Design of Efficient Flyback Switching Power Supply Based on LM5021

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Abstract. The paper introduces the process of designing an efficient flyback switching power supply on basis of LM5021 chip. It describes the process as the following 3 steps:1) designing a current-limiting circuit; 2) calculating the parameters of the transformer for the switching power supply and designing a feedback circuit as well as putting forward a new idea in accordance with the efficient self-driving circuit; 3) conducting prototyping test to prove the validity and realizability of the design.

Introduction:

Nowadays most studies of the switching power supply focus on the isolated power supply, such as a kind of ordinary flyback switching power supply studied in the articles [1] and a design of control circuits for the flyback switching power supply studied in the articles[2], both of which are based on the switching driver chip of UC3842. However, the paper discusses a design of simpler switching power supply with more useful and stable features in line with a TI company's current-type control chip LM5021[3] , which is more efficient in utilizing energy, can apply soft startup and has a more matured market environment compared to the former.

The paper presents the designing process from 3 points:1)Learning the working principle of LM5021;2) Designing a transformer, which is the core device of the switching power supply, and giving forward an efficient method based on a self-drive circuit;3) And verifying the feasibility and practicability of the circuit designed by experiment.

Basic parameters in designing an efficient flyback switching power supply

The working principle [4] of the flyback converter is shown as Fig.1, where the input voltage range is 18～36V and the nominal voltage is 24V. When the MOS is turned on, the output voltage is 15V, the output power is 30W, the output current is 2A, the operating temperature is -45℃～85℃, the circuit load stability is less than 0.02%, and the output ripple is less than10mV.

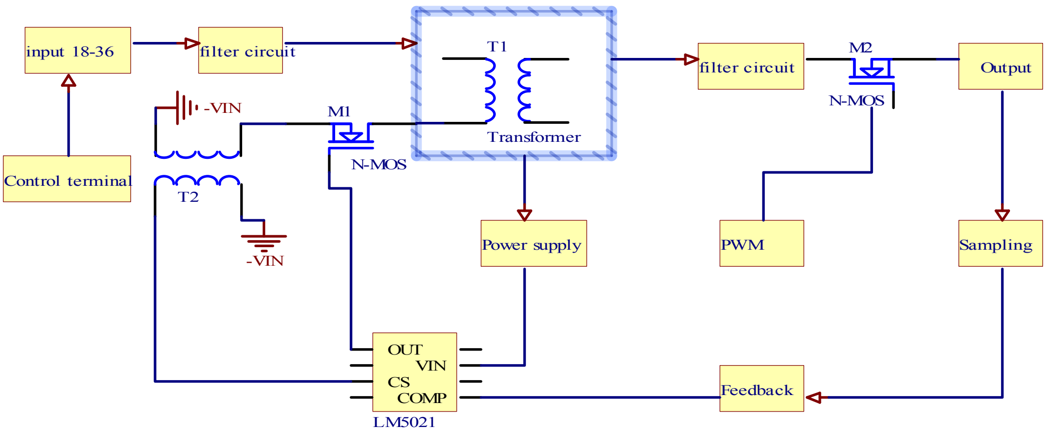

Fig.1 Overall block diagram of the power supply design

One of LM5021's biggest advantages is to realize the soft-start of the power supply so that the power conversion circuits can slowly reach the steady-state operating point, reducing the impact of starting and surge current. The LM5021 chip is able to provide a maximum current of 25μA to charge C15 at SS(as shown in Figure 2). The voltage ramp of C15 rises to limit the rate of rise for COMP, hence limiting rising in amplitude of the output pulse duty ratio to finish soft startup. Once the power supply starts, LM5021 can work through a lower starting current, ensuring high efficiency in using the power source.

Tab.1 The pin function of LM5021

Name	Function
COMP	output of the feedback circuit isolated by optocouplers to control LM5021
VIN	input of an internal bias circuit
VCC	Output of an internal bias circuit
OUT	PWM output
GND	ground return
CS	current sense input
RT	oscillator timing resistor pin and synchronization input
SS	soft-start/hiccup time

Current-limiting circuits

The pin of CS chip used as the current sensor in the paper with a typical output voltage of 0.5V, when the input voltage is above 0.5V, the OUT pin controlled by CS chip stops output, and the over-current protection is triggered.

As shown in Figure 2, the current is sampled when MOS is turned on to allow the current to go through the transformer.and the higher harmonic is filtered when the current goes through the RC low-pass filter network. Then the CS chin gets a steady signal, protecting the circuit. In order to avoid a sudden rise of the voltage caused by leakage inductance when the switch is turned off, a buffer formed by R1, C1 and D4 is designed to make the power supply can work in the normal working range.

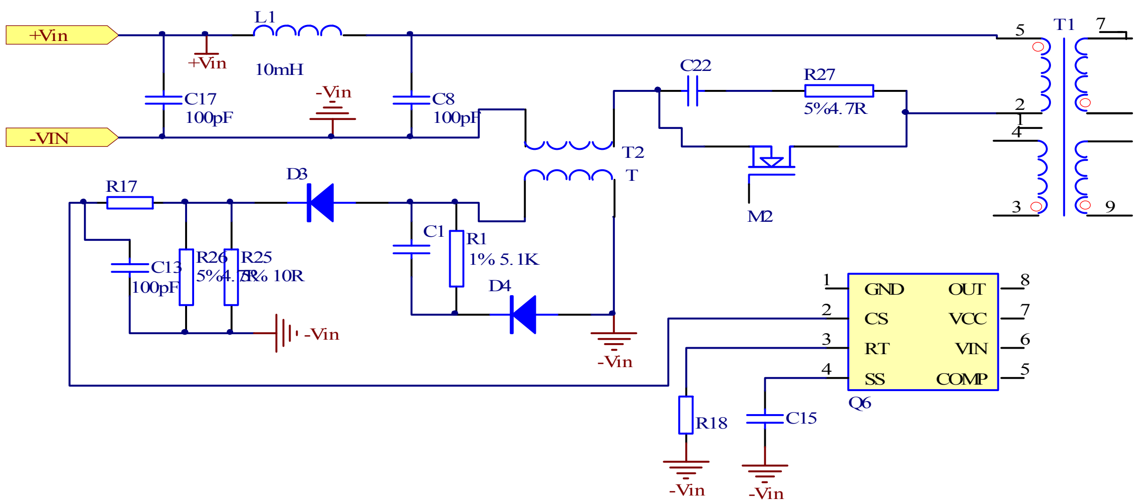

Fig.2 Current limiting circuit

The design of the transformer

As the core of the switching power supply, the flyback transformer is actually a coupled inductor.

Because it can stock and transmit power and transform voltage, its design in the circuit is also very important[5]. The details for designing the transformer is as below.

The primary inductance of the power switching transformer:

The voltage ratio is obtained as:

$$k=\frac{U_{s\max}-U_{in\max}}{U_o}=\frac{60-36}{15}=1.6 \tag{1}$$

Where $U_{s\max}$ is the minimum working voltage, $U_{in\max}$ is the maximum input voltage and U_o is the output voltage.

At this point the primary side peak current of the transformer is obtained as:

$$I_p=\frac{2I_o}{k(1-D_{\max})}=4.54\text{（A)} \tag{2}$$

Then the inductance for the primary side of the transformer is calculated as:

$$L_1=\frac{D_{\max}U_{in\min}}{I_P f_s}==\frac{D_{\max}(1-D_{\max})kU_{in\min}}{2I_o f_s}=6.8(\mu\text{H}) \tag{3}$$

The specifications of the magnetic core

The transformer is designed in accordance with the A_p method and its primary and secondary coils can be regarded as two inductors. The calculation as below:

$$AP_p=\frac{6.33\times L_1\times I_P\times d_w^2\times 10^8}{\Delta B} \tag{4}$$

According to the skin effect, the diameter of the edge winding wire is d_w=0.5mm, the variation of the magnetic induction is $\Delta B=\frac{B_{\max}+0}{2}$, $B_{\max}$=0.2T,($B_{\max}$ is less than 0.3).

$$AP=4AP_p=0.196\,(cm^4) \tag{5}$$

The model of the magnetic core is determined by the size and volume of the power supply. A longer EP20 of TDK is chosen as an optional magnetic core to allow enough length for winding the frame[6]. According to the data provided by TDK, the calculation is:

$$A_eA_w=78\times 55.4=4321\,(mm^4)=0.4321\,(cm^4) \tag{6}$$

Because 0.196<0.4321，the magnetic coil is suitable to the frame.

The air gap length of the iron core

For the same DC bias, reducing the density of working flux and increasing the saturation resistance can be achieved by widening the air gap of the flux in the iron core. The specific width of air gap is calculated as:

$$L_g=\frac{0.4\pi L_1 I_p\times 10^8}{A_e B_{\max}^2}=0.55(\text{mm}) \tag{7}$$

The winding turns of the transformer

The primary winding turns of the transformer N_1 is 9. The calculation is as below:

$$N_1 = \frac{L_1 \times I_p}{A_e B_{\max}} = 8.77(\mathrm{T}) \quad (8)$$

The secondary winding turns of the transformer N_2 is also 9. The calculation is as follows:

$$N_2 = \frac{N_1 (U_o + V_d)(1 - D_{\max})}{U_{i\min} D_{\max}} = 9.16(\mathrm{T}) \quad (9)$$

The feedback winding turns N_3 is 6. The calculation is:

$$N_3 = \frac{N_1 \times V_{in}}{U_{in}} = 6(\mathrm{T}) \quad (10)$$

When N_3 is 6, V_{CC} is the power supply for LM5021, the rang for V_{in} is 8.5V~30V based on the document, and the standard V_{in} is 12V. Therefor, the auxiliary winding turns N_4 is 7 by calculation.

$$\frac{N_2}{N_4} = \frac{U_o}{V_4} \text{ namely } N_4 = \frac{N_2 \times V_4}{U_o} = 7.2(\mathrm{T}) \quad (11)$$

In order to reduce the leakage inductance, the transformer in this paper winds in means of sandwich type. As shown in Figure 3, the black coil $N_1 1/2$ stands for the primary winding of the transformer, which is in the first and the fourth layers with 9T for each; the white coil $N_2 1/2$ represents the secondary winding N_2 in the second and the fifth layers with 9T for each; the third layer stands for the auxiliary winding N_4 with 6T; and the sixth layer represents the feedback winding N_3 with 7T. Thus the the first and the fourth layers, and the second and the fifth layers can be seen as two compact capacitors for absorbing the noise of the transformer. And the double coils spread the current and increase the power, preventing the transformer from burning. What's more, the 3M barrier tape between the coils protects devices from scratching.

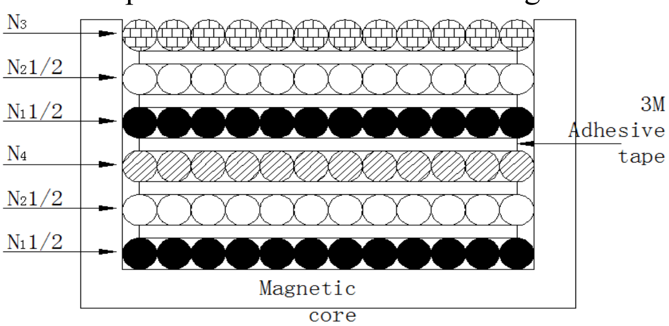

Fig.3 Transformer winding diagram

The designs for the self-drive circuit and the voltage feedback loop

The self-drive circuit.

The flyback circuit with a general switching power supply would connect a break over diode at the output end M1 shown as Figure 4, but this kind of circuit add the load to the diode to drop voltage with the output efficiency of 85%. In order to increase the efficiency, a self-drive circuit can be connected to the output end as Figure 4 to lower the consumption of the output end. The current from the auxiliary end N_4 flows through D6 to charge SP6018, which generates PWM supplied to the grid of MOS, when MOS is turned on, the output voltage is generated, hence reducing the loss caused by the voltage drop difference of the diode.

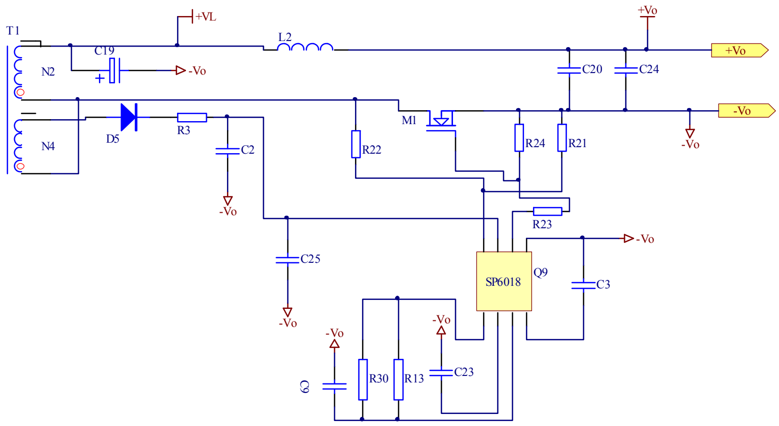

Fig.4 The schematic of self driving circuit

The voltage feedback loop

Due to a higher requirement for the voltage regulation and load regulation, the high-precision reference TL432 and optocoupler TLP291 are used in the design, which form an external error amplifier to isolate the output voltage and primary coil(R9 and C10 as shown in Figure 5 are necessarily used as compensation frequency for TL432). In the feedback circuit equipped with TL432, TL431 and the voltage regulator in parallel connection replace the voltage-regulator tube to regulate the output voltage. Although the circuit is complicated, the voltage regulation performance is best. When the output voltage rise above the defined output amplitude, the optocoupler conduction rate increases, the COMP pin of LM5021 is taken down, MOS is turned off and stops output. When the output voltage recovers to the defined amplitude, the chip works properly and the overload protection is triggered. When the output voltage is lower than the amplitude, the error amplifier's output voltage drops so that the chip adjusts PWM and changes the duty ratio, and the output voltage begins to stabilize. The information above is shown in Figure 5.

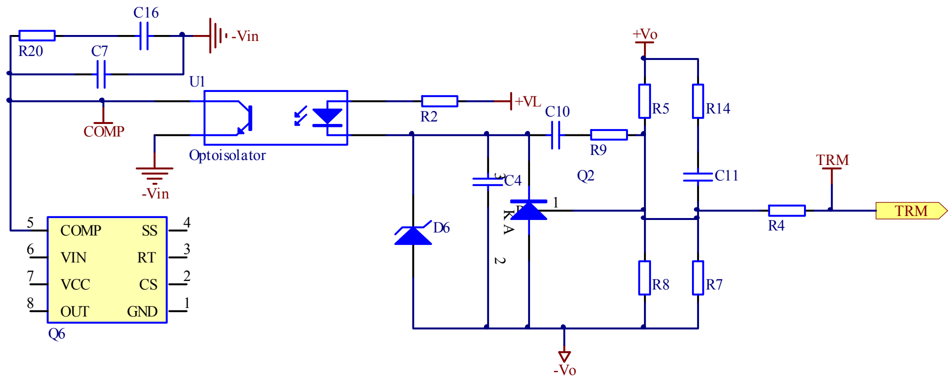

Fig.5 Feedback circuit schematics

According to the technical data of TL432, the reference voltage is 2.5V, the reference input current is 2μA, and the current of $R9$ is usually 100 times of the former. That is:

$$R9 \leq \frac{2.5}{0.002 \times 100} = 12.5(\mathrm{k}\Omega) \qquad (12)$$

$R9$ is 10K based on the actual conditions and needs. The high-precision reference resistance is given as :

$$R7 // R8 = (U_o - V_{ref}) \frac{R9}{V_{ref}} = 50(\text{k}\Omega) \tag{13}$$

According to the technical data of TLP291, the breakover current I_F is 50mA, the breakover voltage V_F is 1.2V and D6 is a voltage-regulator diode. Then the calculation is:

$$R2 = \frac{V_L - V_{ref} - V_F}{I_F} = \frac{U_o - V_{ref} - V_F}{I_F} = 226(\Omega) \tag{14}$$

The results of the experiment

As shown in Figure 6, according to brassboard designed in the design, the following data is obtained. When the output end is a diode, the nominal input voltage is 24V, the output power is 30W, then the input current is 1.46A, and the power efficiency is up to 85.6%; when the output end is a MOS tube, the input voltage is 24V, the output power is 30W, then the input current is 1.36A, and the power efficiency is up to 91.9%. The result tells that the application of a self-drive increases 5% for the efficiency. Figure 7 is the oscillogram for the driver tube of MOS, from which the experiment effect is good and practical.

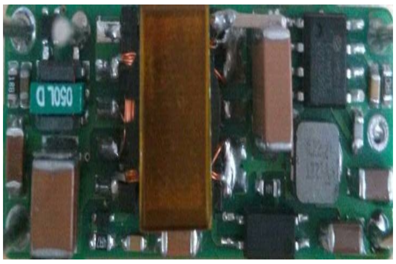

Fig.6 Breadboards

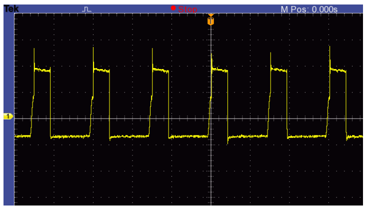

Fig.7 Waveform figure

Conclusion

The paper introduces the design of an efficient DC-DC switching power supply, and describes the process as follows: the designs of a current-limiting circuit, transformer and feedback circuit, and a self-drive circuit increasing the efficiency and an experiment to test the feasibility of the circuit, providing more choices for life.

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