

Modeling a Current-Controlled Flyback Converter using PLECS®

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1 Introduction

The isolated flyback converter is a commonly-used converter for small power supplies such as battery chargers for portable devices and for auxiliary power supplies in electronic equipment. In this report the control design of a flyback converter that provides three low-voltage DC output voltages from a single-phase mains source is explained and the circuit schematic is shown in Fig. 1. The flyback transformer is modeled using an ideal transformer with a magnetizing inductance in parallel. Leakage inductance is ignored because the model is intended for controller design and circuit level simulation rather than simulating the parasitic effects of components. The parameters of the flyback transformer are given in the Table 1. The output voltages of the open-loop flyback converter are heavily affected by the input DC voltage ripple. In order to regulate the output voltages, a current mode control scheme using a type 2 voltage controller to set the reference current is implemented.

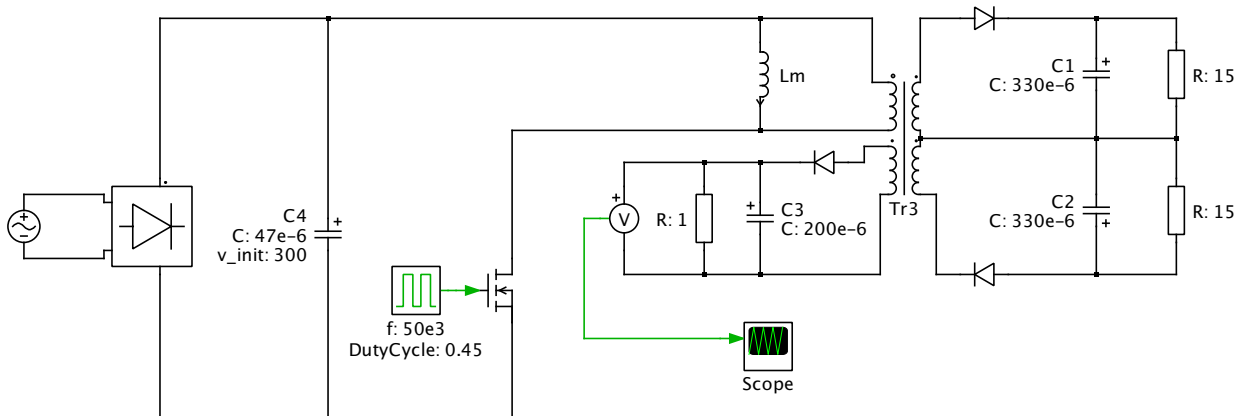


Fig. 1: Flyback converter schematic.

Parameter	Value
Magnetizing inductance, L_m	9.4 mH
Number of primary turns, n_p	80
Number of turns on 5V winding, n_{s1}	2
Number of turns on $\pm 12V$ winding, $n_{s2,3}$	4.5
Maximum duty cycle, d_{max}	0.50

Table 1: Flyback transformer parameters.

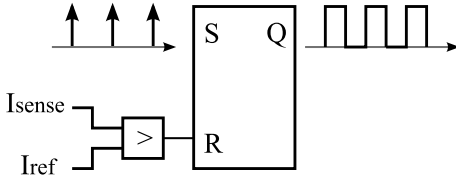


Fig. 2: Current mode controller based on an SR latch.

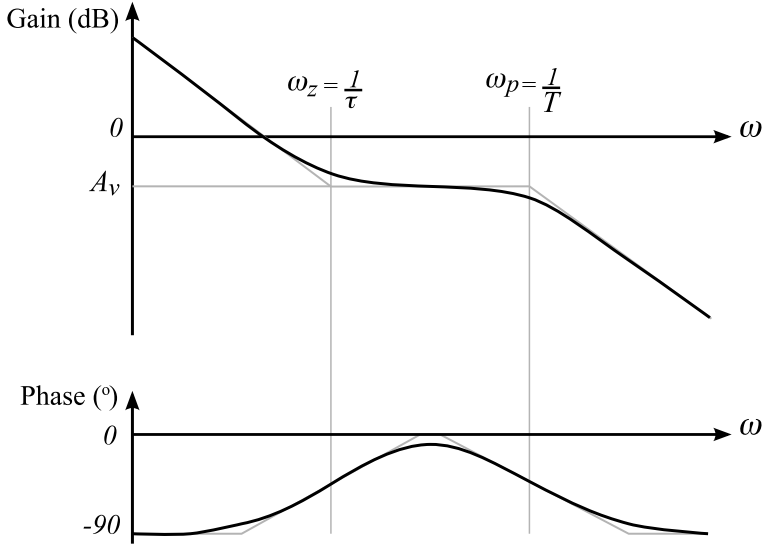


Fig. 3: Bode plot of type 2 controller.

2 Current Controller

The flyback converter uses a two-loop control scheme. The inner current loop, based on a peak current mode controller, provides a fast transient response, and the outer voltage control loop provides a reference current to the inner loop to regulate the output voltage of the 5 V winding. The Peak Current Controller block, found in the PLECS Control component library, is based on an SR latch, as shown in Fig. 2. At the start of each switching cycle, a period signal at the set input, S, sets the output, Q, that controls the switch. The output remains on until the reset input, R, receives a trigger signal. The reset signal is generated by comparing a current sense signal, using a small resistance at the source terminal of the MOSFET, with a fixed 5 V reference signal.

3 Voltage Controller

3.1 Frequency response

The voltage loop is based on a type 2 voltage controller, that is implemented using an inverting op-amp circuit. The type 2 controller is similar to a PI controller that has a pole at 0° and a zero at ω_z . A high frequency pole, ω_p , is added to filter out the switching noise. The frequency response of the type 2 controller is shown in the Bode plot in Fig. 3.

The transfer function of the type 2 controller is given as follows:

$$G(s) = k_p \left(\frac{1 + s\tau}{s\tau} \right) \left(\frac{1}{1 + sT} \right) \quad (1)$$

where the proportional gain $k_p = 10^{\frac{A_v}{20}}$. This is calculated to set the unity gain bandwidth to a defined value, and ω_z and ω_p are tuned to set the phase margin and DC gain of the system.

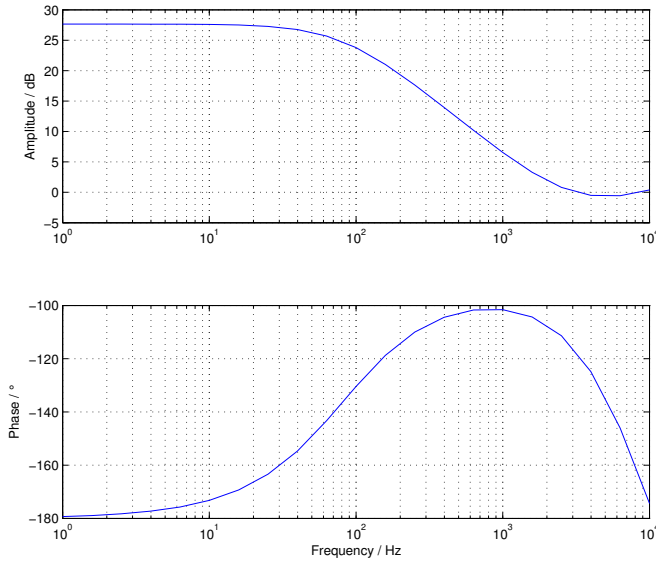


Fig. 4: Bode plot of current-controlled flyback converter.

3.2 Voltage controller design

To design the voltage controller the frequency response of the current-controlled converter is needed. A small-signal transfer function of the converter in the form of a Bode plot can be obtained using the Impulse Response Analysis Tool or AC Sweep Tool, both found in the PLECS library browser under *Extras* > *Analysis Tools* in PLECS Blockset or from the *Simulation* > *Analysis Tools...* menu option in PLECS Standalone. To perform the Impulse Response Analysis, which was the analysis method chosen for this example, the input rectifier and capacitor are replaced with a 300 V DC voltage source to eliminate the input disturbance. The dynamics of the input rectifier are much slower than those of the flyback converter and can therefore be ignored.

The configuration of the Impulse Response Analysis Tool is done with the following parameters:

- System period length: $2e - 5$ s. (This is the period of the signal with the lowest periodic frequency, in other words, the switching signal).
- Frequency sweep range: $[1 \text{ } 1e4]$ Hz.
- Number of points: 21.
- Number of initialization cycles: 10.

When the Impulse Response Analysis is run, the Bode plot shown in Fig. 4 is produced. The unity gain bandwidth of the system is selected to be 500 Hz. This frequency is set five times higher than the 100 Hz input voltage ripple to ensure that the controller can adequately regulate the output despite input disturbances. It can be seen from Fig. 4 that the gain required for the type 2 controller at its midband range, $\omega_z < \omega < \omega_p$, is -11 dB in order to achieve a system unity gain of 0 dB at 500 Hz.

3.3 Op-amp implementation

The type 2 controller is implemented using an inverting op-amp as shown in Fig. 5. Because the op-amp is of the inverting type, an additional inverting stage is required to re-invert the output signal. Alternatively, the output voltage of the 5 V winding can be subtracted from the reference voltage signal and the same inversion is applied. In practice, an inverting op-amp buffer or optocoupler re-inverts the control signal.

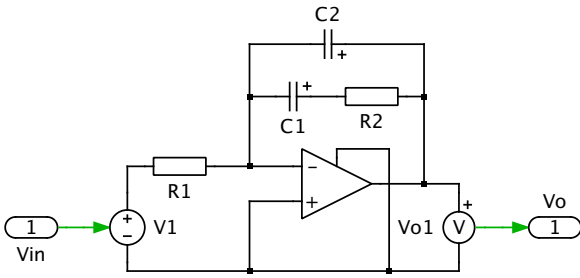


Fig. 5: Type 2 controller-based on inverting op-amp.

The parameters for the voltage controller are $A_v = -11$ dB, $f_z = 100$ Hz, and $f_p = 2$ kHz. The component values for the controller gain, pole, and zero are calculated by assuming a value of $1e4$ Hz for R_1 and using the following formulae:

$$k_p = -\frac{R_2}{R_1} \quad (2)$$

$$\omega_z = \frac{1}{R_2 C_1} \quad (3)$$

$$\omega_p \approx \frac{1}{R_2 C_2} \quad (4)$$

The type 2 controller op-amp circuit is implemented in PLECS as a subsystem. The frequency response of the controller is then obtained using the PLECS AC Sweep Tool with the system period parameter set to 0 s and the same settings that were used in the analysis to obtain the converter transfer function.

Appendices

A Simulation Files - PLECS Blockset

Example files used to demonstrate the design of the voltage controller for a flyback converter using PLECS Blockset accompany this application note:

- *Flyback_Iloop_impulse.mdl*: A model in which the Impulse Response Analysis Tool is used to obtain the open-loop frequency response of the current-controlled converter. The result is written to the MATLAB workspace as a struct.
- *Flyback_Vloop_cct.mdl*: A complete model of the converter with both the inner current control loop and designed voltage controller.

B Simulation Files - PLECS Standalone

Example files used to demonstrate the design of the voltage controller for a flyback converter using PLECS Standalone accompany this application note:

- *Flyback_Iloop_impulse.plecs*: A model in which the Impulse Response Analysis Tool is used to obtain the open-loop frequency response of the current-controlled converter.
- *Flyback_Vloop_cct.plecs*: A complete model of the converter with both the inner current control loop and designed voltage controller.

To run the example models accompanying this documentation you need at least PLECS 2.2.0 installed. The Peak Current Controller component used for the current control loop was not present in previous versions of the PLECS library.