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Application Note

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Selecting L and C Components in the Power Stage of the MC34700 Switching Regulators

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1 Introduction

The MC34700 is a multi-rail power supply IC, consisting of three switch-mode power supplies (SMPS, also known as DC/DC converters), and one low-dropout (LDO) regulator.

All three SMPS regulators are based on a step-down topology. This means that each SMPS regulator generates a voltage at its output that is less than the voltage applied at its input.

Figure 1 is a schematic representation of a step-down converter power stage (also showing the feedback path and the PWM generator block in blue), with the inductor L and the capacitor C_{OUT} being the elements of the LC output filter, and C_{IN} being the input capacitor.

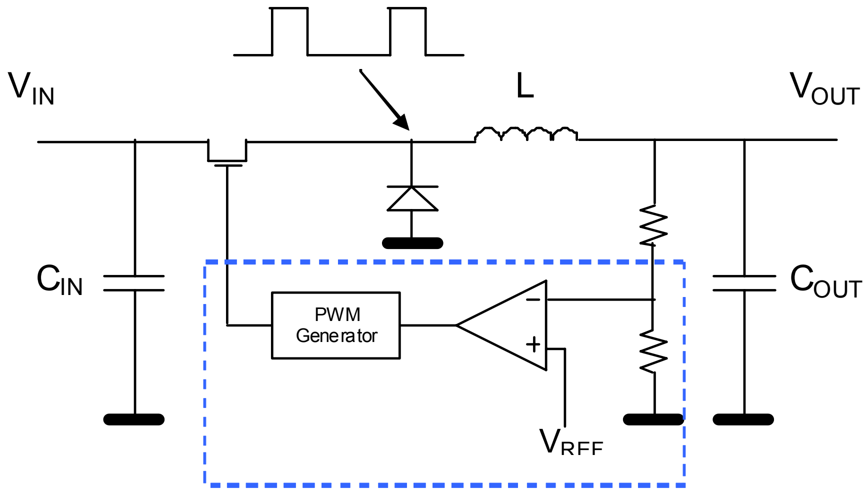

Figure 1. Schematic Representation of a Step-down Converter Power Stage

To ensure proper operation and to optimize the performance of the SMPS regulators, the external L and C components of the power stage need to be selected carefully.

Some guidelines will be provided to help in the selection of the output inductor L, the output capacitor C_{OUT}, and the input capacitor C_{IN}.

2 The LC Output Filter

The LC output filter can be thought of as the element in the converter that receives a voltage square wave at its input (the switching node, indicated in Figure 1 with an arrow), and produces a constant voltage at its output (the regulated output voltage V_{OUT}) by filtering the square wave that is presented at its input.

2.1 Selecting the Output Inductor

In a step-down converter under steady-state conditions, the average current in the inductor I_L is equal to the output current I_{OUT}. Figure 2 represents the inductor current vs. time in CCM (Continuous Conduction Mode, i.e. the inductor is never fully discharged and its current never reaches zero). As can be seen, the inductor current is not constant, but varies around I_{OUT} between a maximum and a minimum value, whose difference ΔI_L is the peak-to-peak inductor current ripple.

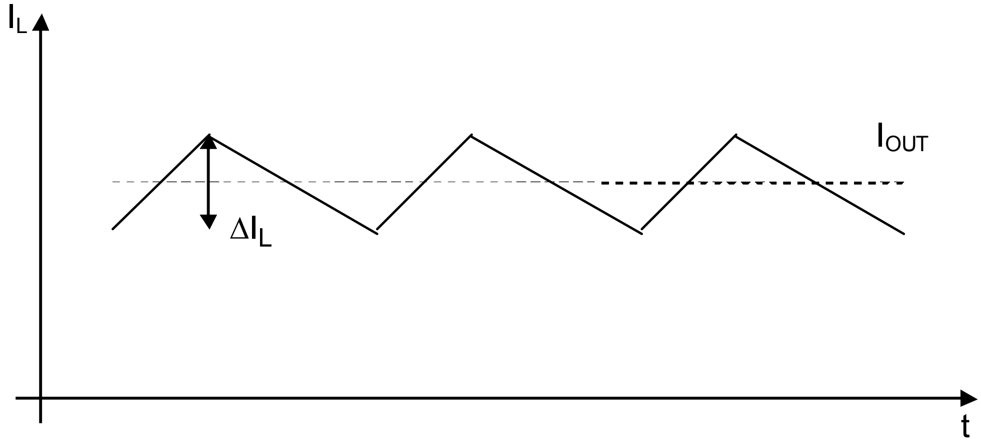

Figure 2. Inductor Current in a Step-down Converter

The first step to select the power inductor is to define an acceptable inductor current ripple ΔI_L at the application level. From there, the inductance value can be calculated as follows:

$$L = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{V_{IN} \cdot f_{sw} \cdot \Delta I_L}$$

where

- V_{IN}: converter's input voltage (in V)
- V_{OUT}: converter's output voltage (in V)
- f_{SW}: converter's switching frequency (in Hz)
- L: inductance (in H
- ΔI_L: peak-to-peak inductor current ripple (in A)

As established from the formula above, larger values of L allow smaller values of ΔI_L , which results in lower output voltage ripple (see next section, "Selecting the Output Capacitor"), better efficiency, and better EMC behavior, but slower load transient response. Therefore, selecting the right inductance is a trade-off between the different factors. Choosing ΔI_L to be between 20% and 40% of I_{OUT} is typically a viable choice.

When selecting a power inductor from one of the various manufacturers, the inductance is not the only parameter to consider. Another important parameter is the saturation current I_{SAT} of the inductor, which should never be exceeded in the application. Operating the inductor above I_{SAT} would cause a significant inductance loss, and a steep increase of the inductor current during the charging phase. As the maximum current flowing in the inductor is:

$$I_{L,\max} = I_{OUT,\max} + \frac{\Delta I_{L,\max}}{2}$$

an inductor with an I_{SAT} greater than $I_{L,MAX}$ must be selected for the application.

In order to minimize resistive power losses, an inductor with a low DCR (DC resistance) should be selected.

2.2 Selecting the Output Capacitor

The role of the output capacitor is to keep a constant output voltage and limit voltage excursions at the output. Both ESR (equivalent series resistance) and capacitance have an influence on the output voltage.

In order to obtain a given peak-to-peak output voltage ripple ($\Delta V_{OUT,RIPPLE}$), the required maximum ESR of the output capacitor can be calculated by using the following equation:

$$ESR = \frac{\Delta V_{OUT,ripple}}{\Delta I_L}$$

where ΔI_L is the inductor current ripple.

To limit the output voltage overshoot when the full output load is removed from the output, the required maximum ESR can be calculated as:

$$ESR = \frac{\Delta V_{OUT,overshoot}}{I_{L,\max}}$$

and the minimum output capacitance can be estimated with the following equation:

$$C_{OUT} = \frac{L \cdot (I_{L,\max})^2}{(V_{OUT} + \Delta V_{OUT,overshoot})^2 - V_{OUT}{}^2}$$

where $\Delta V_{OUT,OVERSHOOT}$ is the maximum voltage overshoot allowed on the output, and $I_{L,MAX}$ is the maximum inductor current.

The RMS current of the output capacitor is:

$$I_{C_{OUT},RMS} = \frac{\Delta I_L}{\sqrt{12}}$$

Due to the internal ESR, this RMS current produces power dissipation and a temperature increase of the capacitor itself. Since excessive temperature negatively affects the reliability and the lifetime of a capacitor, an output capacitor with an adequate current rating should be selected.

To achieve better output voltage filtering, low-ESR capacitors are required. Ceramic capacitors offer very low ESR, but care should be taken when selecting this type of capacitor. Different types exist on the market (e.g. Y5V, X5R, X7R, C0G), with each type having specific temperature and voltage characteristics. Make sure to select the right type for your application, and check for detailed information with the manufacturer .

3 Selecting the Input Capacitor

The bulk input capacitor minimizes the input voltage ripple caused by the discontinuous input current of a step-down regulator.

The value of the input capacitance is not the main consideration when selecting the input capacitor, but rather the RMS current and the voltage rating.

The RMS current of the input capacitor C_{IN} is:

$$I_{C_{IN},RMS} = I_{OUT} \cdot \sqrt{D - D^2}$$

where D = V_{OUT}/V_{IN} is the duty cycle.

The worst case occurs at D = 50% (i.e. V_{IN} = 2 x V_{OUT}), which yields $I_{IN,RMS} = I_{OUT}/2$.

The bulk input capacitor has to sustain this RMS current without overheating, due to its internal ESR (equivalent series resistance). The constraint on low ESR will typically determine the selection of a suitable capacitor.

Ceramic and tantalum capacitors are both suitable as input capacitors. Choose ceramic capacitors with a voltage rating of at least 1.5 times the maximum input voltage. If tantalum capacitors are selected, they should be chosen with a voltage rating of at least 2 times the maximum input voltage.

A small ceramic capacitor in parallel to the bulk capacitor is recommended for high-frequency decoupling.

4 Example

Now examine a numerical example, based on BUCK CONVERTER 1 of the MC34700, to determine the external L and C components of the power stage of this converter. The following analysis assumes that the converter operates in CCM, as indicated previously in the chapter, Selecting the Output Inductor.

Application conditions:

- V_{IN}: 9.0 to 18 V
- V_{OUT}: 5.0 V
- I_{OUT}: 1.0 A

Based on the application conditions above, calculate L, C_{OUT}, and C_{IN}.

Output inductor L:

If choosing to have ΔI_L = 400 mA (40% of I_{OUT}), then

$$L = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{V_{IN} \cdot f_{sw} \cdot \Delta I_L} = \frac{(18V - 5V) \cdot 5V}{18V \cdot 760kHz \cdot 400mA} = 12\mu H$$

Note that worst-case values have been used for V_{IN} and f_{SW} (see the MC34700 datasheet for f_{SW}).

Output capacitor C_{OUT}:

If choosing to allow a maximum output voltage ripple $\Delta V_{OUT,RIPPLE}$ of 50 mV (1% of V_{OUT}), then the maximum ESR is:

$$ESR = \frac{\Delta V_{OUT,ripple}}{\Delta I_L} = \frac{50mV}{400mA} = 125m\Omega$$

If choosing to allow a maximum output overshoot voltage $\Delta V_{OUT,OVERSHOOT}$ of 200 mV (4% of V_{OUT}), and decide to split the 200 mV in equal parts for the contribution of the ESR and capacitance, then the maximum ESR can calculate as:

$$ESR = \frac{\Delta V_{OUT,overshoot}}{I_{L,\max}} = \frac{100mV}{1.2A} = 83m\Omega$$

and the minimum capacitance as:

$$C_{OUT} = \frac{L \cdot (I_{L,\max})^2}{(V_{OUT} + \Delta V_{OUT})^2 - V_{OUT}{}^2} = \frac{12\mu H \cdot (1.2A)^2}{(5V + 100mV)^2 - (5V)^2} = 17\mu F$$

It should be noted that the most stringent requirement for ESR in this numerical example comes from the output overshoot voltage.

The RMS current in the output capacitor is:

$$I_{C_{OUT},RMS} = \frac{\Delta I_L}{\sqrt{12}} = \frac{400mA}{\sqrt{12}} = 115.5mA$$

Input capacitor C_{IN}:

The RMS current of the input capacitor C_{IN} is:

$$I_{C_{IN},RMS} = I_{OUT} \cdot \sqrt{D - D^2}$$

with the worst case occurring when V_{IN} = 10 V (D = 50%). In this case:

$$I_{C_{IN},RMS} = I_{OUT} \cdot \sqrt{D - D^2} = 1A \cdot \sqrt{0.5 - 0.5^2} = 500mA$$

This RMS current will cause power dissipation in the input capacitor due to its internal ESR. The input capacitor needs to have a low ESR to keep power dissipation at low levels. A capacitance value of 22 µF is likely to be adequate. Always check with capacitor manufacturers for detailed information.

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