + K \left| \sin \omega t \right|} \tag{6}$$

Since the average current of the primary side of the high-frequency transformer is obtained by the input current of the power supply by the rectifier bridge, the input current can be expressed in equation (7)

$$i_{in}(t) = \frac{1}{2} I_p \frac{\sin \omega t}{1 + K \left| \sin \omega t \right|} \tag{7}$$

By the equation (8), the flyback converter operating in the critical continuous mode has an ideal case K = 0 in equation (9)

$$K = \frac{U_{in}}{n(U_0 + U_f)} \tag{8}$$

$$i_{in}(t) = \frac{1}{2} I_p \sin \omega t \tag{9}$$

Since the input current wave is an ideal sine wave, its power factor is 1. Therefore, in the actual design of the circuit, it is neccessary to try to make the K value smaller, which can make the power factor close to 1. The smaller K value is, the closer the waveform of the input current is to the sine.

3. Design of High Frequency Transformer

3.1. Magnetic Core Selection
When power ferrite materials in high frequencies,they have the characteristics of high resistivity, low loss and low cost etc..And they are the preferred materials for high-frequency transformer cores. By finding for core manufacturers,EE core is the most popular among everyone due to low cost and the shape[9]. The relationship between the core cross-sectional area S of the high-frequency transformer and the maximum power Pmax that the high-frequency transformer can withstand[10], as shown in equation (10):

$$S = 0.15\sqrt{P_{\max}} \tag{10}$$

The EE20 core is selected this design and its maximum power value P_{max} can be 10W. When it is put in equation (10),S is equal to 47 mm^2.In this design,0.27 T is selected for B_{max} value.

3.2. Inductance of the Primary Winding
The inductance of the primary winding in the high-frequency transformer of the switching power supply can be followed by equation (11)

$$L_P = \frac{\eta(U_{inMIN}D_{\max})^2}{2P_s f} \tag{11}$$

In equation (11) ,P_s is the actual output power, D_{max} is the aximum duty cycle of the pulse signal, and f is the switching frequency of the MOSFET. According to the OZ8027 specification, we can get f is 50 kHz, D_{max} is 48%, and P_s is 13 W,and finally the value of L1 is 1.40 mH.

3.3. Number of Turns for Primary and Secondary Windings

$$N_P = \frac{I_{PK} \cdot L}{A_e \cdot B_w} \tag{12}$$

The number of turns of N_P can be calculated as 102 from equation (15).
    When calculating the number of turns of the secondary winding of the high-frequency transformer, it should be considered for the reflected voltage V_{OR} and the maximum drain voltage that MOSEFT can withstand[11].The ratio n of the high-frequency transformer can be caculated by the radio between the output voltage V_O and the reflected voltage V_{OR} in the equation(16).

$$n = \frac{V_0}{V_{OR}} = \frac{N_P}{N_S} \tag{13}$$

Taking into account the resistance loss on the wire, N_S can be the turns of 62.
    The supply voltage value of OZ8027 is 11~24 V. When the chip works normally, the auxiliary winding N_a gives the power supply to OZ8027.V_f is the forward voltage drop of the output rectifier,and V_f is 0.6 V.In this research, the auxiliary winding output voltage V_a is 20V, the auxiliary winding can be caculated for the turns of 14 from equation (17)

$$N_a = \frac{(V_a + V_f) \times N_s}{V_o + V_f} \tag{14}$$

4. System Testing and Results Analysis

When the driving power supply works in the input voltage of a wide range,some experimental data shows in the Table 1.According to test result, the driving power supply is at the input voltage from 85V to 265V.Its conversion efficiency and output current are basically constant. The ripple coefficient of high efficiency is 92.33% ,and the current is basically stable at 200 mA.The stable ripple factor is 1.65%.

Table 1. Driving power efficiency based on OZ8027(full load).

U_{AC}/V	P_{in}/W	P_O/W	η/%
85	14.56	12.87	88.35
110	14.17	12.73	89.82
220	14.08	12.70	90.15
265	13.70	12.65	92.33

The harmonic test of the circuit can reflect the level of the odd-order wave of the input current. The higher the odd-order harmonic content of the circuit, the lower the efficiency of power utilization and the power factor area.The IEC61000-3-2 Class C (%) standard stipulates that for LED products with active power not exceeding 25W, the content after 11th harmonic cannot be greater than 3%, and the actual test results are all below 3%,which can meet the requirements of the standard.

Table 2. Harmonic distortion test results.

Harmonic number (n)	2	3	5	7	9	11	13	15	17	19
IEC61000-3-2 Class C(%)	2	21	10	7	5	3	3	3	3	3
Actual data (%)	1.5	15.3	9	5.7	2.3	2.5	2.3	1.3	0.4	0.6

As shown in Figure 3, the driving waveform is ideally stable.The maximum peak voltage of the drain voltage obtained from the oscilloscope is 184V. It shows a large safety margin when compared to the maximum standard withstanding voltage 600 V for MOSFET.When the MOSEFT driving signal V_{GS} comes, the drain-source voltage V_{DS} has dropped to zero, At this time,the turn-on loss of the MOSEFT is almost zero. When the drain-source voltage of MOSEFT Q1 reaches the bottom of the valley for the first time, the GATE pin of OZ8027 sends a driving signal to turn on Q1.Therefore,the circuit realizes the quasi-resonant mode of operation, which reduces the switching loss of the circuit and improves its conversion efficiency .
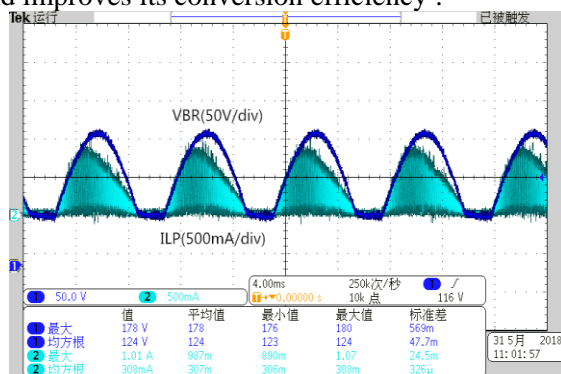

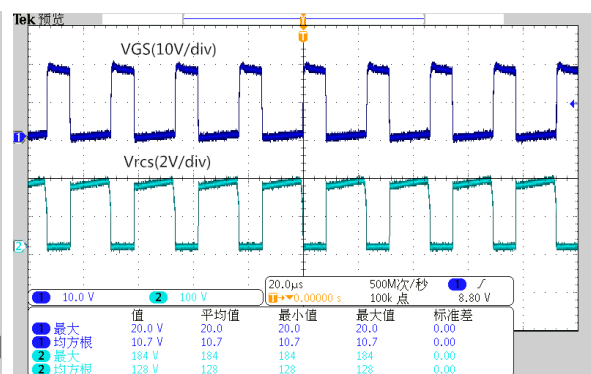| **Figure 3.** DS and GS voltage for MOSFET waveforms at full load output.	**Figure 4.** Input rectified voltage and high frequency transformer primary current waveform

Figure 4 shows that the current of inductor changes with the rectified input voltage when the input voltage is 120V. When the inductance is 0 in a switching cycle, the output voltage is also zero. In general, the resulting power factor value can meet the requirements,when the input current follows the change of the input voltage.When the on-time of MOSEFT is 1/4 of the power-frequency cycle, the

inductor current has reached a peak value, and thereafter, the inductor current gradually decreases linearly.Therefore,it can be verified that the switching power supply is operating in critical mode.

5. Conclusion

This research mainly discusses the design of LED switching power supply based on critical continuous mode (BCM). It mainly adopts the control mode of peak current control. The chip of OZ8027 is used to develop a wide range of input voltages of 85~265 V and a current of 200 mA. The results of the driving power supply shows that the LED current was stabilized at 200 mA, which stabilized the brightness of the LED. At the same time, the power conversion efficiency of the power supply is as high as 92.33% and the output ripple coefficient is 1.65% at the AC input voltage of 85~265 V. This experiment proves that the switching power supply has lower output ripple, higher conversion efficiency and higher practical value.

6. Acknowledgments

7.References

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