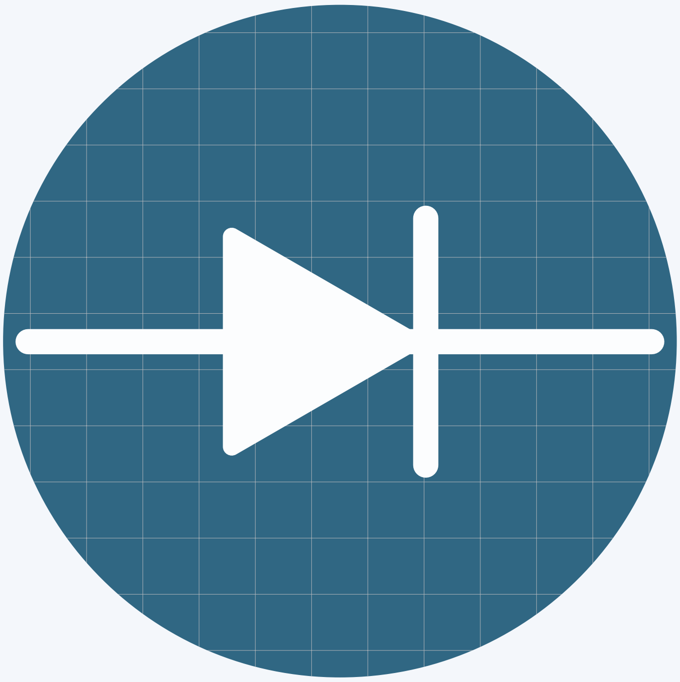
Contributed by Würth Elektronik

EMC and Efficiency Optimization of High Power DC/DC Converters



By Andreas Nadler (Würth Elektronik)

For DC/DC converters with high input and output currents, the choice of the appropriate capacitor technology, power inductors, switching frequency and semiconductors is decisive for the resulting efficiency. However, a switching regulator with high efficiency is only ready for the market if it also complies with all the necessary EMC directives, or the end product in which it is used. For this purpose, suitable filters often have to be incorporated at the input and output in order to reduce interference emissions. But with high input and output currents, it is difficult to find a compromise between efficiency, size, attenuation and cost of the filters as well as the actual power stage. Using a 100 W buck-boost DC/DC design as an example, we will describe the basic considerations, layout hints and components needed to achieve such a compromise.

To begin with, let's look at the required key data of the switching regulator. The output power of 100 W is to be implemented with an efficiency of more than 95 %. With a variable input voltage of 14 – 24 V, an output voltage of 18 V with a very low ripple of less than 20 mV_{PP} should be achieved. The design should be as compact and cost-effective as possible, while complying with all Class B guidelines according to CISPR32. No shielding of any kind is to be used, and the connecting cables at the input and output of the converter are each 1 m long. Due to these strict requirements, it is essential to create a low-inductance, compact layout and to integrate filters that are matched to the converter. Looking at EMC, the cables at the input and output are the dominant antennas in the frequency range up to 1 GHz. Since a modern 4-switch buck-boost converter has high-frequency current loops at the input as well as at the output (see **Figure 1**), depending on the operating mode, both must be provided with filters.

This is to prevent the high-frequency interference caused by fast switching operations of the MOSFETs from being conducted through the cables and also being radiated. The switching regulator used is the LT3790 from Linear Technology (Analog Devices) at a switching frequency of 400 kHz. This has an input voltage range of up to 60 V_{DC}, an adjustable switching frequency and can drive 4 external MOSFETs. This ensures a high degree of design flexibility. The printed circuit board is six-layered and double-sided. Compact 60 V CSD18532Q5B from Texas Instruments with low $R_{DS(on)}$, R_{th} and ESL package are used as MOSFETs.

Selection of the components

Selection of the inductor

With the help of the simulation software REDEXPERT the suitable inductor can be found quickly, easily and precisely (see **Figure 2**). The advantage of inductor selection with REDEXPERT is that different components are not only comparable on the basis of their obvious data (size, rated current, etc.), but can also still be compared on the basis of the complex AC & DC losses, as well as the resulting component heating. For this purpose, the operating parameters (V_{in}, f_{sw}, I_{out}, V_{out}, ΔI) must be entered first for buck, and a second time for boost operation. The current ripple should be approx. 30 % of the nominal current. Buck operation results in a larger inductance and a smaller maximum peak current (7.52 µH / 5.83 A). In boost mode, on the other hand, the inductance is smaller, but the maximum peak current is larger (4.09 µH / 7.04 A). In the present case, a shielded coil of the WE-XHMI series with 6.8 µH and 15 A rated current was selected. Due to the modern manufacturing technology, this has a very low RDC and extremely compact dimensions of only 15 x 15 x 10 mm³ (L/W/H). The innovative core material blend also allows soft and temperature-independent saturation behavior.

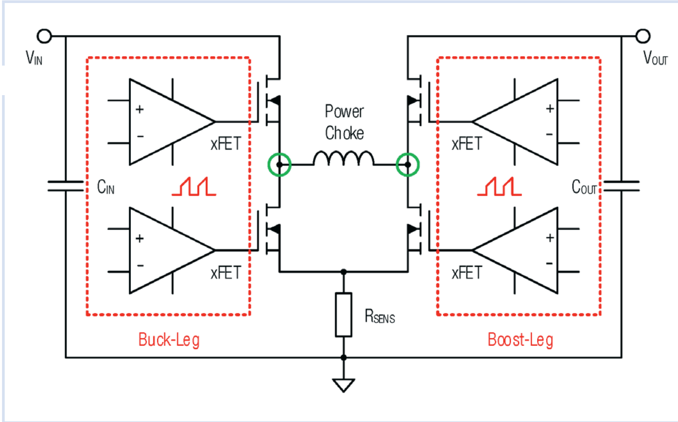


Figure 1: Circuit diagram of the high-frequency Δ_I/Δ_t loops (red) and the critical Δ_U/Δ_t switching nodes (green), depending on the operating mode of the converter.

Selection of the capacitors

Due to the high pulse currents through the blocking capacitors and the required low ripple, a combination of aluminum-polymer and ceramic capacitors is the best choice. By defining the maximum allowed voltage ripple at the input and output, the following formula can be used to calculate the required capacitances.

$$C_{in} \geq \frac{D \cdot (1 - D) \cdot I_{outmax}}{\Delta V_{in\,pp} \cdot f_{sw}} \frac{0{,}78 \cdot (1 - 0{,}78) \cdot 5{,}5A}{100\ mV_{PP} \cdot 400\ kHz} = 21 \mu F$$

In the formula, D is the duty cycle and is specified by the REDEXPERT. Six WCAP-CSGP 885012209048 with 4.7 µF / 50 V / X7R were chosen as a suitable component for the capacitor (28.2 µF). With the help of REDEXPERT, the DC bias of the MLCCs can be determined easily and quickly, resulting in a much more practical value: Due to the DC bias, a 20% lower capacitance at 24 V input voltage can be expected, thus resulting in an effective capacitance of only 23 µF, which is still sufficient. In parallel to the ceramic capacitors, a 68 µF/35 V WCAP-PSLC aluminum polymer capacitor with a 0.22 Ω SMD resistor is connected in series. This is used to maintain stability with respect to the negative input impedance of the voltage converter in combination with the input filter (more information on this topic can be found at *www.we-online.de/ANP044*). Since this capacitor is also exposed to high pulse currents, an aluminum electrolytic capacitor is less suitable

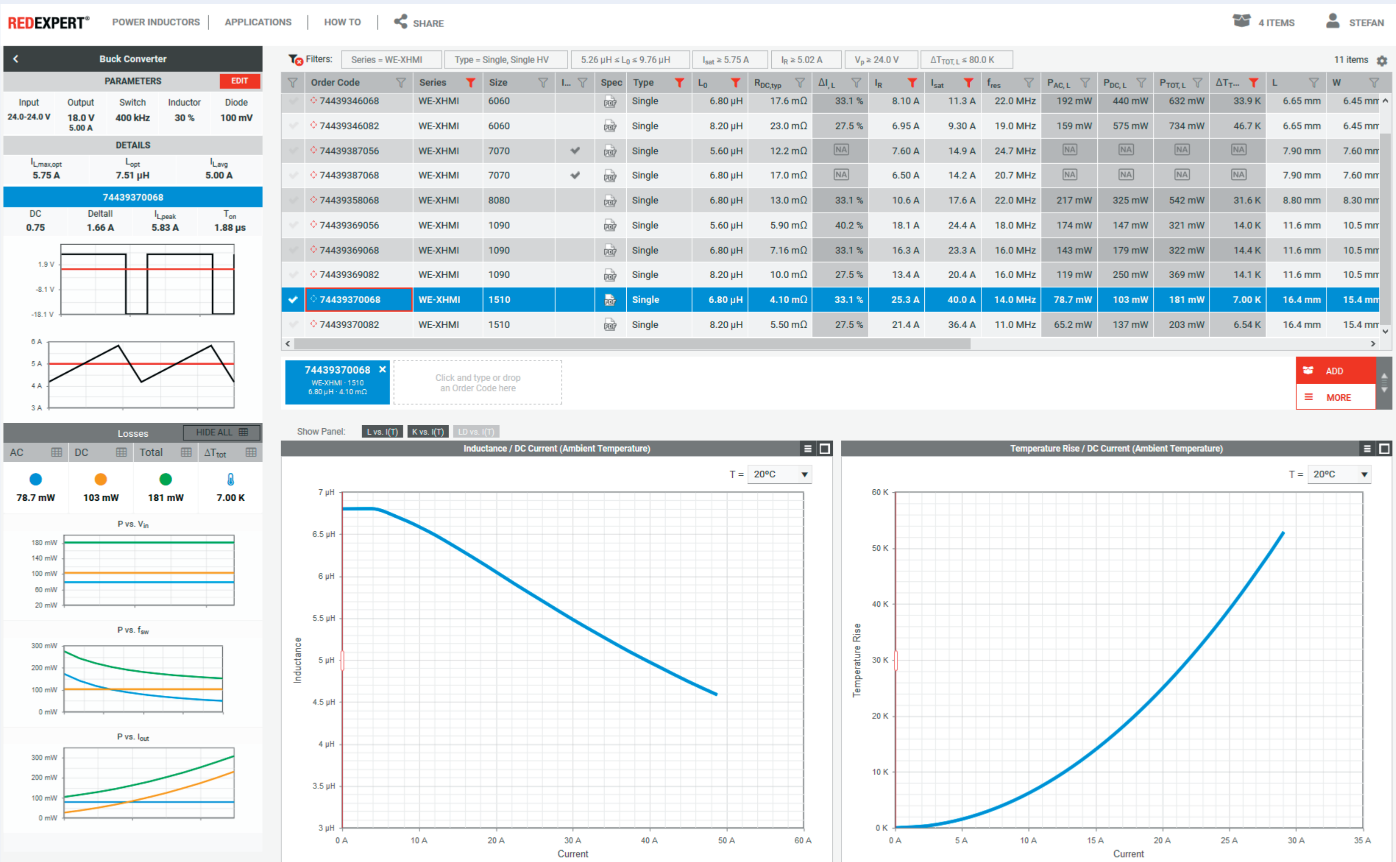


Figure 2: REDEXPERT simulation in buck operation of WE-XHMI 74439370068.

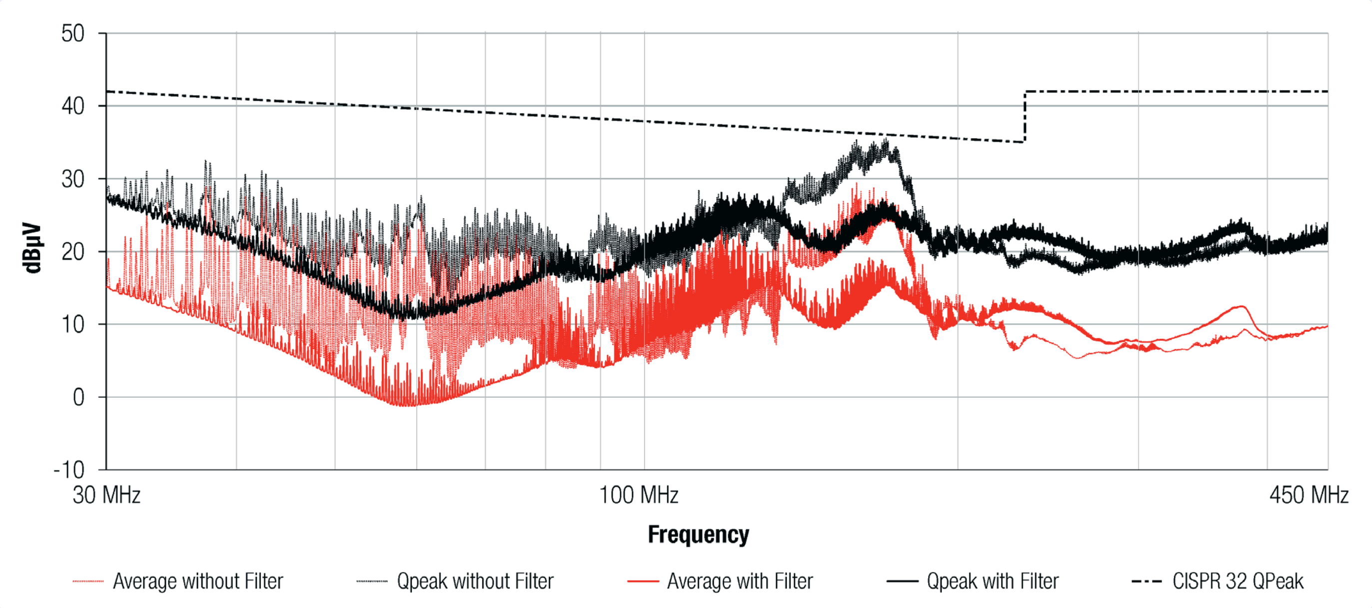


Figure 3: Radiated interference with and without the input and output filters. Interference is sufficiently within the specified limit (horizontally and vertically) across the entire measured range.

in this case, since it would heat up very much due to the higher ESR.

The output capacitance is calculated analogously:

$$C_{OUT} \geq \frac{\Delta I_{L_{BuckMode}}}{8\ V_{OUT\ ripple} \cdot f_{SW}} = \frac{1{,}66\ A}{8 \cdot 20\ mV \cdot 400\ kHz} = 25\ \mu F$$

The value for $\Delta I_{LBuckmode}$ is also specified by REDEXPERT here and six 4.7 µF capacitors are also designed in and the capacity loss is determined with REDEXPERT. The value of 24 µF (approx. 15% DC bias) is still sufficient here. In addition, an aluminum-polymer capacitor (WCAP-PSLC 220 µF / 25 V) was provided to ensure a sufficiently fast response time in case of transients.

Layout guidelines

When creating the layout, some points have to be considered. For example, the input & output loops (current loop area!), which cause a high ΔI/Δt value, should be kept very compact by locating the blocking ceramic capacitors close together. The bootstrap circuit should be compact and close to the switching regulator IC. A wideband Pi filter is necessary to decouple the internal power supply of the switching regulator, and the use of as many vias as possible is important to establish a low-inductance, low-impedance connection to the internal power GND layers and the bottom of the board. Although large copper areas in the layout provide an excellent heat sink and a low R_{DC}, they must not be unnecessarily large, especially at the two "hot" ΔU/Δt switching nodes, in order to avoid capacitive and inductive couplings to neighboring circuits.

Further layout information and a detailed analysis of the design can be found at *www.we-online.com/ANP049*.

Selection of the components of the input and output filter

The components for the filters must be carefully selected in order to achieve broadband interference suppression from 150 kHz to 300 MHz. Thus, the expected conducted and radiated EMC emission should be sufficiently attenuated. However, the filtering effort can be reduced if no, or shorter cables are used at the input or output.

In addition to insertion loss, it is particularly important for the high currents required here that the inductive components have the lowest possible R_{DC} in order to keep efficiency and self-heating within an acceptable range. Unfortunately, a low R_{DC} often also means a larger design, so it is also particularly important here to use state-of-the-art components that offer an excellent compromise between R_{DC}, impedance and size.

Particularly suitable in this case is the series WE-MPSB, as well as a compact design of the series WE-XHMI.

For capacitive filter components in the range above 10 µF, inexpensive aluminum electrolytic capacitors (such as WCAP-ASLI) can be used. If effective inductors are used in the filter area, which can greatly reduce the ripple currents already by a high impedance, a larger ESR is not problematic. A higher ESR causes a lower filter quality and thus prevents unwanted resonances.

The additional losses through the filters result from the ohmic losses of the inductors and amount to $I^2\ R_{DC} = 5.5\ A^2\ 30\ m\Omega = 907\ mW$ at the output filter and $I^2\ R_{DC} = 7\ A^2\ 18.4\ m\Omega = 902\ mW$ at the input filter.

EMC Measurements

In order to demonstrate and evaluate the filter performance, the converter was measured once without and once with filters. **Figure 3** and **4** show the result. As expected, the limit values for conducted interference cannot be complied with despite the good design without filters. In the area of radiated interference, the values are close to the limit, but no safety buffer can be guaranteed. The measurements with a filter look completely different; here, the limits were below the limit values over the entire frequency range.

Measurement of temperature and efficiency with filter at 100W P_{out} (T_a = 22 °C)

The maximum temperature was measured with a thermal imaging

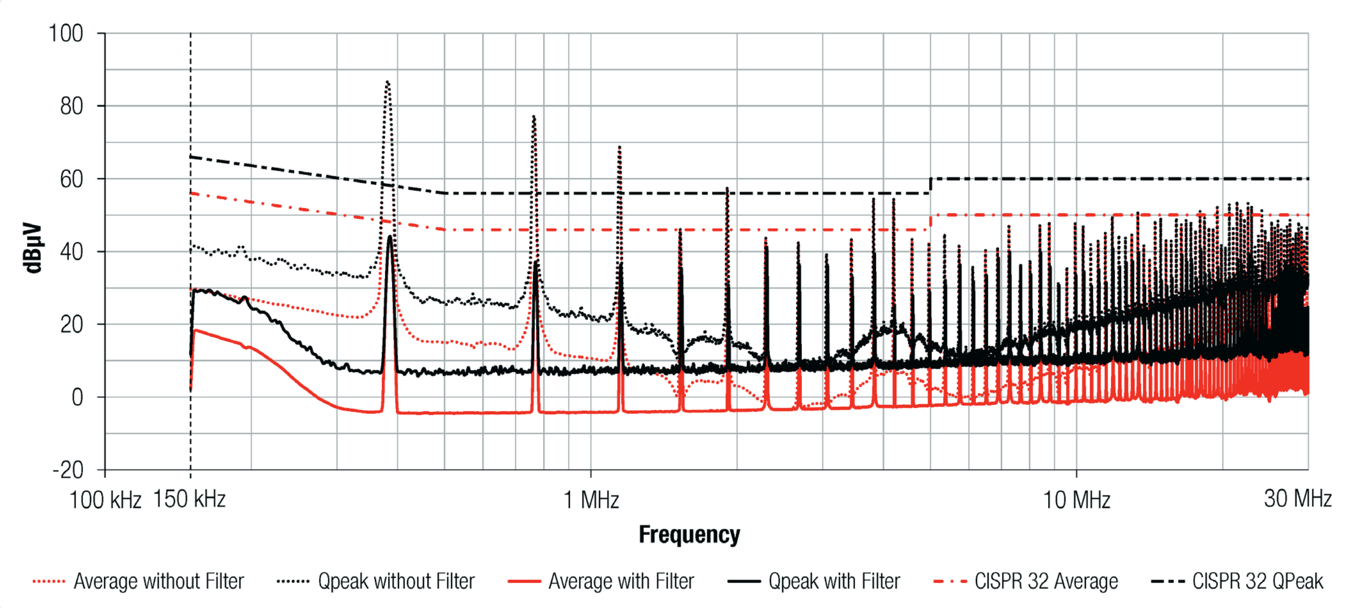


Figure 4: Conducted interference with and without the input filters. Both the average and the quasi peak interference are within the specified limits across the entire measured range.

camera and is below 64 °C, which means enough reserve for higher ambient temperatures as well as a low stress for the components. The efficiency is also at a very high level (buck mode: 96.5%; boost mode: 95.6%), especially when you consider that all components for the filters are already taken into account.

As can be seen from the results, a class B compliant DC/DC converter with the required specifications (long lines, lack of shielding, etc.) cannot be realized without suitably tuned input and output filters. For more information on the present design and details, visit *www.we-online.com/ANP049*.

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