EE 238

Power Engineering – II

Power Electronics

Lecture 9

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STEP-DOWN (BUCK) CONVERTER

Depending on application, either V_d or V_0 remains constant.

Discontinuous-Conduction Mode with Constant *Vd*

In many applications (e.g., dc motor speed control), V_d remains constant and V_0 is controlled by adjusting *D*.

At the edge, $I_{LB} = \frac{DT_s}{2L}(V_d - V_o) = I_{oB}$

Since $V_0 = DV_d$, $I_{LB} = \frac{T_s V_d}{2L} D(1 - D)$

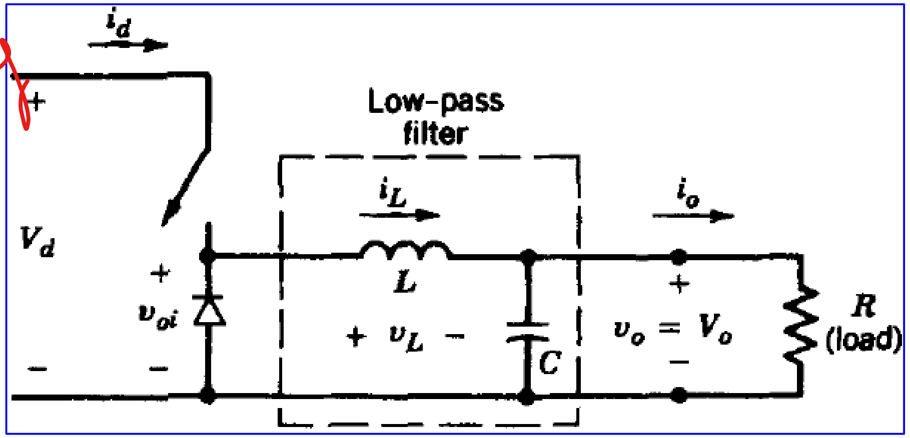
B: Boundary

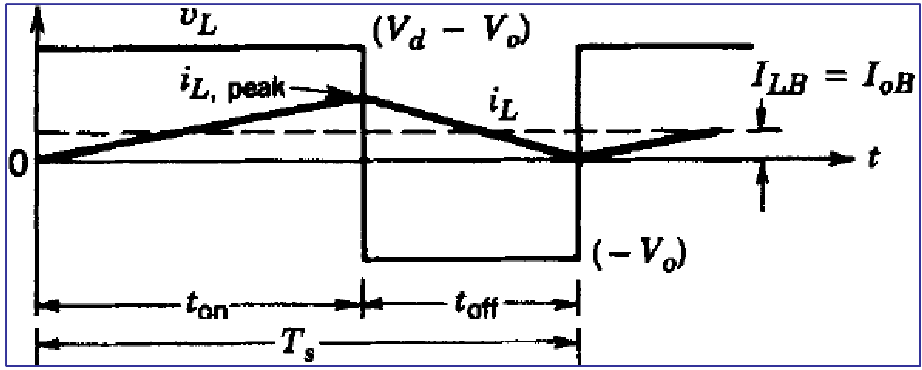
Output current required for CCM is maximum at D = 0.5:

$I_{LB,\max} = \frac{T_s V_d}{8L}$ => $I_{LB} = 4I_{LB,\max} D(1 - D)$

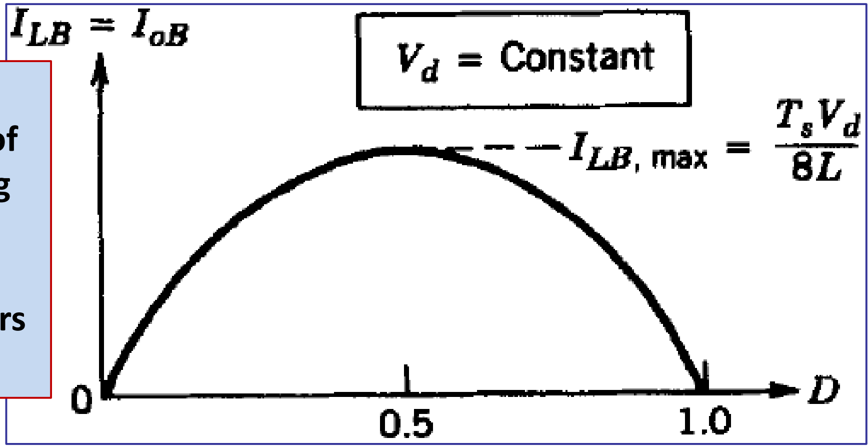
Assuming the converter is operating at the edge for given values of Ts L, *Vd* , and *D.* If these are kept constant and the output load power is decreased (i.e., the load resistance goes up), then the average inductor current will decrease.

Discontinuous-Conduction Mode





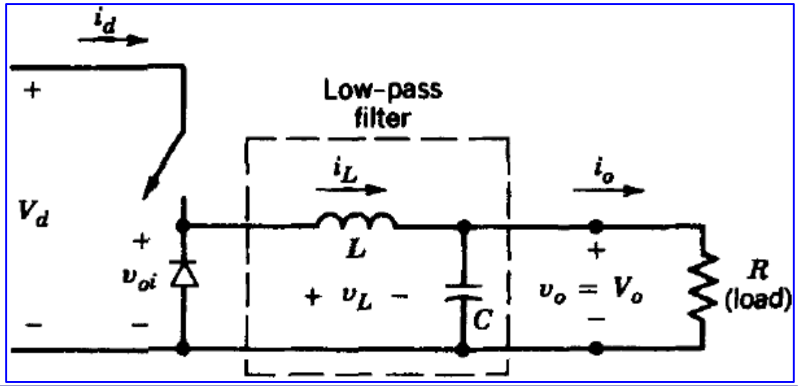
I_{LB} as a function of *D*, keeping V_d and all other parameters constant.



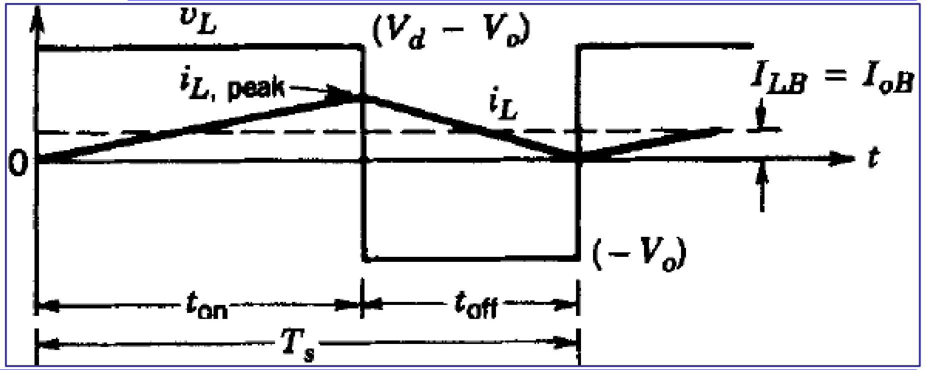
STEP-DOWN (BUCK) CONVERTER

Discontinuous-Conduction Mode

Assumption: converter is operating at the edge for given values of T, L, *Vd* , and *D,* which are kept constant
The output load power is decreased (i.e., the load resistance goes up), then the average inductor current will decrease.



During $\Delta_2 T_s$, power to R is supplied by C alone and *vL* is zero.



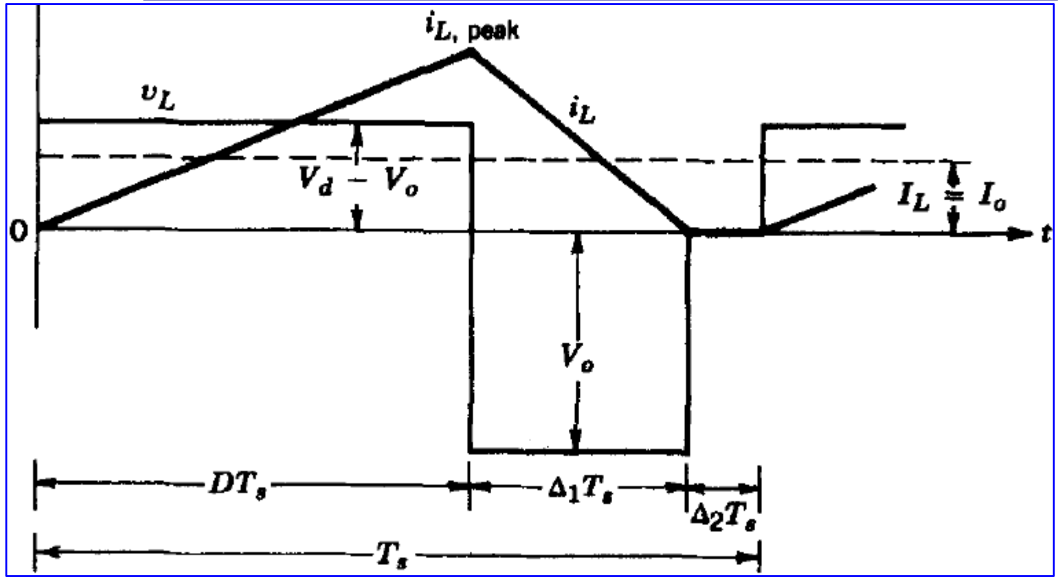
Again, equating the integral of *vL* over one time period to zero yields:

$$(V_d - V_o)\,DT_s + (-V_o)\Delta_1 T_s = 0$$

$$\therefore \frac{V_o}{V_d} = \frac{D}{D + \Delta_1}$$

where $D + \Delta_1 < 1.0$.

Hence, for same D, V_0 in DCM > V_0 in CCM.



STEP-DOWN (BUCK) CONVERTER

Discontinuous-Conduction Mode

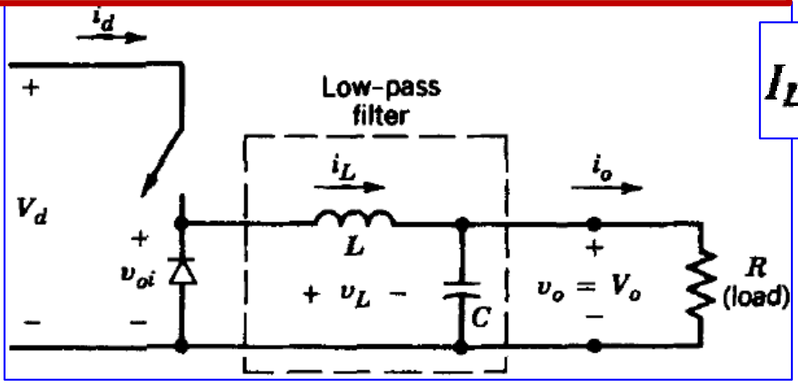
$$-v_0 = L\frac{di_L}{dt} \Rightarrow L\int_{i_{Lpeak}}^{0} di_L = -V_0\int_0^{\Delta_1 T_s} dt$$

$$\Rightarrow i_{Lpeak} = \frac{V_0}{L}\Delta_1 T_s$$

$$\therefore \frac{V_o}{V_d} = \frac{D}{D+\Delta_1}$$

$$I_o = i_{L,\text{peak}}\frac{D+\Delta_1}{2} = \frac{V_o T_s}{2L}(D+\Delta_1)\,\Delta_1$$

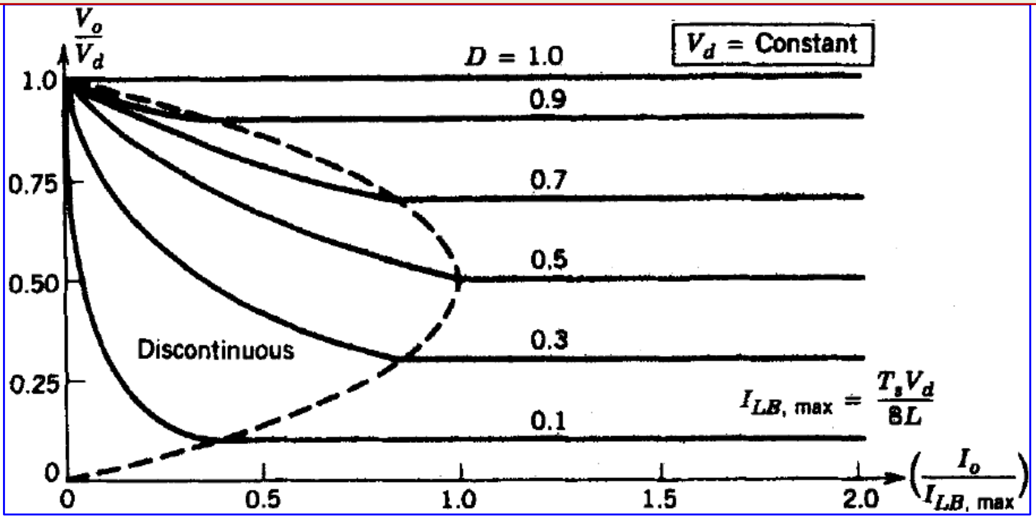
$$= \frac{V_d T_s}{2L}D\Delta_1 = 4I_{LB,\max}D\Delta_1 \quad \therefore \Delta_1 = \frac{I_o}{4I_{LB,\max}D}$$

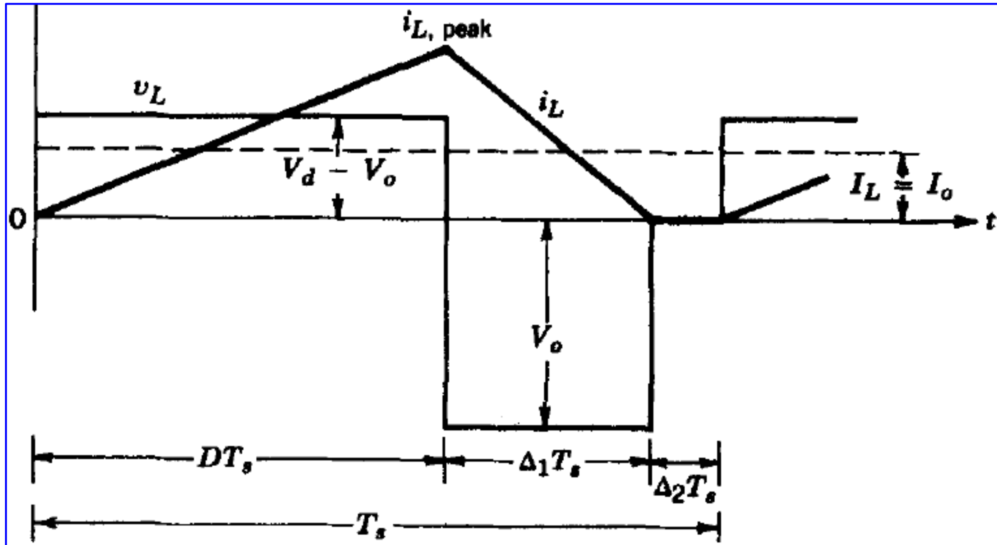


$$I_{LB,\max} = \frac{T_s V_d}{8L}$$

$$\therefore \frac{V_o}{V_d} = \frac{D}{D+\Delta_1} = \frac{D^2}{D^2 + \frac{1}{4}(I_o/I_{LB,\max})}$$

The step-down converter characteristic in both modes of operation for a constant *Vd. V0/Vd* is plotted as a function of *I0/ILBmax* for various values of *D*. The boundary between CCM and DCM is shown by the dashed curve.





Discontinuous-Conduction Mode with Constant V_0

In applications (e.g., regulated dc power supplies), V_d may fluctuate but V_0 is kept constant by adjusting D.

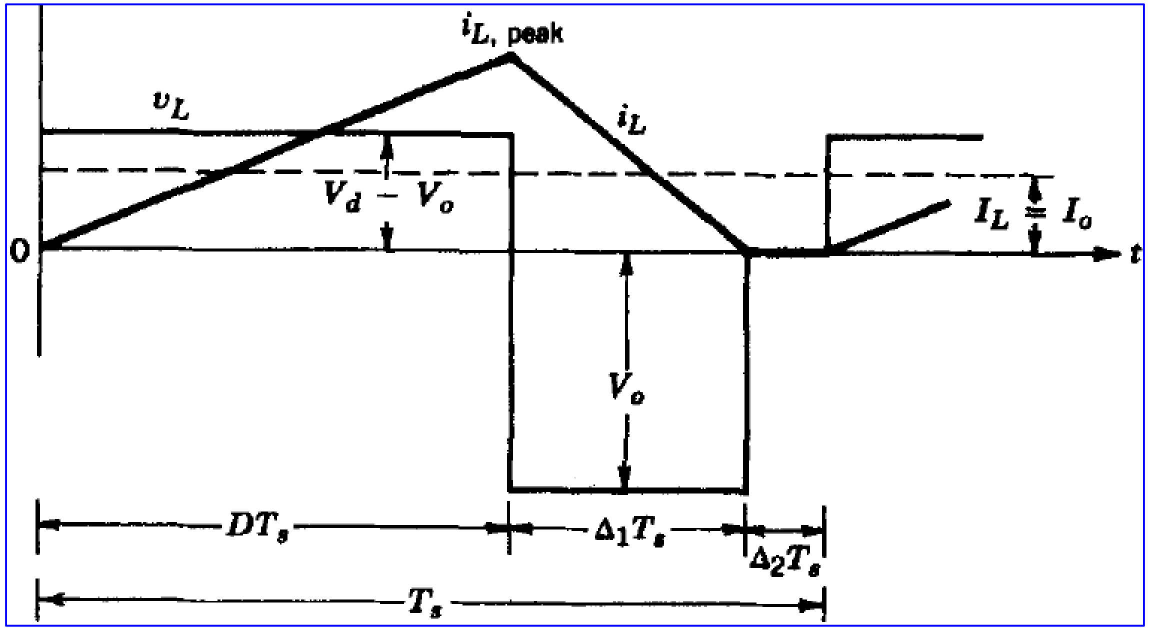
At the boundary, the average inductor current is $I_{LB} = \frac{1}{2} i_{L,\text{peak}} = \frac{t_{\text{on}}}{2L}(V_d - V_o) = \frac{DT_s}{2L}(V_d - V_o) = I_{oB}$

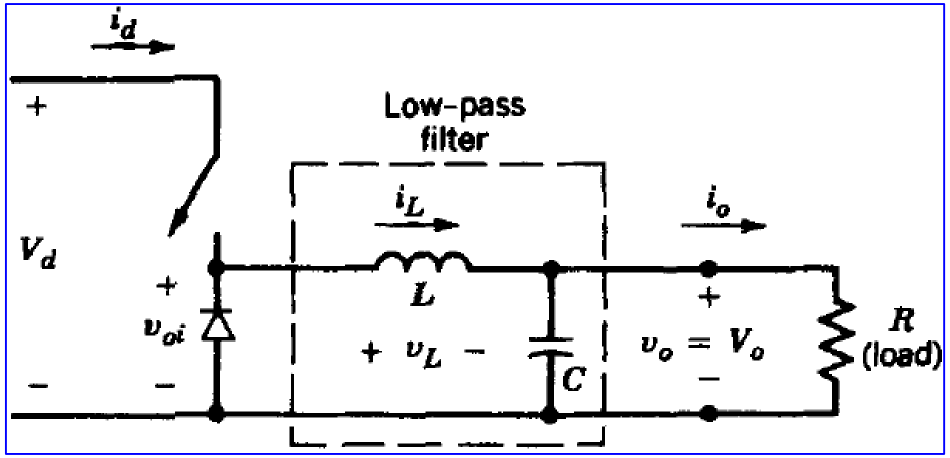
Since $V_d = V_o/D$, $I_{LB} = \frac{T_s V_o}{2L}(1 - D)$

For constant Vo, the maximum I_{LB} occurs at $D = 0$: $I_{LB,\max} = \frac{T_s V_o}{2L}$

It should be noted that the operation corresponding to D = 0 and a finite V_0 is, of course, hypothetical because it would require V_d to be infinite.

$$I_{LB} = (1 - D) I_{LB,\max}$$

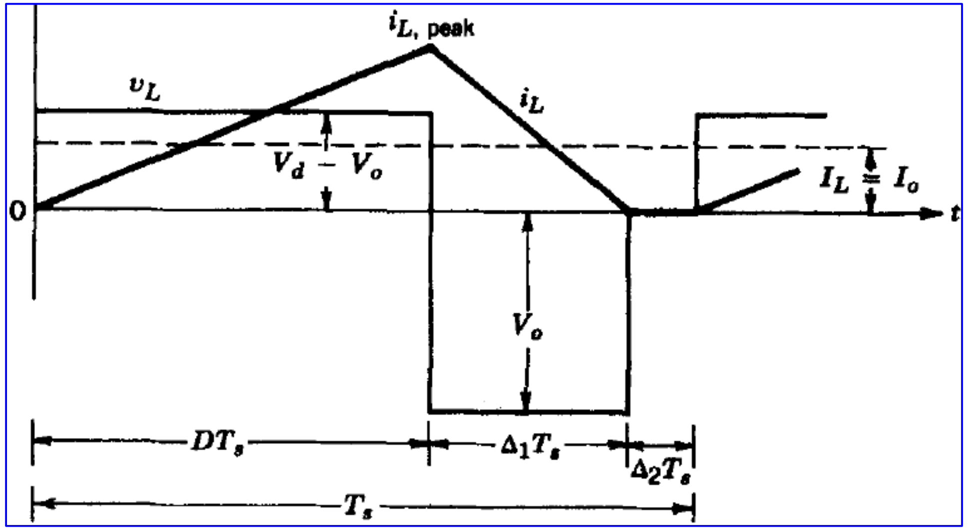




Discontinuous-Conduction Mode with Constant V_0

$$I_{LB} = (1 - D) I_{LB,\max}$$

For the converter operation where *V0* is kept constant, it will be useful to obtain the required D as a function of *I0/ILBmax.*

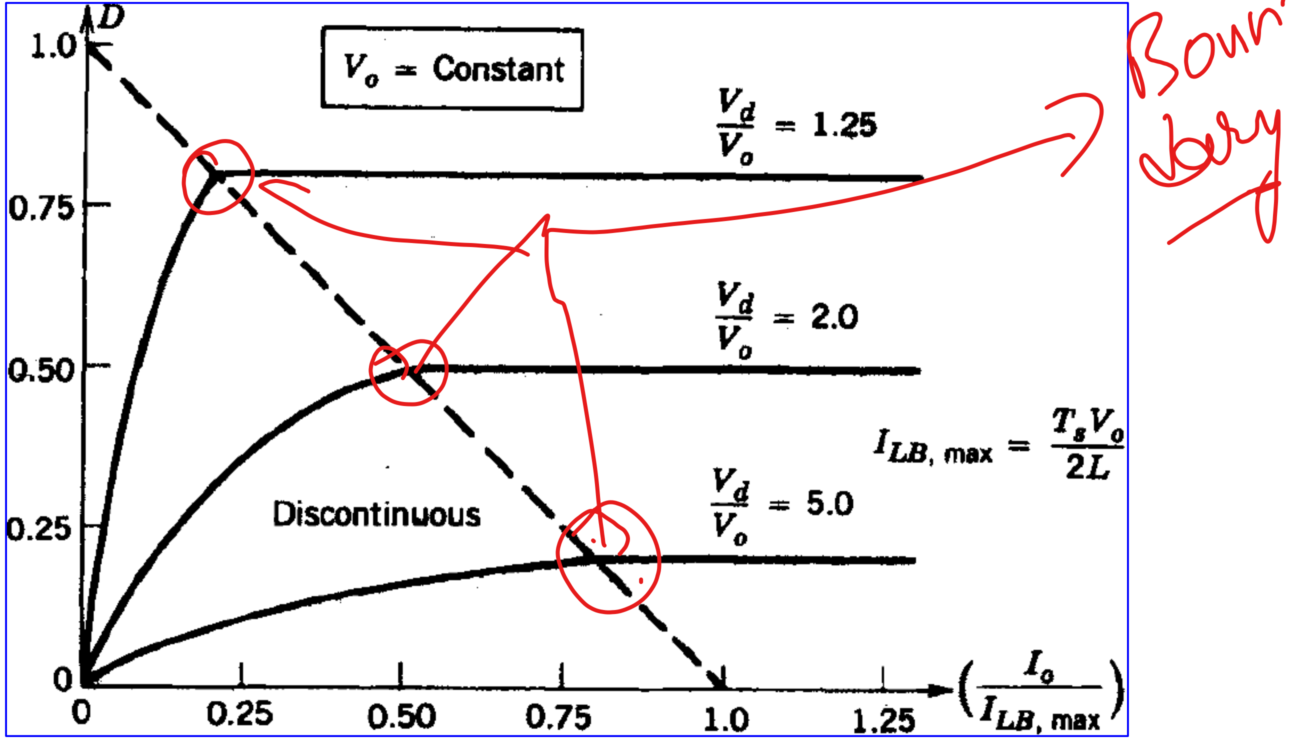


Using $I_{LB,\max} = \dfrac{T_s V_o}{2L}$ $\quad \therefore \dfrac{V_o}{V_d} = \dfrac{D}{D + \Delta_1}$

$$I_o = i_{L,\text{peak}} \frac{D + \Delta_1}{2} = \frac{V_o T_s}{2L}(D + \Delta_1)\,\Delta_1$$

$$I_{LB} = (1 - D) I_{LB,\max}$$

$$\Rightarrow D = \frac{V_o}{V_d}\left(\frac{I_o / I_{LB,\max}}{1 - V_o/V_d}\right)^{1/2}$$



STEP-DOWN (BUCK) CONVERTER

With a practical C, v_0 will have ripples.

Assume CCM.

Assuming that all of the ripple component in iL flows through C and its average component flows through R.

The shaded area represents an additional charge ΔQ. Therefore, the peak-to-peak voltage ripple ΔV0 can be expressed as:

$$\Delta V_o = \frac{\Delta Q}{C} = \frac{1}{C}\frac{1}{2}\frac{\Delta I_L}{2}\frac{T_s}{2}$$

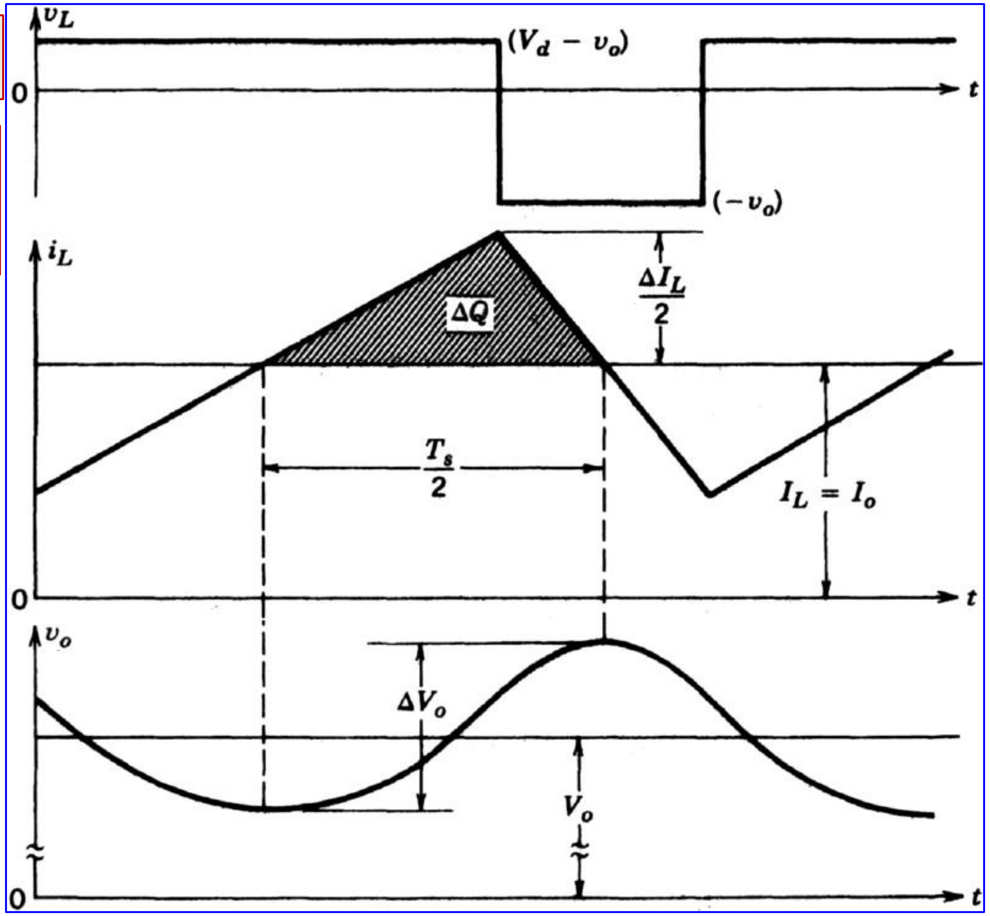
During turn OFF, $\Delta I_L = \frac{V_o}{L}(1 - D)T_s$

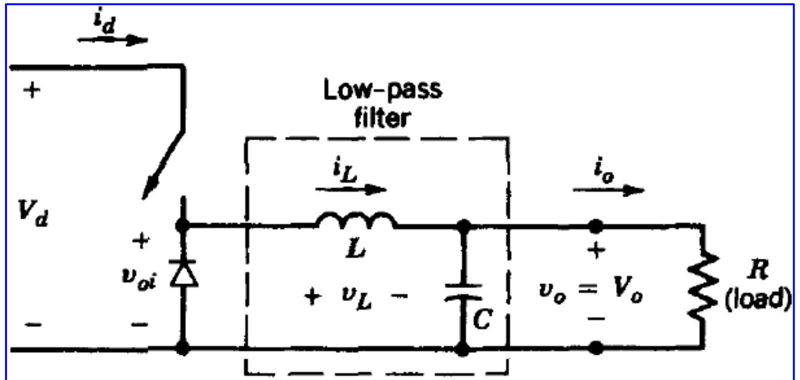
Therefore, $\Delta V_o = \frac{T_s}{8C}\frac{V_o}{L}(1 - D)T_s$

$$\therefore \frac{\Delta V_o}{V_o} = \frac{1}{8}\frac{T_s^2(1 - D)}{LC} = \frac{\pi^2}{2}(1 - D)\left(\frac{f_c}{f_s}\right)^2$$

where $f_s = 1/T_s$ and $f_c = \frac{1}{2\pi\sqrt{LC}}$

Output Voltage Ripple





STEP-DOWN (BUCK) CONVERTER

$$\therefore \frac{\Delta V_o}{V_o} = \frac{1}{8}\frac{T_s^2(1-D)}{LC} = \frac{\pi^2}{2}(1-D)\left(\frac{f_c}{f_s}\right)^2$$

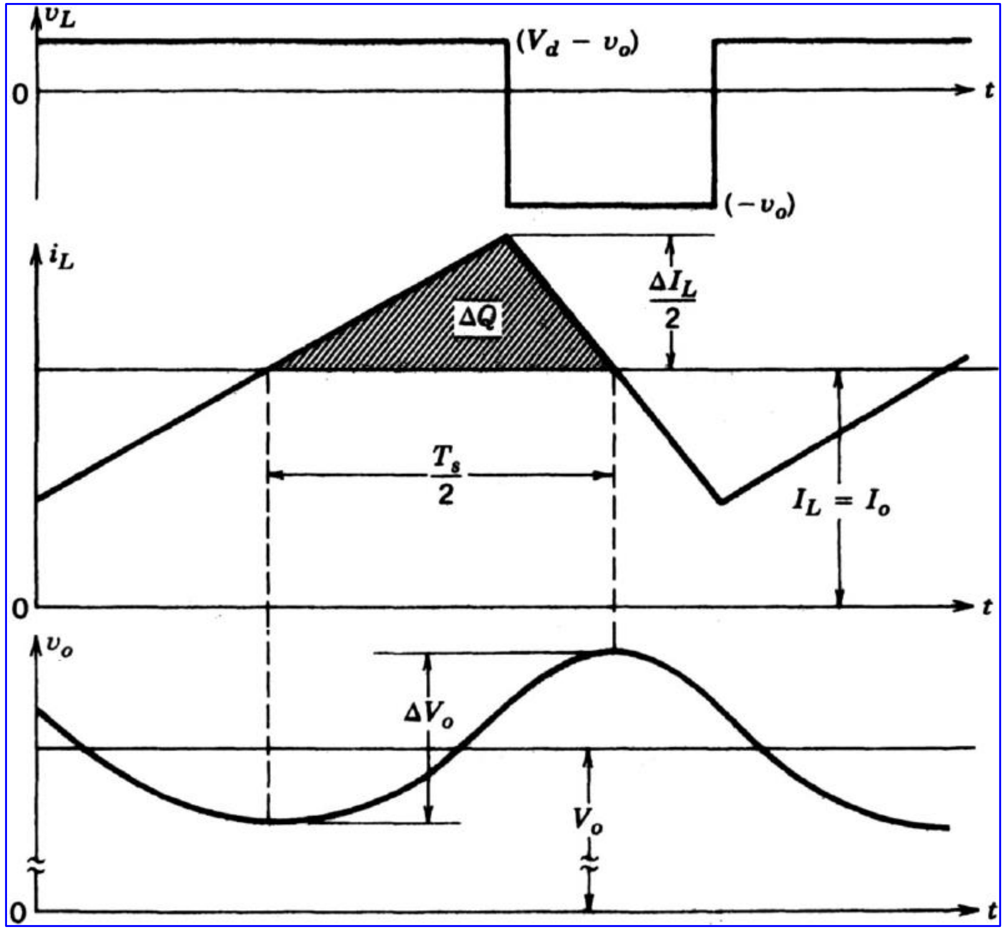
where $f_s = 1/T_s$ and $f_c = \dfrac{1}{2\pi\sqrt{LC}}$

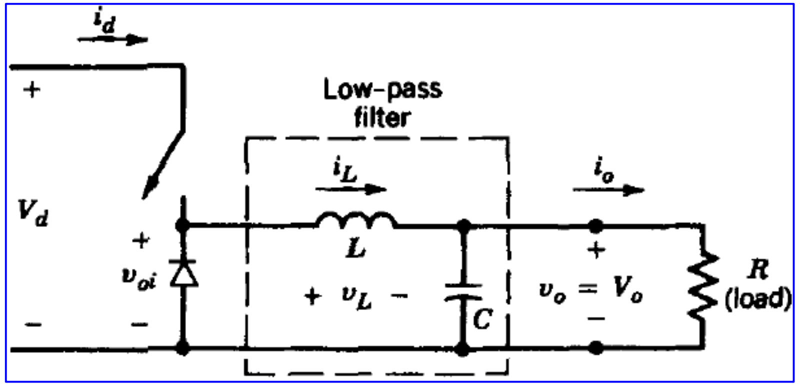
ΔV0 can be minimized by selecting *fc* such that *fc* << *fs.*

- Also, the ripple is independent of the output load power, so long as the converter operates in CCM.
- A similar analysis can be performed for DCM.

- In SMPS, ΔV0 is usually specified to be less than 1%.
- Therefore, the analysis assuming *vo(t)* = V0 is valid.

Output Voltage Ripple





Use of Filter on the Input Side

The major disadvantages of such a pulsed current flow are as follows:

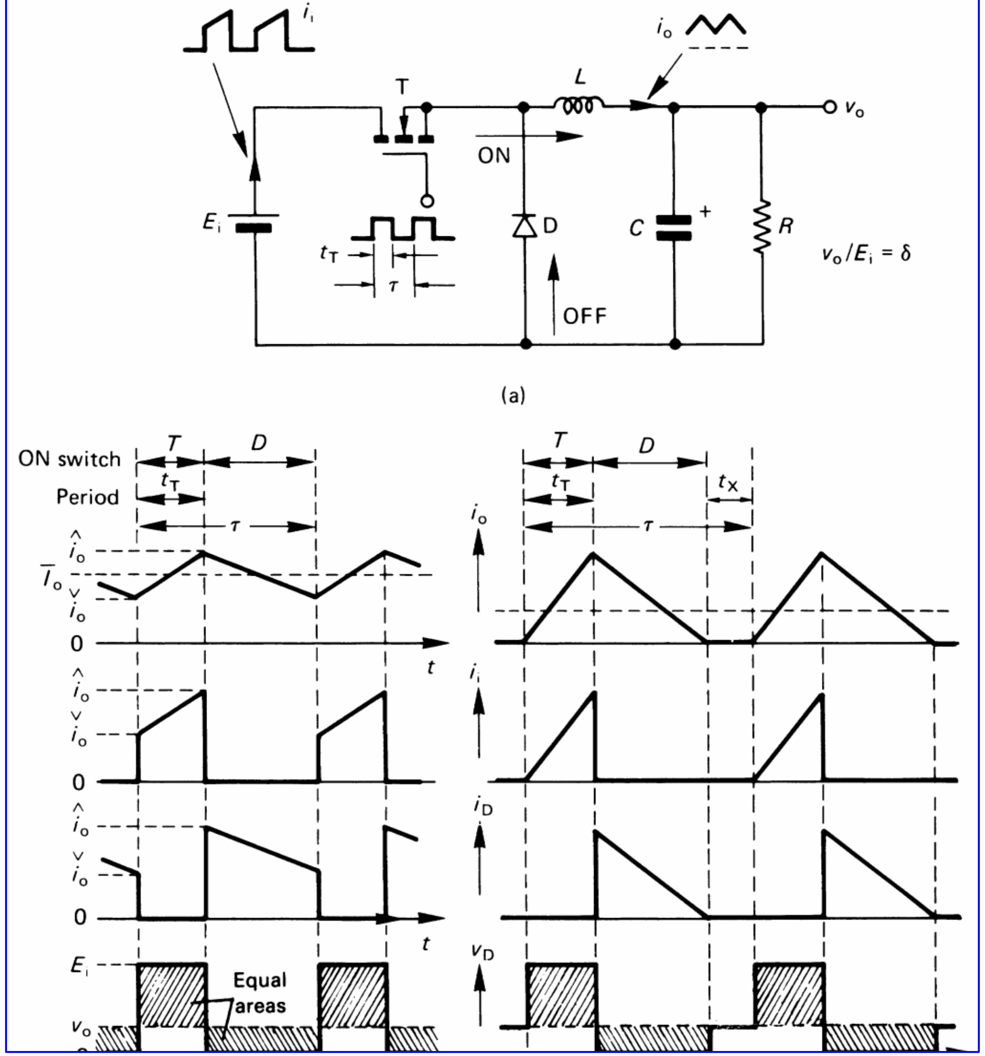
1. The source has to handle a large peak current.
2. There is a higher power loss in resistive paths.
3. There is electromagnetic interference due to the high frequency components in the current and the sharp rising and falling edges of the current pulses.

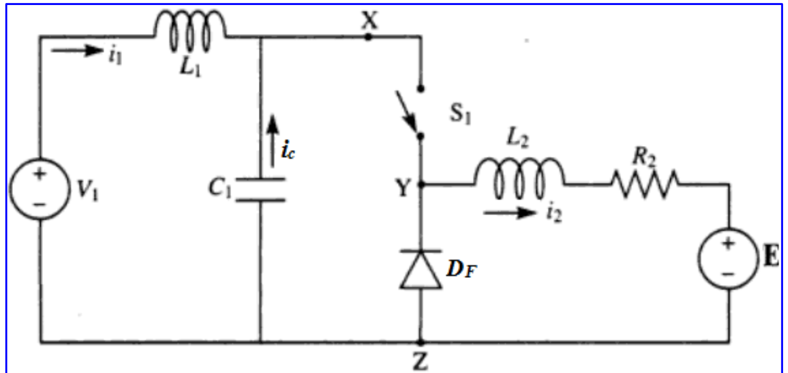
L1 and C1 form the input filter.

The capacitor will lose some charge during TON, with a corresponding drop in the voltage applied to the capacitor. Durning TOFF, capacitor will be charging.

The ripple in the capacitor voltage can be kept low, by choosing a sufficiently large C1.

Electrolytic capacitors are available in compact sizes for large capacitance values.

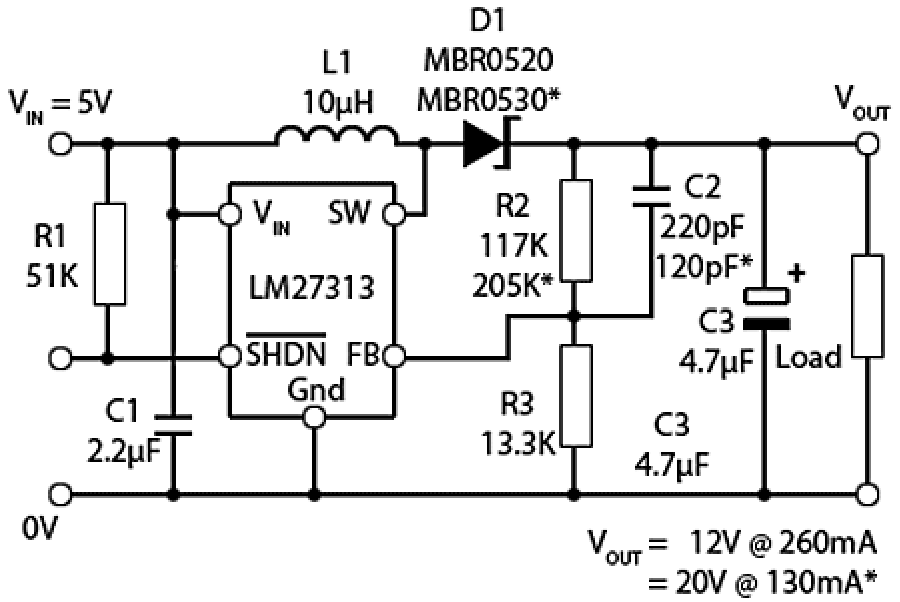




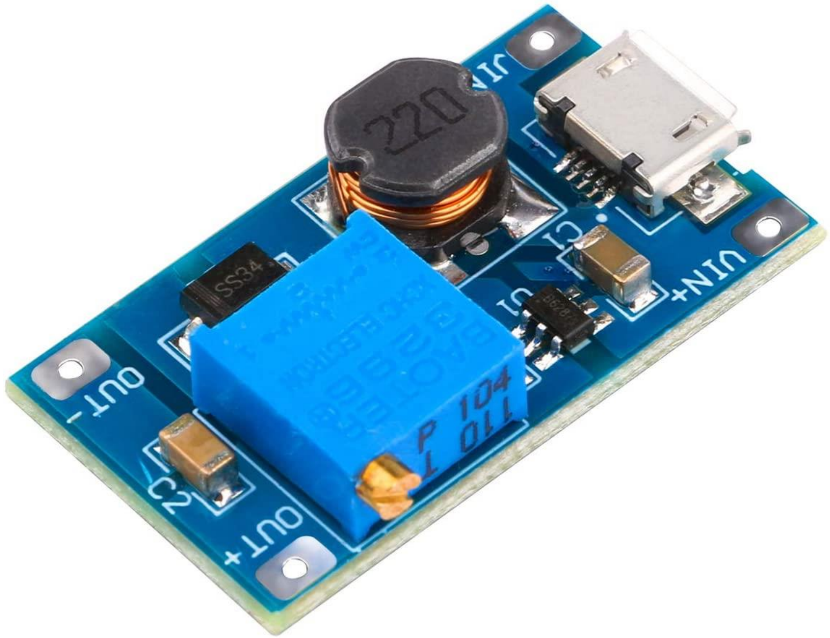
Boost Converters

Applications:

- Automotive applications
- Power amplifier applications
- Adaptive control applications
- Battery power systems
- Consumer Electronics
- Communication Applications
- Battery Charging circuits
- In heaters and welders
- DC motor drives
- Power factor correction circuits
- Distributed power architecture systems

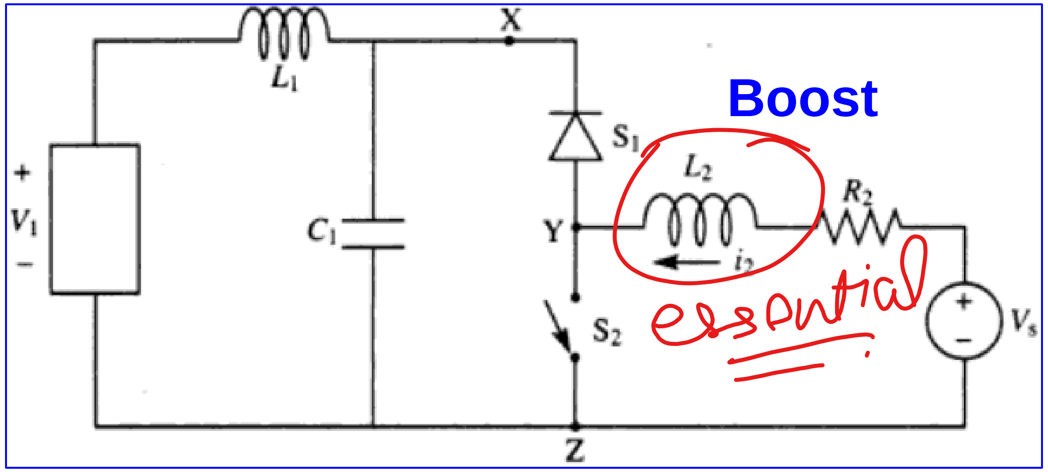


Typical I.C. Boost Converter (LM27313)

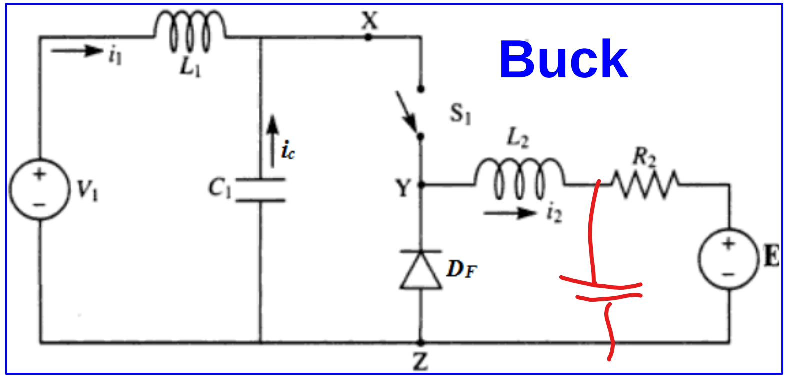


STEP-UP (BOOST) CONVERTER

As the name implies, the output voltage is always greater than the input voltage.



In boost converter, the positions of diode and switch are interchanged as compared to the buck converter circuit.



Vs feeds power into the load, which is at a higher voltage V1. C1 and L1 is used on the high voltage side here also. With this filter, the current flowing into the load will have reduced ripple.

L2 on the low voltage side is similar to the smoothing inductance used on the low voltage side for the buck chopper, to smooth out the low voltage side ripple current. **It is an essential requirement for the step up mode of operation.**

L2 functions as an interim reservoir of energy, drawing energy from the DC source during the ON time, and feeding the same energy into the source at a higher voltage during the OFF time. **It also serves to smooth out ripple current on the low voltage side**, which is the input side.