Flyback Converter Design and Analysis

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1 Introduction

A flyback converter is a type of DC-DC converter widely used in applications requiring a single output voltage and galvanic isolation between input and output. This document details the design of a single-output flyback converter with a 25V DC input and a 12V DC output. The converter includes an RC snubber and an RCD clamp to handle switching transients and protect the components.

2 System Diagram

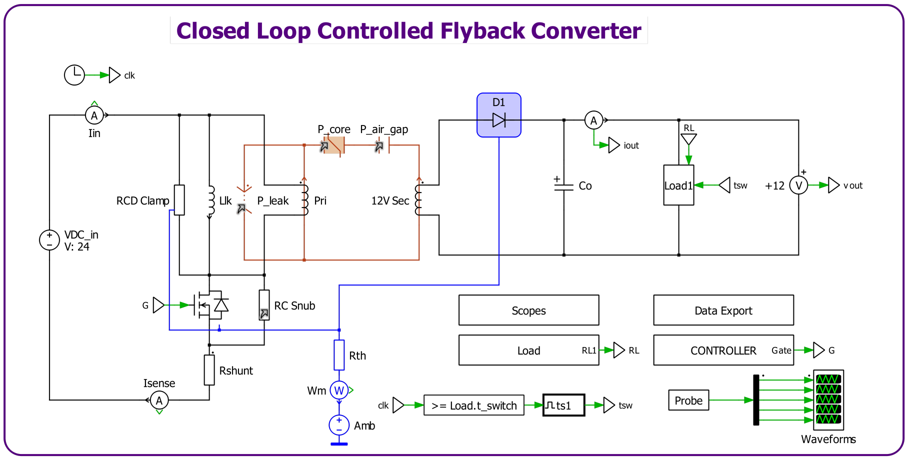

Figure 1: Flyback Converter System Diagram

3 System Description

The flyback converter operates by storing energy in a transformer during the switch-on period and releasing it to the output during the switch-off period. This section elaborates on each part of the system.

3.1 Transformer

The transformer in a flyback converter serves two primary purposes:

- **Energy Storage and Transfer**: During the switch-on period, energy is stored in the transformer's magnetic field. During the switch-off period, this energy is transferred to the output.
- **Voltage Transformation and Isolation**: The transformer steps down the input voltage to the required output level and provides galvanic isolation between the input and the output.

3.1.1 Turns Ratio Calculation

The turns ratio is calculated to meet the output voltage requirements based on the input voltage and the desired duty cycle.

$$\frac{N_{pri}}{N_{sec}} = \frac{V_{out} + V_f}{V_{in} \times D_{max}}$$

Where:

- N_{pri} is the number of turns on the primary winding.
- N_{sec} is the number of turns on the secondary winding.
- V_f is the forward voltage drop of the diode.
- D_{max} is the maximum duty cycle, typically 0.4 to 0.6 for flyback converters.

3.1.2 Primary Inductance

The primary inductance L_{pri} is crucial for determining the converter's mode of operation. For continuous conduction mode (CCM), L_{pri} must be sufficiently large.

$$L_{pri} = \frac{V_{in} \times D_{max} \times (1 - D_{max})}{f_s \times I_{pri,peak}}$$

Where:

- $I_{pri,peak}$ is the peak current through the primary winding.
- f_s is the switching frequency.

3.1.3 Core Selection

The core material and size are selected based on the required inductance and the peak magnetic flux density (B_{max}).

$$B_{max} = \frac{V_{in} \times D_{max}}{N_{pri} \times A_e \times f_s}$$

Where:

- A_e is the effective core area.

3.2 Output Rectification and Filtering

The output rectification and filtering stages convert the AC voltage from the transformer's secondary winding into DC voltage and reduce voltage ripple.

3.2.1 Output Diode

The diode rectifies the AC voltage from the transformer into DC. It must be selected based on its peak reverse voltage and average forward current ratings.

$$V_{R,peak} = V_{in} + V_{out} \times \frac{N_{pri}}{N_{sec}}$$

$$I_{avg} = \frac{P_{out}}{V_{out}}$$

Where:

- $V_{R,peak}$ is the peak reverse voltage the diode must withstand.
- I_{avg} is the average current the diode must carry.

3.2.2 Output Capacitor

The capacitor filters the rectified voltage to reduce ripple and provide a stable DC output.

$$C_{out} = \frac{I_{out} \times D_{max}}{f_s \times \Delta V_{out}}$$

Where:

- I_{out} is the output current.
- ΔV_{out} is the allowable ripple voltage.

3.3 RC Snubber Circuit

The RC snubber circuit is used to dampen oscillations caused by the transformer's leakage inductance during the switching transitions.

3.3.1 Purpose of the RC Snubber

The RC snubber protects the MOSFET switch from voltage spikes and reduces EMI by damping high-frequency oscillations.

3.3.2 Snubber Resistor and Capacitor Calculation

The resistor and capacitor in the snubber circuit are chosen to critically dampen the oscillations.

$$R_s = \sqrt{\frac{L_{leak}}{C_s}}$$

$$C_s = \frac{1}{2\pi \times f_{ring} \times R_s}$$

Where:

- L_{leak} is the leakage inductance of the transformer.
- f_{ring} is the ringing frequency, typically a few MHz.

3.4 RCD Clamp Circuit

The RCD (Resistor-Capacitor-Diode) clamp circuit limits the peak voltage across the MOSFET by diverting excess energy from the leakage inductance.

3.4.1 Purpose of the RCD Clamp

The RCD clamp prevents the MOSFET from being damaged by voltage spikes due to the transformer's leakage inductance.

3.4.2 Clamp Resistor and Capacitor Calculation

The clamp resistor dissipates the energy stored in the leakage inductance, and the capacitor stores the energy to limit voltage spikes.

$$R_{clamp} = \frac{V_{clamp} - V_{in}}{I_{leak}}$$

$$C_{clamp} = \frac{\Delta E}{\Delta V_{clamp}^2}$$

Where:

- V_{clamp} is the clamping voltage.
- ΔE is the energy stored in the leakage inductance.
- ΔV_{clamp} is the allowable voltage ripple on the clamp capacitor.

Reverse Polarity Protection

When the input is connected correctly (positive to the source of the PMOS and negative to the drain), the PMOS will be in the ON state, allowing current to flow. If the polarity is reversed, the PMOS remains OFF, preventing current from flowing and protecting your circuit.

Below is a step-by-step guide on how to choose these components:

1. Selecting the PMOS Transistor

- **Voltage Rating (V_{DS}):** The PMOS should have a drain-source voltage rating higher than the maximum input voltage. Since the input can go up to 36V, a PMOS with at least 40V V_{DS} rating is good to provide a margin.
- **Current Rating (I_D):** The PMOS must handle the maximum current drawn by your circuit. Since the circuit could draw more than 2A, we choose a PMOS with a current rating higher than 2A, preferably 5A or more for safety.
- **$R_{DS(on)}$:** This is the on-state resistance of the PMOS when it's fully turned on. Lower $R_{DS(on)}$ values reduce power loss and heat dissipation. Usually a PMOS with $R_{DS(on)}$ in the range of a few milliohms (mΩ).

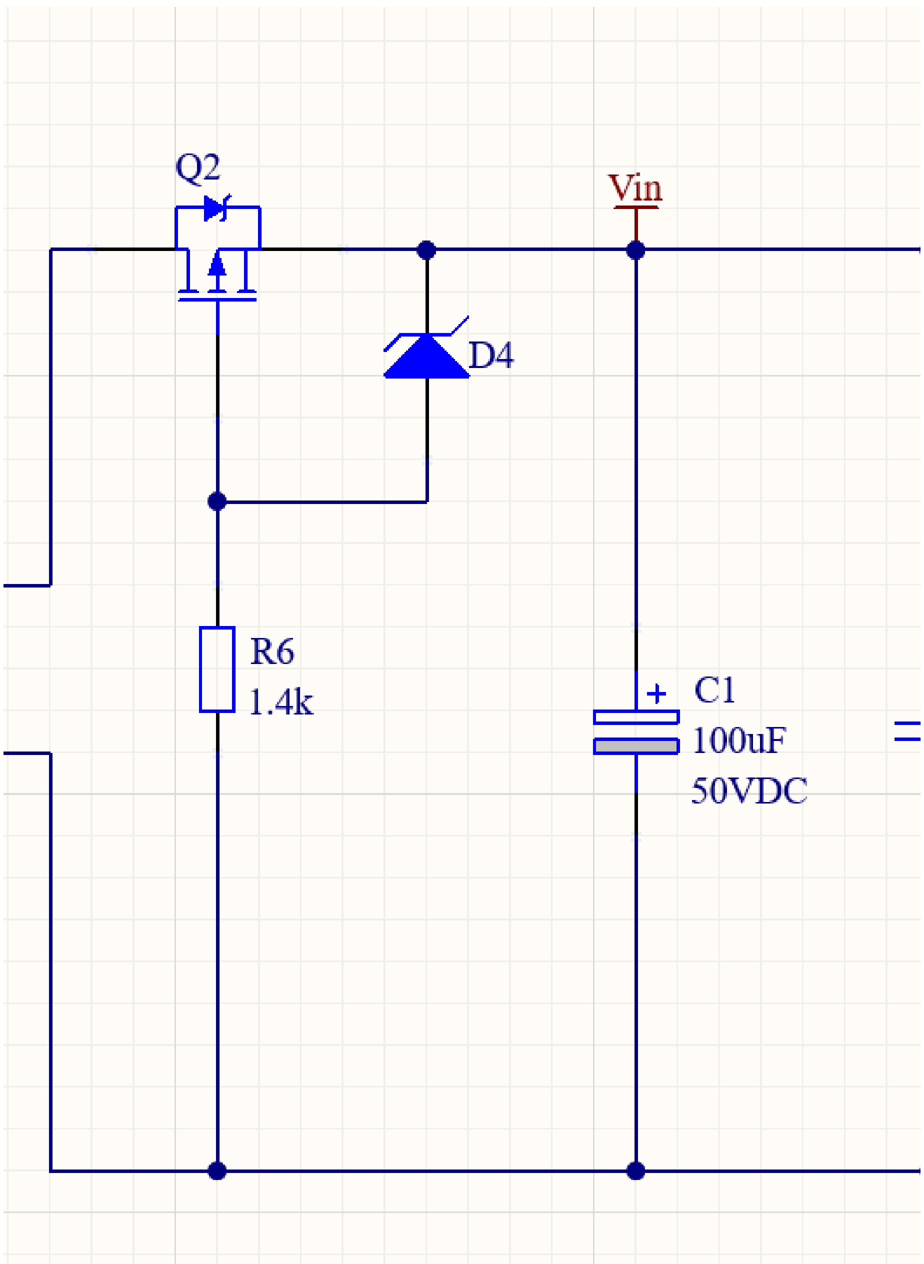

Figure 2: Reverse Polarity Protection

2. Selecting the Zener Diode

- **Zener Voltage (V$_Z$):** The Zener diode is used to ensure the gate-source voltage (V$_{GS}$) of the PMOS stays within safe limits. We go for a Zener voltage slightly higher than the PMOS gate threshold voltage (V$_{GS(th)}$) but lower than the maximum allowed V$_{GS}$ for the PMOS.

- **For example:** If the PMOS has a V$_{GS(th)}$ of -2V and a maximum V$_{GS}$ of -20V, we could choose a Zener diode with a V$_Z$ of 10V. This ensures the gate is clamped to a voltage that fully turns on the PMOS but doesn't exceed the maximum V$_{GS}$.

3. Selecting the Resistor

- **Resistor Value (R):** The resistor is used to limit the current flowing through the Zener diode and to ensure that the PMOS gate is pulled to the source ground when the input is connected with the correct polarity.

- **Calculation:** The resistor value can be calculated using Ohm's Law:

$$R = \frac{V_{in} - V_Z}{I_Z}$$

  Where V_{in} is the input voltage, V_Z is the Zener voltage, and I_Z is the Zener current, which should be enough to activate the Zener diode but not too high to damage it (typically in the range of 5-20mA).

- **Example:** in this case we chose a Zener with a 10V rating and want a current of 10mA, and the input voltage is 24V, the resistor then value would be:

$$R = \frac{24V - 10V}{10mA} = 1.4k\Omega$$

4 References

1. R. W. Erickson, *Fundamentals of Power Electronics*, New York: Chapman & Hall, 1997.

5 Units

1. Farads (**F**).................: Unit of capacitance.
2. Amps (**A**)..................: Unit of electric current.
3. Volts (**V**)...................: Unit of electric potential.
4. Ohms (Ω)............: Unit of electrical resistance.
5. Henrys (**H**).................: Unit of inductance.

6. Watts (**W**).................: Unit of power.
7. Hertz (**Hz**).................: Unit of frequency.
8. Teslas (**T**)...................: Unit of magnetic flux density.
9. Webers (**Wb**).............: Unit of magnetic flux.
10. Decibels (**dB**).............: Unit of measurement for the power level of an electrical signal.