

## Buck-Boost Converter Operated in CCM

Christophe Basso - Switch Mode Power Supplies: SPICE Simulations and Practical Designs  
Second Edition - January 2014

### 1) Input data

$$V_{in} := 10 \text{ V} \quad L_1 := 17.6 \text{ } \mu\text{H} \quad T_{sw} := 10 \text{ } \mu\text{s} \quad R_{loadCCMbb} := 6 \text{ } \Omega \quad V_{outCCMbb} := 12 \text{ V}$$

### 2) Calculations

$$F_{sw} := \frac{1}{T_{sw}} = 100 \text{ kHz}$$

Beyond this load value, the converter operates in DCM:  $R_{crit} := 2 \cdot L_1 \cdot F_{sw} \cdot \left( \frac{V_{in} + V_{outCCMbb}}{V_{in}} \right)^2 = 17.037 \text{ } \Omega$

$$P_{outCCMbb} := \frac{V_{outCCMbb}^2}{R_{loadCCMbb}} = 24 \text{ W} \quad I_{outCCMbb} := \frac{V_{outCCMbb}}{R_{loadCCMbb}} = 2 \text{ A}$$

duty ratio expression:  $D_{CCMbb} := \frac{V_{outCCMbb}}{V_{in} + V_{outCCMbb}} = 0.545$

inductor ripple current:  $\Delta I_{LCCMbb} := \frac{V_{in}}{L_1} \cdot D_{CCMbb} \cdot T_{sw} = 3.099 \text{ A}$

$$\tau_L := \frac{L_1}{R_{loadCCMbb} \cdot T_{sw}} = 0.293$$

inductor peak current:  $I_{pCCMbb} := \frac{I_{outCCMbb}}{1 - D_{CCMbb}} + \frac{V_{in}}{2 \cdot L_1} \cdot D_{CCMbb} \cdot T_{sw} = 5.95 \text{ A}$

inductor valley current:  $I_{vCCMbb} := \frac{I_{outCCMbb}}{1 - D_{CCMbb}} - \frac{V_{in}}{2 \cdot L_1} \cdot D_{CCMbb} \cdot T_{sw} = 2.85 \text{ A}$

### 2.1) Inductor rms current

$$I_{LCCMbb\text{rms}} := \sqrt{\frac{(I_{vCCMbb}^2 + I_{pCCMbb}^2 + I_{pCCMbb} \cdot I_{vCCMbb})}{3}} = 4.49 \text{ A}$$

$$I_{LCCMbb\text{rms}2} := \frac{1}{L_1 \cdot (1 - D_{CCMbb})} \cdot \sqrt{\frac{D_{CCMbb}^4 \cdot T_{sw}^2 \cdot V_{in}^2 - 2 \cdot D_{CCMbb}^3 \cdot T_{sw}^2 \cdot V_{in}^2 + D_{CCMbb}^2 \cdot T_{sw}^2 \cdot V_{in}^2 + 12 \cdot I_{outCCMbb}^2 \cdot L_1^2}{12}} = 4.49 \text{ A}$$

$$I_{LCCMbb\text{rms}3} := \sqrt{\frac{\Delta I_{LCCMbb}^2}{12} + \frac{I_{outCCMbb}^2}{(1 - D_{CCMbb})^2}} = 4.49 \text{ A}$$

$$\frac{V_{outCCMbb}}{R_{loadCCMbb}} \cdot \sqrt{\frac{1}{(1 - D_{CCMbb})^2} + \frac{1}{3} \cdot \left( \frac{1}{2 \cdot \tau_L} \right)^2 \cdot (1 - D_{CCMbb})^2} = 4.49 \text{ A}$$

$$I_{LCCMbb\text{rms}4} := I_{outCCMbb} \cdot \sqrt{\frac{1}{(1-D_{CCMbb})^2} + \frac{(1-D_{CCMbb})^2 \cdot R_{loadCCMbb}^2}{12 \cdot F_{sw}^2 \cdot L_1^2}} = 4.49 \text{ A}$$

## 2.2) Switch rms current

$$I_{SWCCMbb\text{rms}1} := \sqrt{D_{CCMbb} \cdot \left( \frac{\Delta I_{LCCMbb}^2}{12} + \frac{I_{outCCMbb}^2}{(1-D_{CCMbb})^2} \right)} = 3.316 \text{ A}$$

$$I_{SWCCMbb\text{rms}2} := I_{outCCMbb} \cdot \sqrt{\frac{D_{CCMbb}}{(1-D_{CCMbb})^2} + \frac{D_{CCMbb} \cdot (1-D_{CCMbb})^2 \cdot R_{loadCCMbb}^2}{12 \cdot F_{sw}^2 \cdot L_1^2}} = 3.316 \text{ A}$$

$$\frac{V_{outCCMbb}}{R_{loadCCMbb}} \cdot \sqrt{\frac{D_{CCMbb}}{(1-D_{CCMbb})^2} + \frac{1}{3} \cdot \left( \frac{1}{2 \cdot \tau_L} \right)^2 \cdot D_{CCMbb} \cdot (1-D_{CCMbb})^2} = 3.316 \text{ A}$$

## 2.3) Diode rms current

$$I_{dCCMbb\text{rms}1} := \sqrt{(1-D_{CCMbb}) \cdot \left( \frac{\Delta I_{LCCMbb}^2}{12} + \frac{I_{outCCMbb}^2}{(1-D_{CCMbb})^2} \right)} = 3.027 \text{ A}$$

$$\frac{V_{outCCMbb}}{R_{loadCCMbb}} \cdot \sqrt{\frac{1}{(1-D_{CCMbb})} + \frac{1}{3} \cdot \left( \frac{1}{2 \cdot \tau_L} \right)^2 \cdot (1-D_{CCMbb})^3} = 3.027 \text{ A}$$

$$I_{dCCMbb\text{rms}2} := I_{outCCMbb} \cdot \sqrt{\frac{1}{(1-D_{CCMbb})} + \frac{(1-D_{CCMbb})^3 \cdot R_{loadCCMbb}^2}{12 \cdot F_{sw}^2 \cdot L_1^2}} = 3.027 \text{ A}$$

## 2.4) Output capacitor rms current

$$I_{Coutb\text{rms}1} := \sqrt{(1-D_{CCMbb}) \cdot \left( \frac{\Delta I_{LCCMbb}^2}{12} + \frac{I_{outCCMbb}^2}{(1-D_{CCMbb})^2} \right) - I_{outCCMbb}^2} = 2.272 \text{ A}$$

$$I_{Coutb\text{rms}2} := I_{outCCMbb} \cdot \sqrt{\frac{D_{CCMbb}}{(1-D_{CCMbb})} + \frac{(1-D_{CCMbb})^3 \cdot R_{loadCCMbb}^2}{12 \cdot F_{sw}^2 \cdot L_1^2}} = 2.272 \text{ A}$$

$$I_{Coutb\text{rms}3} := I_{outCCMbb} \cdot \sqrt{\frac{D_{CCMbb}}{(1-D_{CCMbb})} + \frac{1}{3} \cdot \left( \frac{1}{2 \cdot \tau_L} \right)^2 \cdot (1-D_{CCMbb})^3} = 2.272 \text{ A}$$

## 2.5) Input capacitor rms current

$$I_{CinbbDCMRMS3} := \sqrt{I_{SWCCMbb\text{rms}1}^2 - \left( \frac{V_{outCCMbb}}{V_{in}} \cdot I_{outCCMbb} \right)^2} = 2.288 \text{ A}$$

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### 3) Input data

$$V_{in} := 10 \text{ V} \quad L_1 := 5 \text{ } \mu\text{H} \quad T_{sw} := 10 \text{ } \mu\text{s} \quad R_{loadbbDCM} := 6 \text{ } \Omega \quad V_{outbbDCM} := 12 \text{ V}$$

### 4) Calculations

$$P_{outbbDCM} := \frac{V_{outbbDCM}^2}{R_{loadbbDCM}} = 24 \text{ W}$$

$$I_{outbbDCM} := \frac{P_{outbbDCM}}{V_{outbbDCM}} = 2 \text{ A}$$

Below this load value, the converter operates in CCM:  $R_{crit} := 2 \cdot L_1 \cdot F_{sw} \cdot \left( \frac{V_{in} + V_{outbbDCM}}{V_{in}} \right)^2 = 4.84 \text{ } \Omega$

$$\tau_L := \frac{L_1}{R_{loadbbDCM} \cdot T_{sw}} = 0.083$$

$$D_{1bbDCM} := \sqrt{\frac{L_1 \cdot 2 \cdot P_{outbbDCM}}{T_{sw}}} \cdot \frac{1}{V_{in}} = 0.49$$

$$D_{2bbDCM} := \sqrt{\frac{L_1 \cdot 2 \cdot P_{outbbDCM}}{T_{sw}}} \cdot \frac{1}{V_{outbbDCM}} = 0.408$$

$$D_{3bbDCM} := 1 - D_{1bbDCM} - D_{2bbDCM} = 0.102$$

$$\text{inductor peak current: } I_{pbbDCM} := \frac{V_{in}}{L_1} \cdot D_{1bbDCM} \cdot T_{sw} = 9.798 \text{ A} \text{ or } \sqrt{\frac{2 \cdot P_{outbbDCM}}{L_1 \cdot F_{sw}}} = 9.798 \text{ A}$$

$$\text{Average inductor current: } I_{LavgbbDCM} := I_{outbbDCM} \cdot \frac{V_{in} + V_{outbbDCM}}{V_{in}} = 4.4 \text{ A}$$

#### 4.1) Inductor rms current

$$I_{LbbDCMrms1} := I_{pbbDCM} \cdot \sqrt{\frac{1 - D_{3bbDCM}}{3}} = 5.361 \text{ A}$$

$$I_{LbbDCMrms2} := \frac{V_{in} \cdot D_{1bbDCM} \cdot T_{sw}}{L_1} \cdot \sqrt{\frac{(V_{in} + V_{outbbDCM}) \cdot D_{1bbDCM}}{3 \cdot V_{outbbDCM}}} = 5.361 \text{ A}$$

$$I_{LLDCMrms3} := I_{outbbDCM} \cdot \sqrt{\frac{2 \cdot D_{1bbDCM} \cdot R_{loadbbDCM}}{3 \cdot F_{sw} \cdot L_1} + \frac{8 \cdot R_{loadbbDCM}}{9 \cdot F_{sw} \cdot L_1}} = 5.361 \text{ A}$$

$$I_{LLDCMrms4} := I_{outbbDCM} \cdot \sqrt{\frac{2 \cdot D_{1bbDCM}}{3 \cdot \tau_L} + \frac{8}{9 \cdot \tau_L}} = 5.361 \text{ A}$$

#### 4.2) Switch rms current

$$I_{SWbbDCMrms1} := I_{pbbDCM} \cdot \sqrt{\frac{D_{1bbDCM}}{3}} = 3.959 \text{ A}$$

$$I_{SWbbDCMrms2} := I_{outbbDCM} \cdot \sqrt{\frac{2 \cdot D_{1bbDCM} \cdot R_{loadbbDCM}}{3 \cdot F_{sw} \cdot L_1}} = 3.959 \text{ A}$$

$$I_{SWbbDCMrms4} := I_{outbbDCM} \cdot \sqrt{\frac{2 \cdot D_{1bbDCM}}{3 \cdot \tau_L}} = 3.959 \text{ A}$$

$$I_{SWbbDCMrms3} := I_{LbbDCMrms} \cdot \sqrt{\frac{D_{1bbDCM}}{1 - D_{3bbDCM}}} = 3.959 \text{ A}$$

$$I_{SWbbDCMrms5} := \frac{V_{in} \cdot D_{1bbDCM} \cdot T_{sw}}{L_1} \cdot \sqrt{\frac{(V_{in} + V_{outbbDCM})}{3 \cdot V_{outbbDCM}} \cdot \frac{1}{1 - D_{3bbDCM}}} = 3.959 \text{ A}$$

### 4.3) Diode rms current

$$I_{dcbDCMrms1} := \frac{V_{in} \cdot D_{1bbDCM} \cdot T_{sw}}{L_1} \cdot \sqrt{\frac{D_{1bbDCM} \cdot (V_{in} + V_{outbbDCM})}{3 \cdot V_{outbbDCM}} \cdot \frac{D_{2bbDCM}}{1 - D_{3bbDCM}}} = 3.614 \text{ A}$$

$$I_{outbbDCM} \cdot \sqrt{\sqrt{\frac{8 \cdot R_{loadbbDCM}}{9 \cdot F_{sw} \cdot L_1}}} = 3.614 \text{ A}$$

$$I_{outbbDCM} \cdot \sqrt{\sqrt{\frac{8}{9 \cdot \tau_L}}} = 3.614 \text{ A} \quad I_{outbbDCM} \cdot \left(\frac{8}{9 \cdot \tau_L}\right)^{\frac{1}{4}} = 3.614 \text{ A}$$

### 4.4) Output Capacitor rms current

$$I_{CoutbbDCMRMS} := \sqrt{I_{pbbDCM}^2 \cdot \left(\frac{D_{1bbDCM} \cdot (V_{in} + V_{outbbDCM})}{3 \cdot V_{outbbDCM}} \cdot \frac{D_{2bbDCM}}{1 - D_{3bbDCM}}\right) - I_{outbbDCM}^2} = 3.011 \text{ A}$$

$$I_{CoutbbDCMRMS2} := I_{outbbDCM} \cdot \sqrt{\sqrt{\frac{8 \cdot R_{loadbbDCM}}{9 \cdot F_{sw} \cdot L_1}} - 1} = 3.011 \text{ A}$$

$$I_{CoutbbDCMRMS3} := I_{outbbDCM} \cdot \sqrt{\sqrt{\frac{8}{9 \cdot \tau_L}} - 1} = 3.011 \text{ A}$$

### 4.5) Input Capacitor rms current

$$I_{CinbbDCMRMS3} := \sqrt{I_{SWbbDCMrms1}^2 - \left(\frac{V_{outbbDCM}}{V_{in}} \cdot I_{outbbDCM}\right)^2} = 3.149 \text{ A}$$