Buck-Boost Converter (`PE_buck_boost_5.sqproj`)

Question: A buck boost converter operating at 20 kHz is shown in Fig.1. The output capacitor C is sufficiently large to ensure a ripple-free output voltage. The input voltage V_{in} is 15 V. The converter is supplying a load of 10 W. If the output voltage is required to be 10 V, find the duty ratio (D) of the switch.

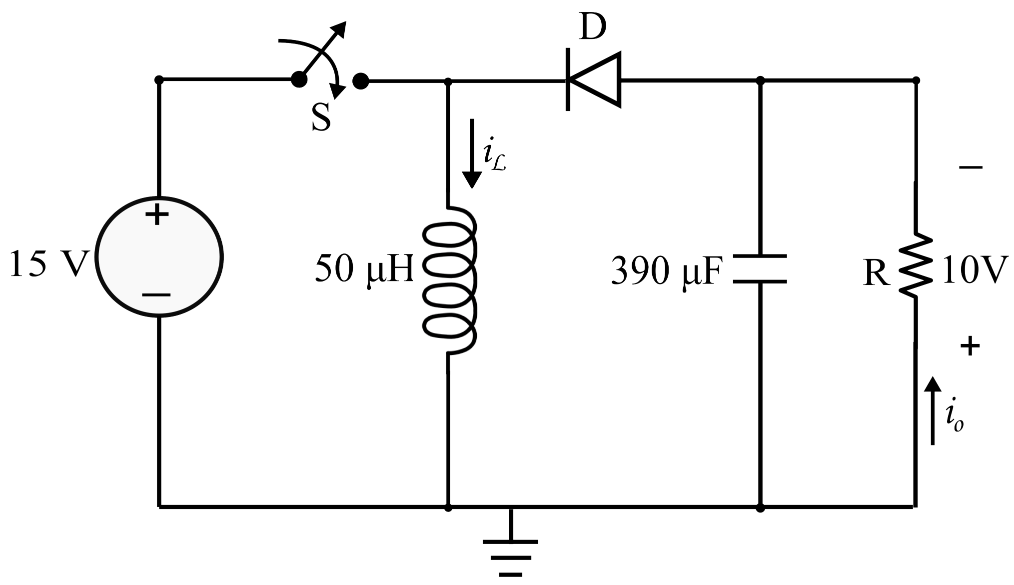

Figure 1: Buck-Boost converter

Solution :

Assume that the inductor current is continuous as shown in Fig. 2.

Applying the volt-sec balance equation, $V_o = V_{in}\left(\dfrac{D}{1-D}\right) \implies D = 0.4.$

Applying the amp-sec balance equation, $I_L^{\text{avg}} = \dfrac{I_o}{1-D}$

$$P_o = V_o I_o \implies I_o = 1\,\text{A} \qquad ; \qquad \therefore\, I_L^{\text{avg}} = \frac{I_o}{1-D} = 1.67\text{A}$$

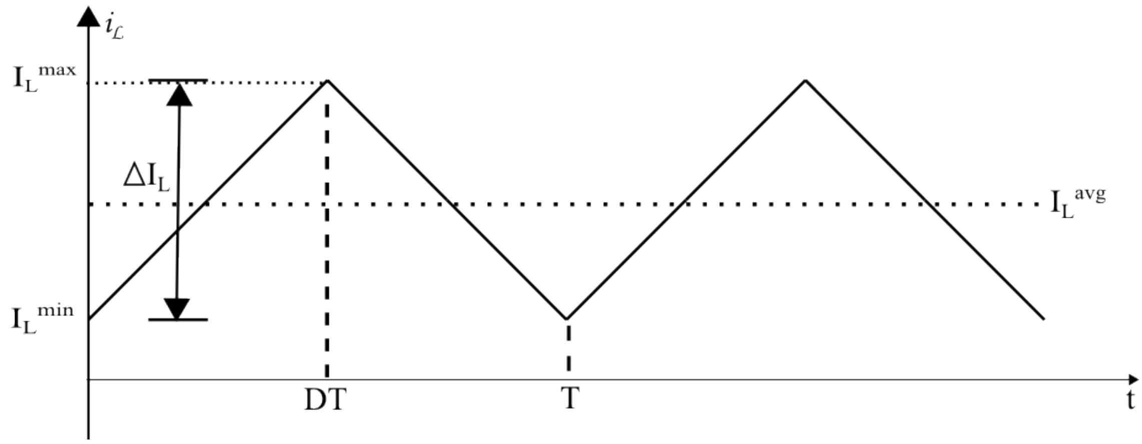

Figure 2: Inductor current waveform for continuous conduction

From Fig. 2, we can see that the peak-to-peak ripple inductor current is

$$\Delta I_L = I_L^{\text{max}} - I_L^{\text{min}}$$

At $0 < t < DT$, $\qquad i_L(t) = \dfrac{V_{in} \times t}{L} + I_L^{min}$

At $t = DT$, $\qquad i_L(t) = I_L^{\text{max}}$

$$\therefore\, I_L^{\text{max}} = \frac{V_{in}\, DT}{L} + I_L^{\text{min}}$$

$$\boxed{\Delta I_L = \frac{V_{in}\, D}{L\, f}}$$

$$\therefore\, \Delta I_L = \frac{15 \times 0.4}{(50 \times 10^{-6}) \times (20 \times 10^{3})} = 6\,\text{A}$$

When the inductor current is continuous, $I_L^{\text{avg}} > \dfrac{\Delta I_L}{2}$, where I_L^{avg} is the average inductor current and ΔI_L is the peak-to-peak ripple inductor current.

From the above calculations, $I_L^{\text{avg}} < \dfrac{\Delta I_L}{2}$, i.e., inductor current is discontinuous and hence our assumption is wrong.

Figs. 3 (a) and 3 (b) show ON and OFF conditions of switch S, respectively.

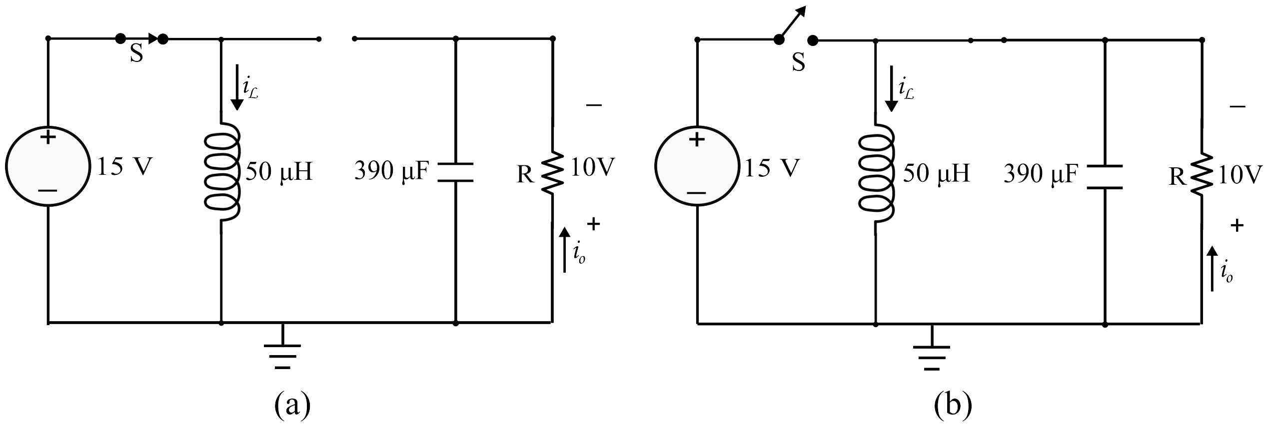

Figure 3: Buck-Boost converter circuit. (a) switch is ON, (b) switch is OFF and i_L is non-zero

The circuit is operating under steady state, i.e., the energy stored in the inductor during the ON interval should be released during the OFF interval. Since the inductor current is discontinuous, the inductor releases the complete stored energy before starting the next cycle .

Operation: When the switch is ON ($0 < t < DT$), the diode is reverse biased and the inductor stores energy. When the switch is OFF and the inductor is releasing energy ($DT < t < \beta T$), the diode is forward biased. When the inductor current is zero ($\beta T < t < T$), the diode is again reverse biased.

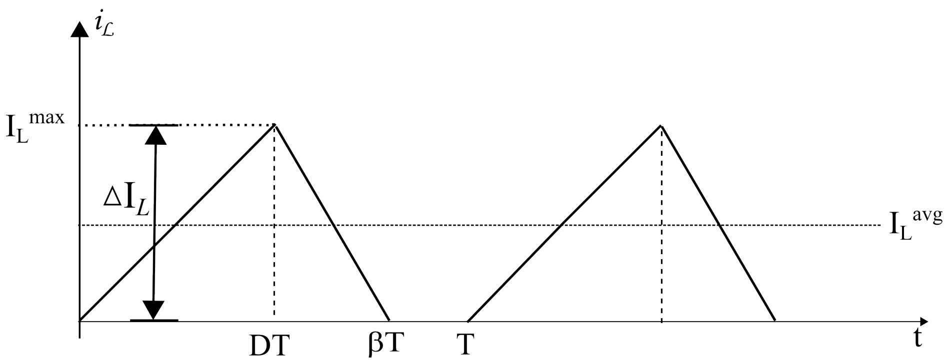

Figure 4: Inductor current waveform for discontinuous conduction

For loss less conversion, $V_o I_o = V_{in} I_{in}$ $\therefore I_{in} = \dfrac{V_o I_o}{V_{in}} = 0.67\text{A}$

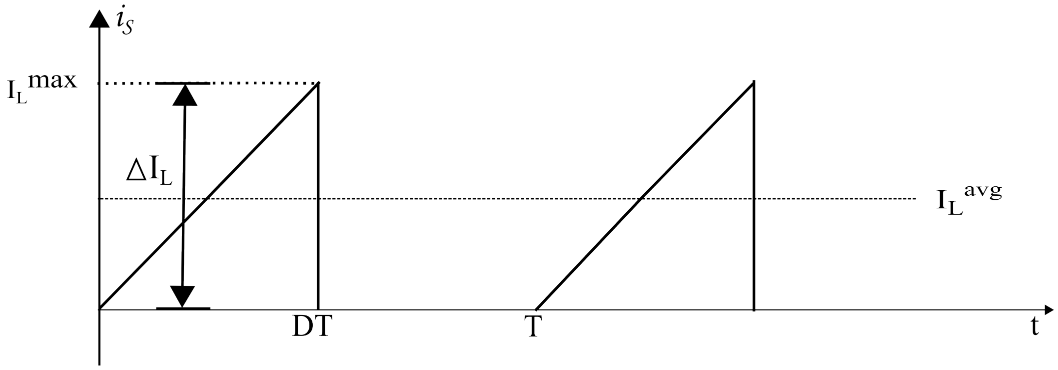

Figure 5: Source current waveform

$$\begin{aligned}\text{From Fig. 5,}\quad I_{in} &= \frac{1}{T}\cdot\int_0^T i_s\,dt = \frac{1}{T}\cdot\int_0^{DT} i_s\,dt \\ &= \frac{1}{T}\Big(\frac{1}{2}DT\,.\,I_L^{\max}\Big) = \frac{D}{2}\,I_L^{\max} \qquad \therefore\; I_L^{\max} = \frac{4}{3D}\end{aligned}$$

From Fig. 4, we can see that the peak-to-peak ripple inductor current is

$$\Delta I_L = I_L^{\max} - I_L^{\min}$$

For $0 < t < DT$, $\quad i_L(t) = \dfrac{V_{in}\,t}{L} + I_L^{min}$

At $t = DT$, $\quad i_L(t) = I_L^{\max}$

$$\therefore\; I_L^{\max} = \frac{V_{in}\,DT}{L} + I_L^{\min}$$

$I_L^{\min}$ is zero for discontinuous conduction.

$$\boxed{\therefore I_L^{\max} = \Delta I_L = \frac{V_{in}\,D}{L\,f}}$$

$$\therefore\; \frac{15\times 0.4}{(50\times 10^{-6})\times(50\times 10^{-6})} = \frac{4}{3D} \qquad \Longrightarrow \qquad D = 0.3$$

SequelApp Exercises:

(1) In a buck-boost converter, the switching frequency is 20 kHz. The input and output voltages are 20 V and 50 V, respectively. If the average source current is 10 A and peak-to-peak inductor current is 30A, find the value of inductance and load resistance.

Verify your answer using SequelApp.