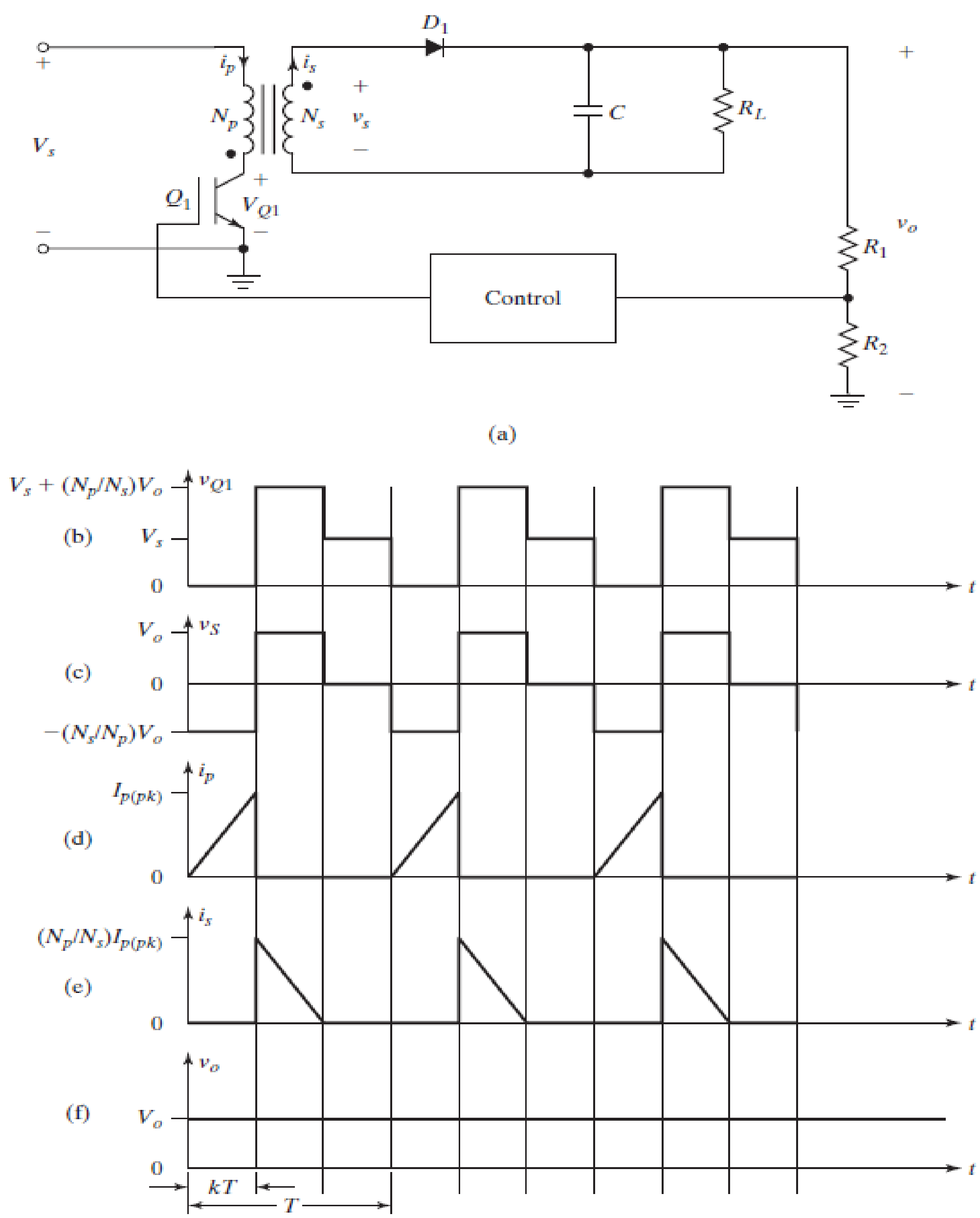
Flyback Converter

Figure .1 (a) shows the circuit of a flyback converter. There are two modes of operation: (1) mode 1 when switch Q1 is turned on, and (2) mode 2 when Q1 is turned off. Figure.1 (b–f) shows the steady-state waveforms under a discontinuous-mode operation.



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It is assumed that the output voltage as shown in Figure 13.1f is ripple free.

Mode 1. This mode begins when switch Q1 is turned on and it is valid for $0 < t \leq kT$, where k is the duty-cycle ratio and T is the switching period. The voltage across the primary winding of the transformer is Vs. The primary current i_p starts to build up and stores energy in the primary winding. Due to the opposite polarity arrangement between the input and output windings of the transformer, diode D_1 is reverse biased. There is no energy transferred from the input to load RL. The output filter capacitor C maintains the output voltage and supplies the load current i_L. The primary current ip that increases linearly is given by

$$i_p = \frac{V_s t}{L_p}$$

where L_p is the primary magnetizing inductance. At the end of this mode at t = kT, the peak primary current reaches a value equal to $I_{p(pk)}$ as given by

$$I_{p(pk)} = i_p(t = kT) = \frac{V_s kT}{L_p}$$

The peak secondary current $I_{se(pk)}$ is given by

$$I_{se(pk)} = \left(\frac{N_p}{N_s}\right) I_{p(pk)}$$

Mode 2. This mode begins when switch Q_1 is turned off. The polarity of the windings reverses due to the fact that i_p cannot change instantaneously. This causes diode D_1 to turn on and charges the output capacitor C and also delivers current to RL. The secondary current that decreases linearly is given by

$$i_{se} = I_{se(pk)} - \frac{V_o}{L_s} t$$

where L_s is the secondary magnetizing inductance. Under the discontinuous-mode operation, i_{se} decreases linearly to zero before the start of the next cycle.

Because energy is transferred from the source to the output during the time Interval 0 to kT only, the input power is given by

$$P_i = \frac{\frac{1}{2} L_p I_{p(pk)}^2}{T} = \frac{(kV_s)^2}{2fL_p} \tag{13.5}$$

For an efficiency of η, the output power P_o can be found from

$$P_o = \eta P_i = \frac{\eta (V_s k)^2}{2fL_p} \tag{13.6}$$

which can be equated to $P_o = V_o^2/R_L$ so that we can find the output voltage V_o as

$$V_o = V_s k \sqrt{\frac{\eta R_L}{2fL_p}} \tag{13.7}$$

Thus, V_o can be maintained constant by keeping the product $V_s kT$ constant. Because the maximum duty cycle k_{max} occurs at minimum supply voltage $V_{s(min)}$, the allowable k_{max} for the discontinuous mode can be found from Eq. (13.7) as

$$k_{max} = \frac{V_o}{V_{s(min)}} \sqrt{\frac{2fL_p}{\eta R_L}} \tag{13.8}$$

Therefore, V_o at k_{max} is then given by

$$V_o = V_{s(min)} k_{max} \sqrt{\frac{\eta R_L}{2fL_p}} \tag{13.9}$$

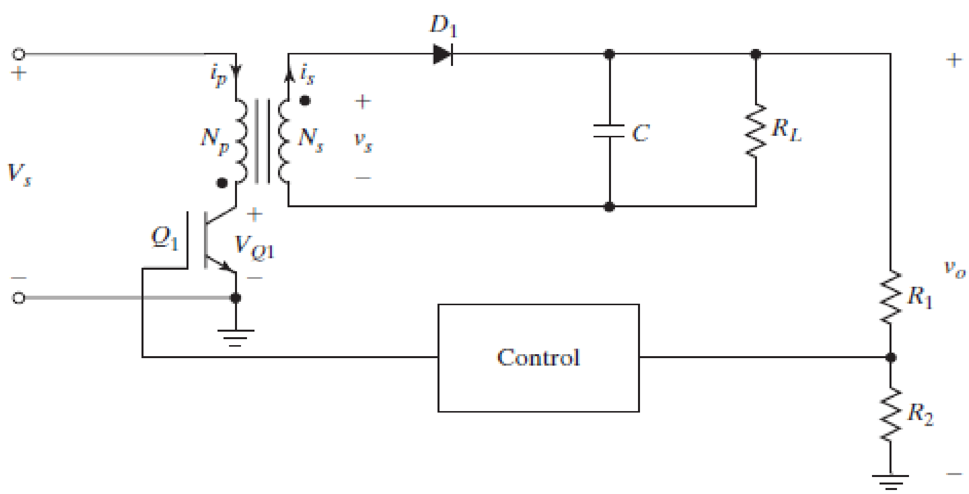
Because the collector voltage V_{Q1} of Q_1 is maximum when V_s is maximum, the maximum collector voltage $V_{Q1(max)}$, as shown in Figure 13.1b, is given by

$$V_{Q1(max)} = V_{s(max)} + \left(\frac{N_p}{N_s}\right) V_o \tag{13.10}$$

The peak primary current $I_{p(pk)}$, which is the same as the maximum collector current $I_{C(max)}$ of the power switch Q_1, is given by

$$I_{C(max)} = I_{p(pk)} = \frac{2P_i}{kV_s} = \frac{2P_o}{\eta V_s k} \tag{13.11}$$

Example.1: The average (or dc) output voltage of the flyback circuit in Figure is Vo = 24 V at a resistive load of R = 0.8 Ω. The duty-cycle ratio is k = 50% and the switching frequency is *f* = 1 kHz. The on-state voltage drops of transistors and diodes are V_t = 1.2 V and V_d = 0.7V, respectively. The turns ratio of the transformer is a = Ns/Np = 0.25. Determine (a) the average input current I_s, (b) the efficiency, (c) the average transistor current I_A, (d) the peak transistor current I_p, (e) the rms transistor current I_R, (f) the open-circuit transistor voltage V_{oc}, and (g) the primary magnetizing inductor L_p. Neglect the losses in the transformer and the ripple current of the load.



(a)

Solution:

$a = N_s/N_p = 0.25$ and $I_o = V_o/R = 24/0.8 = 30$ A.

a. The output power $P_o = V_o I_o = 24 \times 30 = 720$ W. The secondary voltage $V_2 = V_o + V_d = 24 + 0.7 = 24.7$ V. The primary voltage $V_1 = V_2/a = 24.7/0.25 = 98.8$ V. The input voltage $V_s = V_1 + V_t = 98.8 + 1.2 = 100$ and the input power is

$$P_i = V_s I_s = 1.2 I_A + V_d I_o + P_o$$

Substituting $I_A = I_s$ gives

$$I_s(100 - 1.2) = 0.7 \times 30 + 720$$

$$I_s = \frac{741}{98.8} = 7.5 \text{ A}$$

b. $P_i = V_s I_s = 100 \times 7.5 = 750$ W. The efficiency $\eta = 7.5/750 = 96.0\%$.

c. $I_A = I_s = 7.5$ A.

d. $I_p = 2I_A/k = 2 \times 7.5/0.5 = 30$ A.

e. $I_R = \sqrt{k/3}I_p = \sqrt{0.5/3} \times 30 = 12.25$ A, for 50% duty cycle.

f. $V_{oc} = V_s + V_2/a = 100 + 24.7/0.25 = 198.8$ V.

g. Using Eq. (13.2) for I_p gives $L_p = V_s k/fI_p = 100 \times 0.5/(1 \times 10^{-3} \times 30) = 1.67$ mH.

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