APPLICATION NOTE

Loss-Free Filtered

Stefan Klein

1. Requirements for an output filter

Switching controllers exhibit a residual ripple in their output, which disturbs downstream assemblies and may cause electromagnetic interference. Output filters are therefore often used for interference suppression, which may, under certain circumstances, exert an influence on the control loop. Compensation of the control loop may be required to prevent losses in output power. Irrespective of which switching controller topology is in use, the output current causes unwanted residual ripple through the parasitic series resistance ESR and the parasitic inductance ESL of the output capacitor. A relatively large residual ripple arises which depends on the capacitor type selected and has different waveforms. For example, a common electrolytic capacitor displays a ripple voltage of up to several hundred millivolts depending on the output voltage of the switching controller. Selecting a ceramic capacitor, the remaining ripple voltage may only be a few tenths of a millivolt. High residual ripple is undesirable and can disturb the subsequent electronic assemblies. Special analog and HF circuits require a stable, smoothed and clean supply voltage. However, the high frequency component of harmonic oscillations on the output voltage cannot be overlooked, as this may lead to increased electromagnetic interference emission. Here the output filter can reduce the residual ripple and filter out high frequency components.

2. Reduction of residual ripple

In practice, the decision is usually made for a LC low-pass filter in order to reduce the residual ripple to a few millivolts and to suppress high frequency components. Figure 1 shows such a low-pass filter, which can, for instance, be realized with an unshielded coil, a WE-PD2 and a conventional electrolytic capacitor.

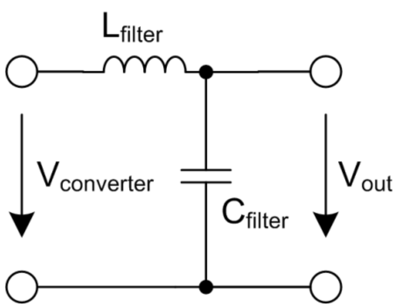

Figure 1: Simple low-pass filter

If a particularly clean output voltage is required, the LC low-pass filter is extended with a downstream low-pass filter consisting of a ferrite and a capacitor. Figure 2 shows this type of two-stage output filter, which can be realized inexpensively, for example with a WE-PD2 coil and a WE-MPSB SMD ferrite.

APPLICATION NOTE

Loss-Free Filtered

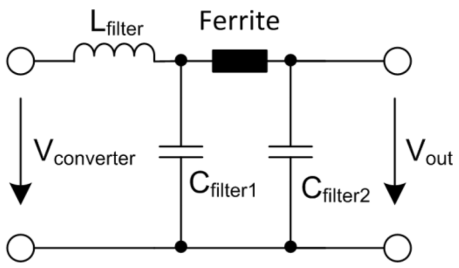

Figure 2: Two-stage output filter

"L_{filter}" and "$C_{filter}1$" act as a low-pass filter, which filters out the clock frequency of the switching controller and attenuates its harmonic oscillations. Further high frequency components of the switching controller output voltage are converted into heat by the SMD ferrite and together with "$C_{filter}2$" their amplitude is attenuated. An output filter of this type reduces the residual ripple to a few millivolts and even allows sensitive analog circuits to be supplied.

3. Direct current losses at the output filter

Above a certain switching controller output power, the output filter causes large direct current losses of the output power and thus a reduction in the efficiency of the switching controller. The direct current resistance RDC of the coils and ferrites now generates a significant voltage drop across the output filter and therefore causes a reduction in the resulting output voltage. Figure 3 shows this effect.

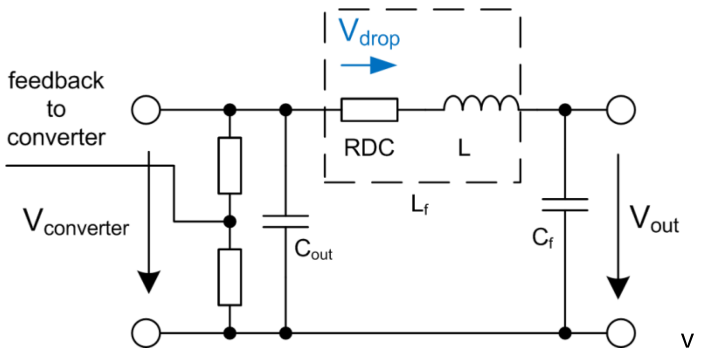

Figure 3: Voltage drop at the filter coil

According to the dependence of the size of the coil, the RDC may be between a few milliohms and several ohms and is therefore not negligible for high output currents. Even an SMD high current ferrite can have an RDC of up to 0.04 Ω. To determine the actual voltage, for switching controllers the output voltage is tapped from a voltage divider and is passed to the feedback connection of the switching controller IC. To reduce output voltage losses due to an output filter, there is the option of implementing the output filter in the control loop by determining the actual value after the output filter. Figure 4 shows the schematic arrangement of this method.

APPLICATION NOTE

Loss-Free Filtered

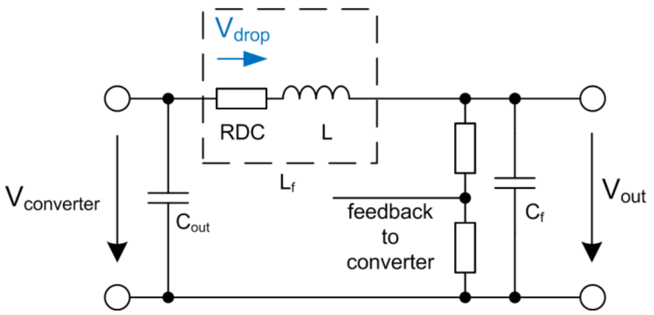

Figure 4: Implementation of the output filter in the control circuit

4. Stability of the control circuit

However, the filter coil, ferrite and the filter capacitors cause an unwanted phase shift, which disturbs the stability of the control loop. This unwanted phase shift gives rise to a reduction in the amplitude and phase reserve. In extreme cases, it leads to instability and the output voltage tends to oscillate. In order to ensure stability, an amplitude margin of > 12 dB and a phase reserve of > 45 is necessary in practice, such that the control circuit does not oscillate on excitation. The control circuit is considered dynamically stable if the loop amplification drops to 0 dB before the associated phase shift has attained a value of -180 . Here the amplitude response of the loop amplification should cross the x-axis, i.e. at 0 dB with 20 dB / decade. Figure 5 shows a Bode plot of a stable-regulated step-down (buck) converter. This example shows an amplitude reserve of 32 dB and a phase reserve of 56°.

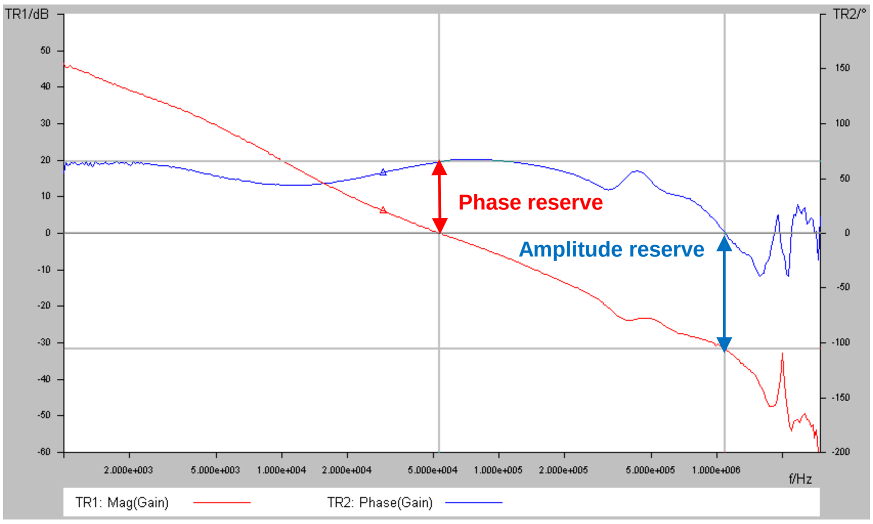

Figure 5: Bode plot of a stable-regulated switching controller

If the stability criteria of a switching controller are not met with an output filter, compensation of the control loop is required to ensure a stable output voltage. The stability of the control section thus exerts an influence on the stability of the output voltage.

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5. Transient response

In the event of a voltage fluctuation at the input of the switching controller, the output voltage should remain stable. Analogously, in case of a sudden drop or rise of the output current, the output voltage should readjust quickly. This is what transient response means. Figure 6 shows the transient response of a stable-regulated switching controller (yellow curve) with an output voltage of 5 V and a sudden change in load from 0 A to 1 A (green curve).

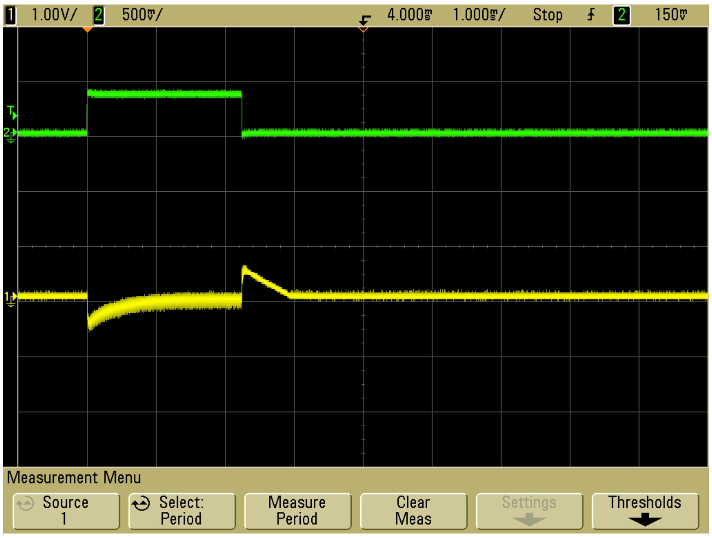

Figure 6: Transient response of a stable-regulated switching controller

A sudden change in load should lead to a rapid step response of the control circuit, which promptly regulates the output voltage to its target value. The step response should not cause too great an amplitude in the output voltage, as otherwise downstream assemblies could be destroyed by overvoltage. Ideally, the output voltage should be promptly regulated to the target value following the step response, without generating an overshoot or even ringing. Ringing during the compensation phase would therefore be attributable to instability of the switching controller. If there is a fast step response and a timely compensation phase, the switching controller may be considered to be stable-regulated.

6. Summary

If the output filter is implemented in the control section, the control section is 2nd order. The switching controller must therefore be operated with a higher integration component, which attenuates the control section and hence slows it down. Complicated compensation of the control section is now required. The method of implementing the output filter in the control section is therefore not recommended. The switching controller output voltage should be tapped directly at the switching controller output capacitor, i.e. prior to an output filter. It is recommended to select filter coils and ferrites with the lowest possible R_{DC} in order to reduce DC losses in the output filter.

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CONTACT INFORMATION

Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Str. 1, 74638 Waldenburg, Germany
Tel.: +49 (0) 7942 / 945 – 0
Email: appnotes@we-online.de
Web: http://www.we-online.com