High Power Converter – 150 W Buck-Boost in Detail

APEC 2019 in Anaheim
Capacitor Workshop PSMA

Andreas Nadler
Field Application Engineer
Short Introduction of Today‘s Presenter

Andreas Nadler
Field Application Engineer
EMC & Inductive Solutions

Background:

- Many years of experience as hardware engineer in the field of switched-mode power supplies, EMC and analogue circuit technology
- Since 2015 working as Field Application Engineer

+49 7942945 4098
andreas.nadler@we-online.com
www.we-online.com
Agenda

- What is the Purpose?
- Component Selection
- Layout Analysis & EMC Properties
- Efficiency and Temperature Measurement
- Conclusion
What is the Purpose?

- The voltage of a battery with 5 lithium ion cells in series should be regulated to stable $18 \text{ V}_\text{DC}$
- The voltage of a cell varies $\sim 3.0 \text{ V to } 4.2 \text{ V}$

\[
\begin{array}{c}
\text{DC} & \text{DC} \\
\hline
\text{V}_{\text{out}} 18 \text{ V@5 A}
\end{array}
\]

- 5 cells in series gives an input voltage range of 15 V to 21 V
- Continuous current of 5 A is required
- The DC/DC converter is to be designed for a input voltage range from 14 V to 24 V
Buck-Boost with LT3790 & external MOSFETs
Buck-Boost with LT3790 & external MOSFETs

- 6 layer PCB
- Components on TOP & BOT
Power Stage with low ESR/ESL Capacitors

Cin

$68 \mu F$

$6 \times 4.7 \mu F$

$1 \Omega$

MLCC X7R 50V

$6.8 \mu H$

$f_{sw} = 400 \text{ kHz}$

Power Choke
WE-XHMI 1510

MOSFETs
60V/100A/2.5mΩ

Cout

$6 \times 4.7 \mu F$

$220 \mu F$

Aluminum Polymer Capacitor

WCAP-CSGP

WCAP-PSLC

WCAP-PHGP
Critical $\Delta I/\Delta t$ Loops & high $\Delta V/\Delta t$ Nodes

Requirements for the design:

- Long I/O connection cables (1 m)
- No shielding possible
- Emission Limits CISPR32 Class B
- Efficiency over 95% @ 100 W
Simulation of the I/O Filter Components

30 MHz to 300 MHz

Ferrite

Coil

Coil

Ferrite

Ferrite

CMC

E-Cap

CMC

E-Cap

C µF

C µF

C µF

C µF

C nF

C nF

C nF

C nF

-120 dB

-100 dB

-80 dB

-60 dB

-40 dB

-20 dB

0 dB

20 dB

100 kHz

1 MHz

10 MHz

100 MHz

500 MHz
Simulation of the I/O Filter Components in LTspice

All components are simulated with parasitic elements:

- Losses on the output filter: $I^2 \cdot R_{dc} = 5.5 \, A^2 \cdot 30 \, m\Omega = 907 \, mW$
- Losses on the input filter: $I^2 \cdot R_{dc} = 7 \, A^2 \cdot 18.4 \, m\Omega = 902 \, mW$

![Diagram of the I/O Filter Components in LTspice](attachment:image.png)
Calculation of the input capacitors (REDEXPERT)

- Calculation of input capacitors for max. allowed AC voltage

\[
C_{\text{in}} \geq \frac{D \times (1 - D) \times I_{\text{out max}}}{\Delta V_{\text{in pp}} \times f_{\text{sw}}}
\]

\[
C_{\text{in}} \geq \frac{0.78 \times (1 - 0.78) \times 5.5 A}{100 \text{ mVpp} \times 400 \text{ kHz}} = 21 \mu F
\]

- Selected: 6 x 4.7 µF / 50 V / X7R = 28.2 µF - 20% DC-Bias = 23 µF
Calculation of the input capacitors (REDEXPERT)

<table>
<thead>
<tr>
<th>Order Code</th>
<th>Series</th>
<th>Size</th>
<th>堪称</th>
<th>Spec</th>
<th>Ty...</th>
<th>Description</th>
<th>C</th>
<th>V_R</th>
<th>R_xo</th>
<th>ESR @400 kHz</th>
<th>ΔC(V_DC=140V) @24.0 V</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>885012209048</td>
<td>WCAP-CSPG</td>
<td>1210</td>
<td>X/R</td>
<td>X/R1210475050DFT10000</td>
<td>4.70 pF</td>
<td>50.0 V</td>
<td>&gt; 20.0 Ω</td>
<td>2.53 mΩ</td>
<td>-21.8 %</td>
<td>5.0 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph 1: Impedance vs Frequency](image1)

![Graph 2: ESR vs Frequency](image2)

![Graph 3: Capacitance Change vs DC-bias Voltage](image3)
Filter Damping to fulfil Middlebrooks Criteria

- Calculation of the Aluminum Polymer Capacitor

\[ C_{damp} \sim 4 \times C_{inMLCC} = 4 \times 23 \, \mu F = 92 \, \mu F \]

- Selected: 68 \, \mu F \Rightarrow WCAP-PSLC with 35 V

- Details for DC/DC filter design, stability etc. \( \rightarrow \) Wurth Electronic AppNote ANP044
Calculation of the Output Capacitors

- Maximum coil current $\Delta I$ in Buck Mode = 1.6 A

\[
C_{OUT} \geq \frac{\Delta I_L}{8 \times V_{OUT\text{ ripple}} \times f_{SW}}
\]

\[
C_{OUT} \geq \frac{1.6 A}{8 \times 20mV \times 400 kHz} = 25 \mu F
\]

- Selected:
  - 6 x 4.7 $\mu$F / 50 V / X7R
  - 28.2 $\mu$F – 15% DC-Bias = 24 $\mu$F

- Plus:
  - Aluminum Polymer Capacitor for transient response
  - WCAP-PSLC 220 $\mu$F / 25 V
Analysis of the Layout - TOP
Analysis of the Layout - BOTTOM & Inner Layers
EMC - Conducted Emission Test

- Conducted emission 150 kHz – 30 MHz
- Buck Mode 100 W

**PASS**
EMC - Radiated Emission Test

- Radiated emission 30 MHz – 450 MHz
- Buck Mode 100 W

PASS
Temperature of the PCB & Components

<table>
<thead>
<tr>
<th>Side</th>
<th>Sp1</th>
<th>Sp2</th>
<th>Sp3</th>
<th>Sp4</th>
<th>Sp5</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP side</td>
<td>48,7</td>
<td>55,7</td>
<td>53,2</td>
<td>50,1</td>
<td>53,7</td>
</tr>
<tr>
<td>BOTTOM side</td>
<td>49,8</td>
<td>49,3</td>
<td>53,3</td>
<td>52,7</td>
<td>63,1</td>
</tr>
</tbody>
</table>

Efficiency @ 100W → Buck Mode 96,5% & Boost Mode 95,6%
Questions?