APPLICATION NOTE

Influence of control loop by an Outputfilter
Output voltage filtered without losses

ANP006B BY STEFAN KLEIN

1. Introduction

The output voltage of switching regulators has a voltage ripple that can disturb with electrical power supplied circuits and lead to electromagnetic disturbances. Thus output filters are often used for noise suppression, which may under certain circumstances have an influence on the control loop. To prevent output power losses it may be necessary to compensate the control loop.

No matter what switching regulator topology is used, as a result of the parasitic series resistor ESR and the parasitic inductance ESL of the output capacitor, the output current causes an undesired residual ripple. Depending on the capacitor type selected, a relatively large residual ripple is created, which has varying wave forms. A common electrolytic capacitor, for example, can have a ripple voltage of up to a few hundred millivolt, depending on the output power of the switching regulator. If a ceramic capacitor is chosen, the ripple voltage may only be a few tenth of a Volt.

A high residual ripple is undesired and can disturb with electrical power supplied circuits. In particular analog and HF circuits require a stable, smooth and clean supply voltage. Nevertheless, the high-frequency component of output voltage harmonics, which can give rise to increased electromagnetic interference, must also be taken into consideration. An output filter is able to reduce residual ripple and filter out high-frequency components.

LC low-pass filters are usually used in practical application to reduce the residual ripple. If a particularly clean output voltage is required, the LC low-pass filter is expanded with a further low-pass filter comprising a ferrite and a capacitor. Figure 1 depicts such a two-stage output filter, which can be made up cost-effectively with, for example, a WE-PD2 coil and an SMD ferrite WE-MPSB by Würth Elektronik eiSos.

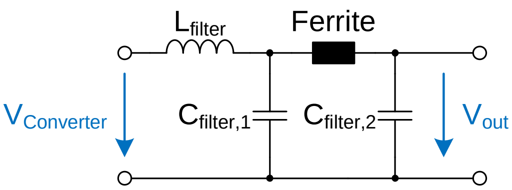

Figure 1: Two-stage output filter

L_{Filter} und $C_{Filter1}$ act as low-pass filter, which filter out the clock frequency of the switching regulator and smooth its harmonics. Further high-frequency components of the switching regulator output voltage are converted into heat by the SMD ferrite and, together with $C_{filter2}$, their amplitude is damped. A simple output filter of this kind reduces the residual ripple to only a few millivolt and can be used in power supplies even for radio-controlled circuits.

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2. Main part of technical article

On from a certain output power of the switching regulator, the output filter causes significant DC losses in the output power and thus a reduction in efficiency of the switching regulator. The DC resistance R_{DC} of the coils and ferrites now causes a significant voltage drop across the output filter, which results in a reduction of the final output voltage. Depending on the type of coil used, the R_{DC} can be between a few milliohm up to a few Ohm, which is not negligible at high output currents. Even an SMD high-current ferrite may have a R_{DC} of up to 0.04Ω.

To determine the actual voltage, the output voltage of switching regulators is taken from a voltage divider and is connected to the feedback oin of the switching regulator IC. In order to reduce losses in output voltage through an output filter, it is possible to include the output filter into the control loop in that the actual value is taken at the output of the filter. Figure 2 shows the schematic arrangement of this method.

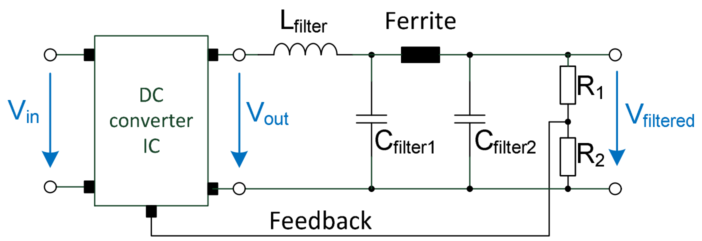

Figure 2: Inclusion of the output filter into the control loop

However, the filter coil, the ferrite and the filter capacitors cause an unwanted phase shift, which interferes with the stability of the converter.

This unwanted phase shift leads to the reduction of gain margin and phase margin. In extreme cases this leads to instability and the output voltage tends to oscillate. To ensure stability a gain margin of >12dB and a phase margin of >45° is required in practical application so that the control loop does not tend towards oscillating by any kind of perturbations. The control loop is deemed to be dynamically stable if the loop gain is 0dB before the respective phase shift has reached -180°. Here the amplitude response of the loop gain should extend through the intersection of the X axis, that is, at 0dB with 20dB/decade. Figure 3 shows the Bode plot of a stabilized buck converter. This example shows a gain margin of 32dB and a phase margin of 56°.

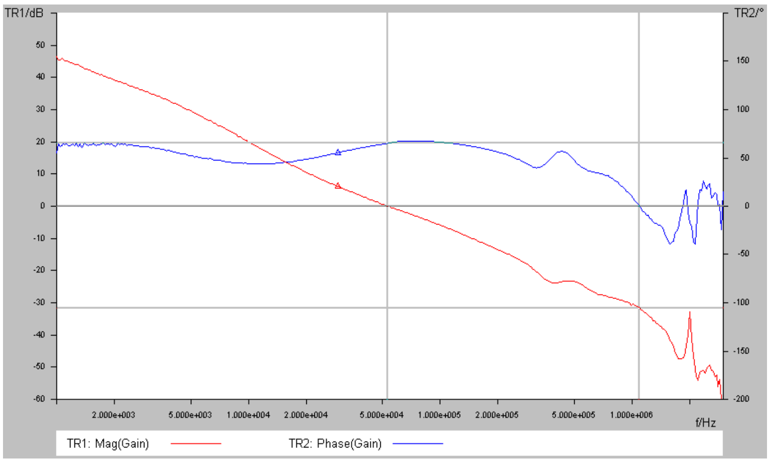

Figure 3: Bode plot of a stabilized switching regulator

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If the stability criteria of a switching regulator with output filter are not met, compensation of the control loop is required to ensure a stable output voltage.

If there is a change in voltage at the input of the switching regulator, the output voltage must remain stable. Similarly, in the instance of a sudden drop or rise of the output current, the output voltage must be stable again quickly. This is called transient response. Figure 4 shows the transient response of a stabilized switching regulator (yellow trace) at an output voltage of 5 V and a sudden load change from 0 A to 1 A (green trace).

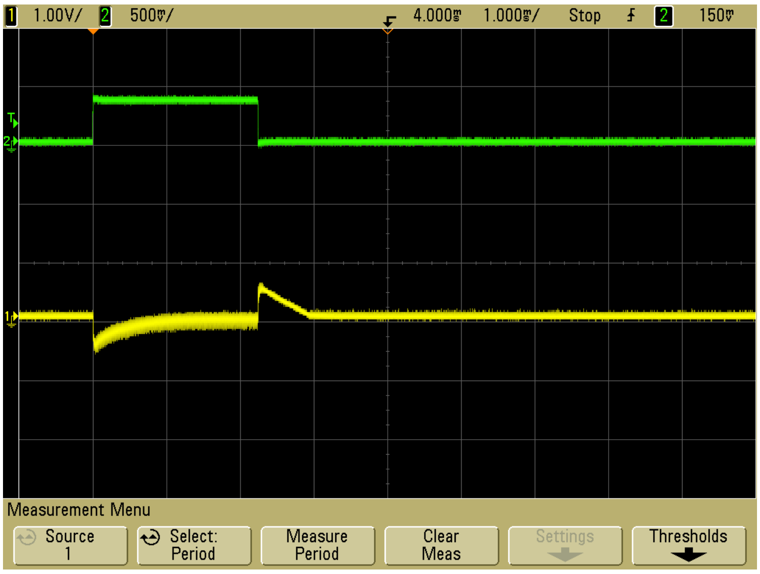

Figure 4: Transient response of a stabilized switching regulator

A sudden load change must cause a fast transient response of the control loop so that the output voltage is returned quickly to its set point value. The transient response must not cause high voltage overshoot in the output voltage or subsequent components may be destroyed at a too high voltage. Ideally, after the voltage drop the output voltage should be brought back quickly to the set point value without overshooting or ringing. A ringing during the equalization phase would therefore be caused by an instability of the switching regulator. If a quick step response and a timely equalization phase are achieved, the switching regulator is deemed to be stabilized.

3. Résumé and conclusion of the technical article

If the output filter is integrated into the control loop, this is called a control loop of the 2nd order. The switching regulator must therefore be operated with a higher integral-action coefficient, which dampens the control loop and makes it slower. This now requires a more complex compensation of the control loop. Thus the method of including the output filter into the control loop is not recommended. The output voltage of the switching regulator should be taken at the output capacitor of the switching regulator, in front of an output filter. To reduce DC losses due to the output filter, it is recommended to select filter coils and ferrites with the smallest possible R_{DC}.

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Application Notes:
http://www.we-online.com/app-notes

REDEXPERT Design Tool:
http://www.we-online.com/redexpert

Toolbox:
http://www.we-online.com/toolbox

Product Catalog:
http://katalog.we-online.de/en/

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