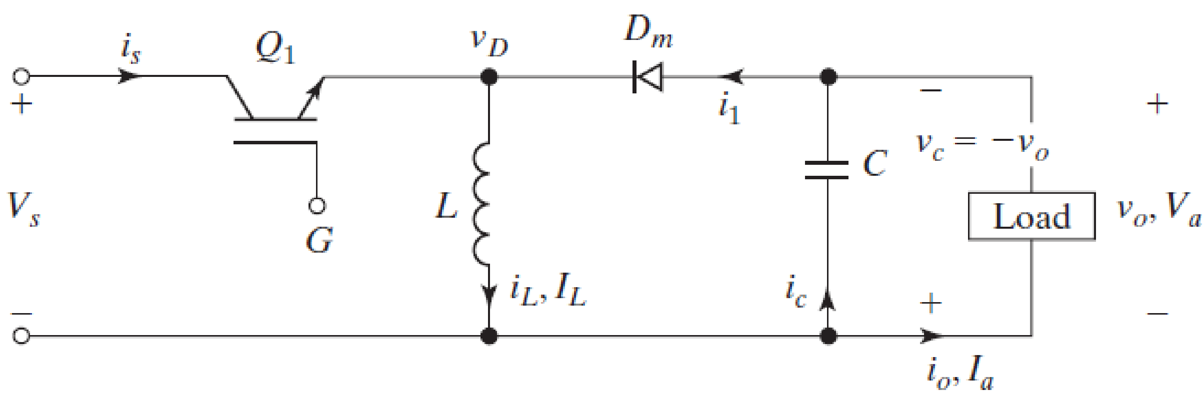
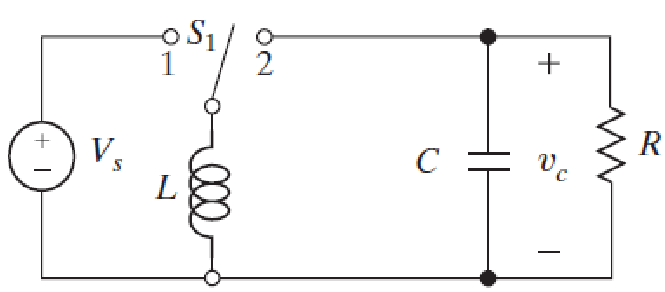
1. Buck-Boost Regulators

A buck–boost regulator provides an output voltage that may be less than or greater than the input voltage—hence the name "buck–boost"; the output voltage polarity is opposite to that of the input voltage. This regulator is also known as an inverting regulator. The circuit arrangement of a buck–boost regulator is shown in Figure.1 (a). Transistor Q1 acts as a controlled switch and diode Dm is an uncontrolled switch. They operate as two SPST current-bidirectional switches. The circuit in Figure.1(a) is often represented by two switches as shown in Figure.1(b).



(a) Circuit diagram



(b) Switch representation

Figure.1: Buck–boost regulator with continuous iL

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The circuit operation can be divided into two modes. During mode 1, transistor Q_1 is turned on and diode D_m is reversed biased. The input current, which rises, flows through inductor L and transistor Q_1. During mode 2, transistor Q_1 is switched off and the current, which was flowing through inductor L, would flow through L, C, D_m, and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until transistor Q_1 is switched on again in the next cycle. The equivalent circuits for the modes are shown in Figure.2.

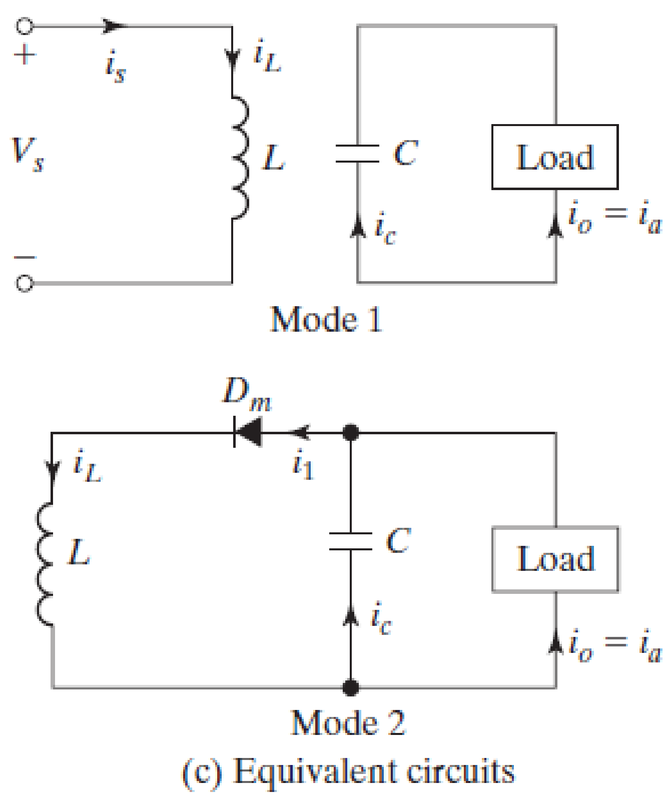

Figure.2: Two Mode

The waveforms for SteadyState voltages and currents of the buck–boost regulator are shown in Figure.3 for a continuous load current.

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Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1,

$$V_s = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1}$$

$$t_1 = \frac{\Delta I L}{V_s}$$

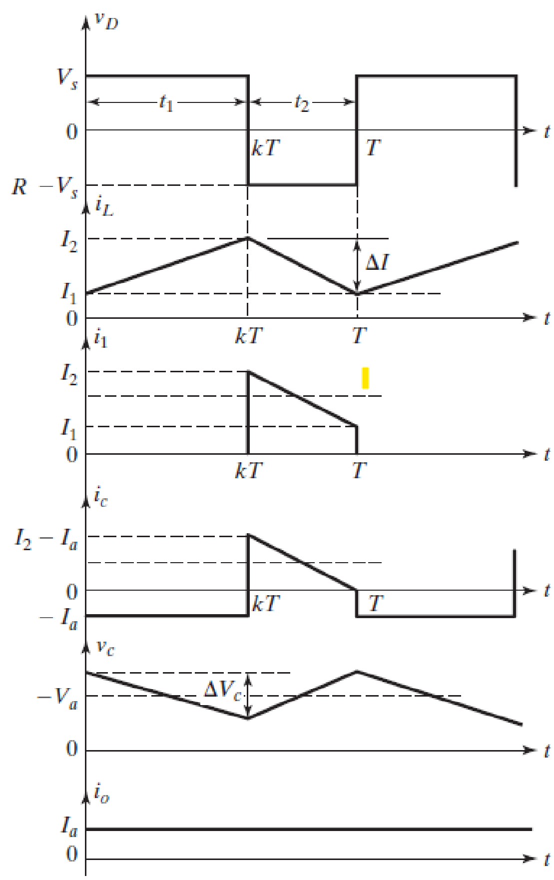
and the inductor current falls linearly from I_2 to I_1 in time t_2,

$$V_a = -L\frac{\Delta I}{t_2}$$

or

$$t_2 = \frac{-\Delta I L}{V_a}$$

where $\Delta I = I_2 - I_1$ is the peak-to-peak ripple current of inductor L



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$$\Delta I = \frac{V_s t_1}{L} = \frac{-V_a t_2}{L}$$

Substituting $t_1 = kT$ and $t_2 = (1 - k)T$, the average output voltage is

$$V_a = -\frac{V_s k}{1 - k}$$

and the average input current I_s is related to the average output current I_a by

$$I_s = \frac{I_a k}{1 - k}$$

The peak-to-peak ripple current,

$$\Delta I = \frac{V_s V_a}{fL(V_a - V_s)}$$

or

$$\Delta I = \frac{V_s k}{fL}$$

The average inductor current is given by

$$I_L = I_s + I_a = \frac{kI_a}{1 - k} + I_a = \frac{I_a}{1 - k}$$

Peak-to-peak capacitor ripple voltage. When transistor Q1 is on, the filter Capacitor supplies the load current for t = t1. The average discharging current of the capacitor is $I_c = -I_a$ and the peak-to-peak ripple voltage of the capacitor is

$$\Delta V_c = \frac{I_a k}{fC}$$

Condition for continuous inductor current and capacitor voltage. If IL is the average inductor current, at the critical condition for continuous conduction the inductor ripple current I = $2I_L$.

which gives the critical value of the inductor L_c as

$$L_c = L = \frac{(1-k)R}{2f} \tag{5.96}$$

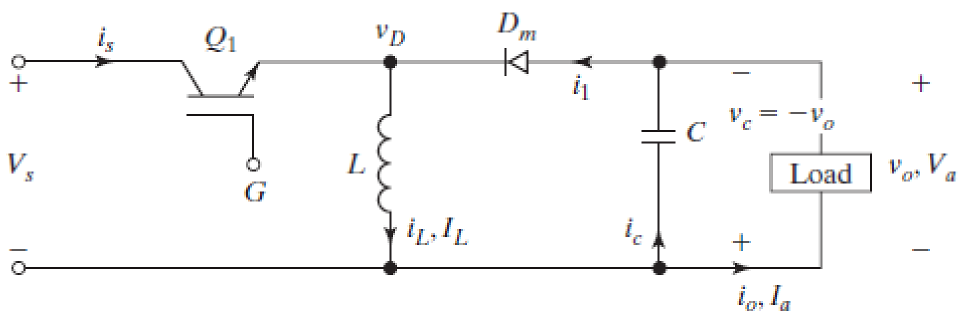
If V_c is the average capacitor voltage, at the critical condition for continuous conduction the capacitor ripple voltage $\Delta V_c = -2V_a$. Using Eq. (5.95), we get

$$-\frac{I_a k}{Cf} = -2V_a = -2I_a R$$

which gives the critical value of the capacitor C_c as

$$C_c = C = \frac{k}{2fR} \tag{5.97}$$

Example.1: The buck–boost regulator in Figure has an input voltage of V_s = 12 V. The duty cycle k = 0.25 and the switching frequency is 25 kHz. The inductance L = 150 μH and filter capacitance C = 220 μF. The average load current I_a = 1.25 A. Determine (a) the average output voltage, V_a; (b) the peak-to-peak output voltage ripple, V_c; (c) the peak-to-peak ripple current of inductor, I; (d) the peak current of the transistor, I_p; and (e) the critical values of L and C.



(a) Circuit diagram

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Solution:

$V_s = 12\,\text{V}, k = 0.25, I_a = 1.25\,\text{A}, f = 25\,\text{kHz}, L = 150\,\mu\text{H}$, and $C = 220\,\mu\text{F}$.

a. From Eq. (5.86), $V_a = -12 \times 0.25/(1 - 0.25) = -4\,\text{V}$.

b. From Eq. (5.95), the peak-to-peak output ripple voltage is

$$\Delta V_c = \frac{1.25 \times 0.25}{25{,}000 \times 220 \times 10^{-6}} = 56.8\,\text{mV}$$

c. From Eq. (5.92), the peak-to-peak inductor ripple is

$$\Delta I = \frac{12 \times 0.25}{25{,}000 \times 150 \times 10^{-6}} = 0.8\,\text{A}$$

d. From Eq. (5.89), $I_s = 1.25 \times 0.25/(1 - 0.25) = 0.4167\,\text{A}$. Because I_s is the average of duration kT, the peak-to-peak current of the transistor,

$$I_p = \frac{I_s}{k} + \frac{\Delta I}{2} = \frac{0.4167}{0.25} + \frac{0.8}{2} = 2.067\,\text{A}$$

e. $R = \dfrac{-V_a}{I_a} = \dfrac{4}{1.25} = 3.2\,\Omega$

From Eq. (5.96), we get $L_c = \dfrac{(1 - k)R}{2f} = \dfrac{(1 - 0.25) \times 3.2}{2 \times 25 \times 10^3} = 450\,\mu\text{H}$.

From Eq. (5.97), we get $C_c = \dfrac{k}{2fR} = \dfrac{0.25}{2 \times 25 \times 10^3 \times 3.2} = 1.56\,\mu\text{F}$.