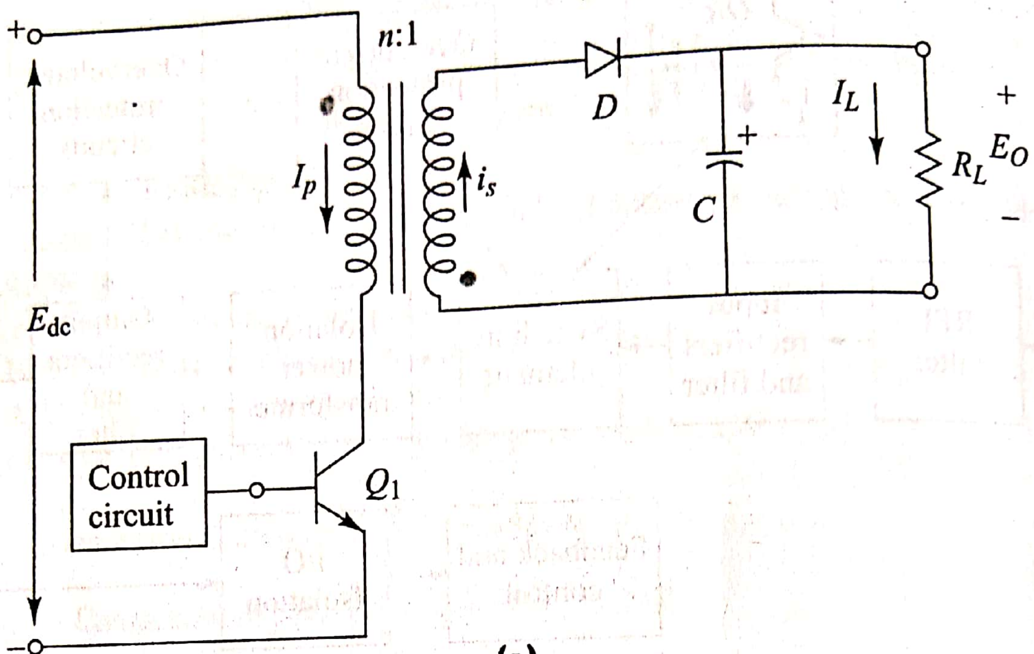
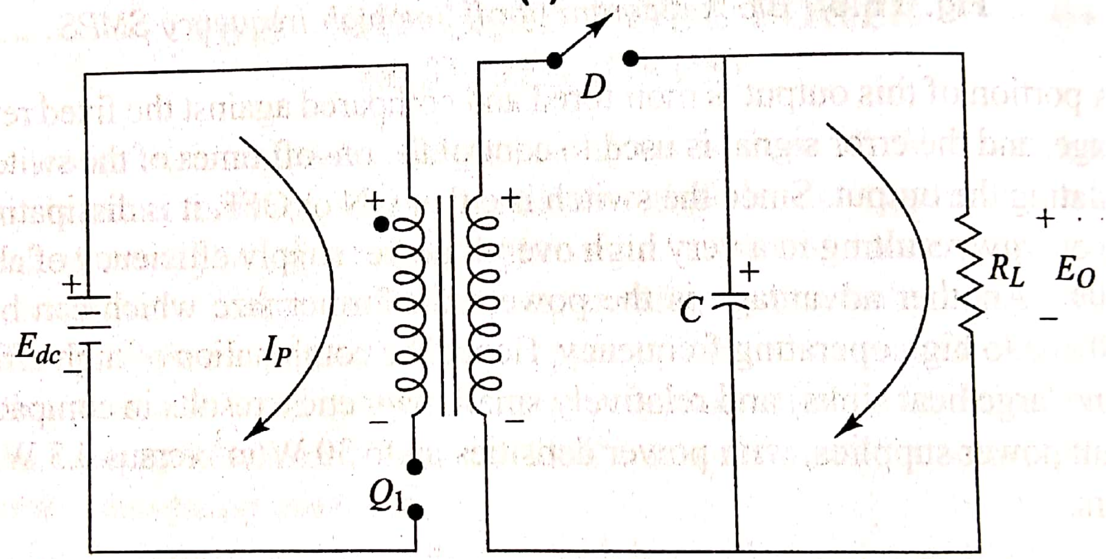
16.3.1.1 Discontinuous Mode (Flyback Converter)

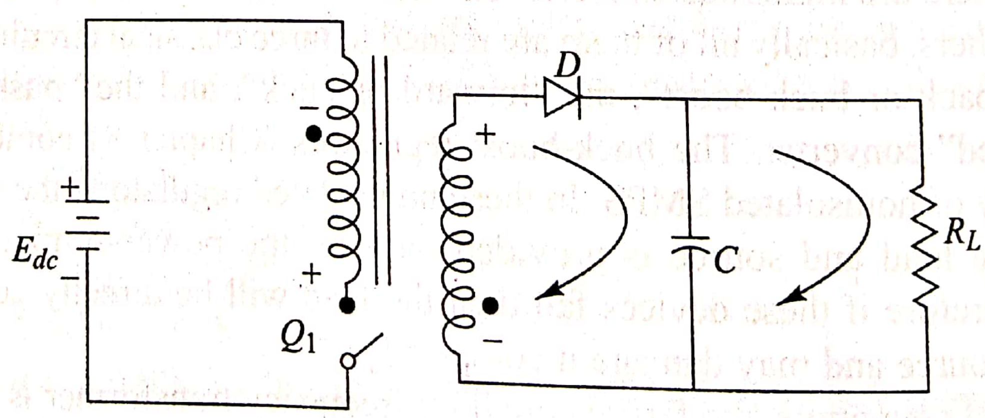
The circuit diagram for the discontinuous flyback converter is shown in Fig. 16.7 and associated steady-state waveforms are shown in Fig. 16.8. The circuit operates as follows:



(a)



(b) Mode I equivalent circuit



(c) Mode II equivalent circuit

Fig 16.7 *Flyback converters*

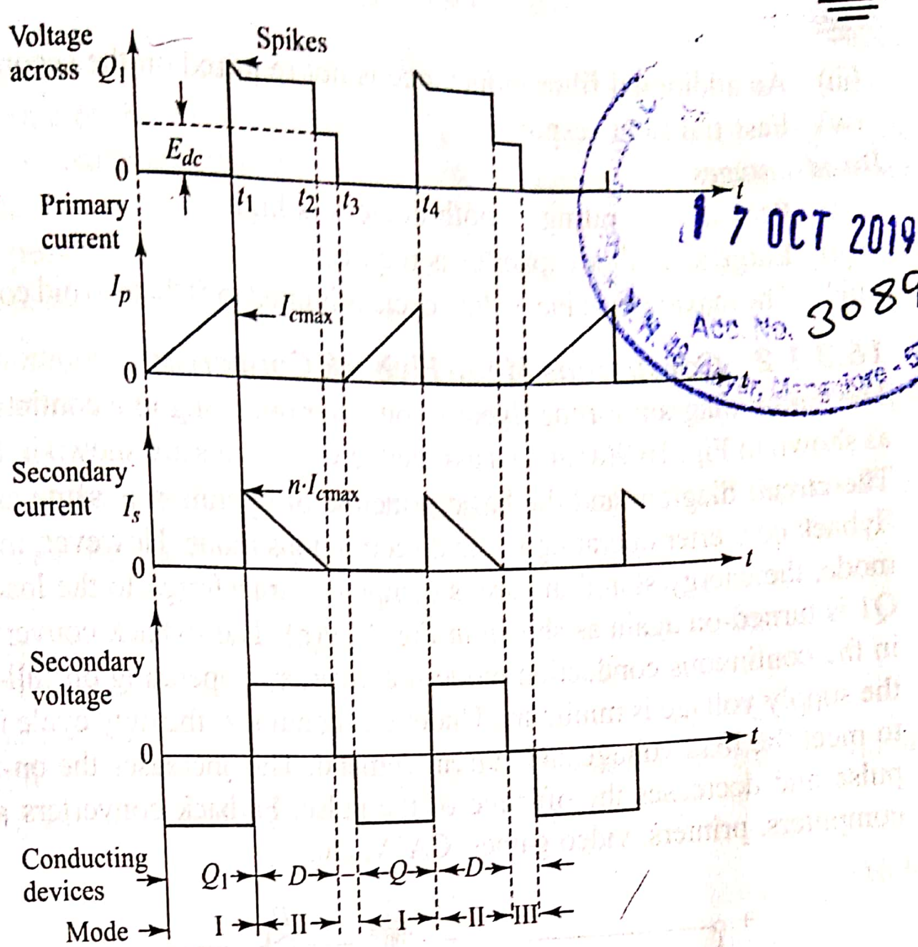


Fig. 16.8 *Flyback converter associated waveforms.*

Mode I $(t_0 - t_1)$: When transistor Q_1 is ON at $t = 0$, primary current starts to build-up in the primary winding, storing energy. Due to the opposite primary arrangement between the input and output windings of the transformer choke, there is no energy transferred to the load since diode D is reverse-biased. Transistor Q_1 is turned-off abruptly at instant $t = t_1$ The equivalent circuit for this mode is shown in Fig. 16.7 (b).

Mode II $(t_1 - t_2)$: When the transistor is turned-off at $t = t_1$, the polarity of the windings reverses due to the collapsing magnetic field. Now, diode D is conducting, charging the output capacitor C and delivering current I_L to load.

The voltage across Q_1 is the sum of input supply voltage (E_{dc}) and the self induced voltage across the primary winding (Ldi/dt), therefore it is higher than the supply voltage (E_{dc}). The equivalent circuit for this mode is shown in Fig. 16.7(c). The secondary current goes to zero at $t = t_2$. Thus, the stored energy in the transformer core is delivered to the load during this mode of operation.

(iii) Mode III $(t_2 - t_3)$: In this mode, transistor and diode both are in the off-state. Therefore, primary and secondary currents are zero. As there is no voltage drop across the primary winding of the transformer, the voltage across the transistor Q_1 is equal to the dc supply voltage (E_{dc}). The secondary voltage is zero. The one-cycle operation completes in this mode and repeats itself.

Advantages of Discontinuous Mode

(i) Slower diodes can be used on the secondary side for rectification.

(ii) Size of transformer is smaller than that in the continuous mode.

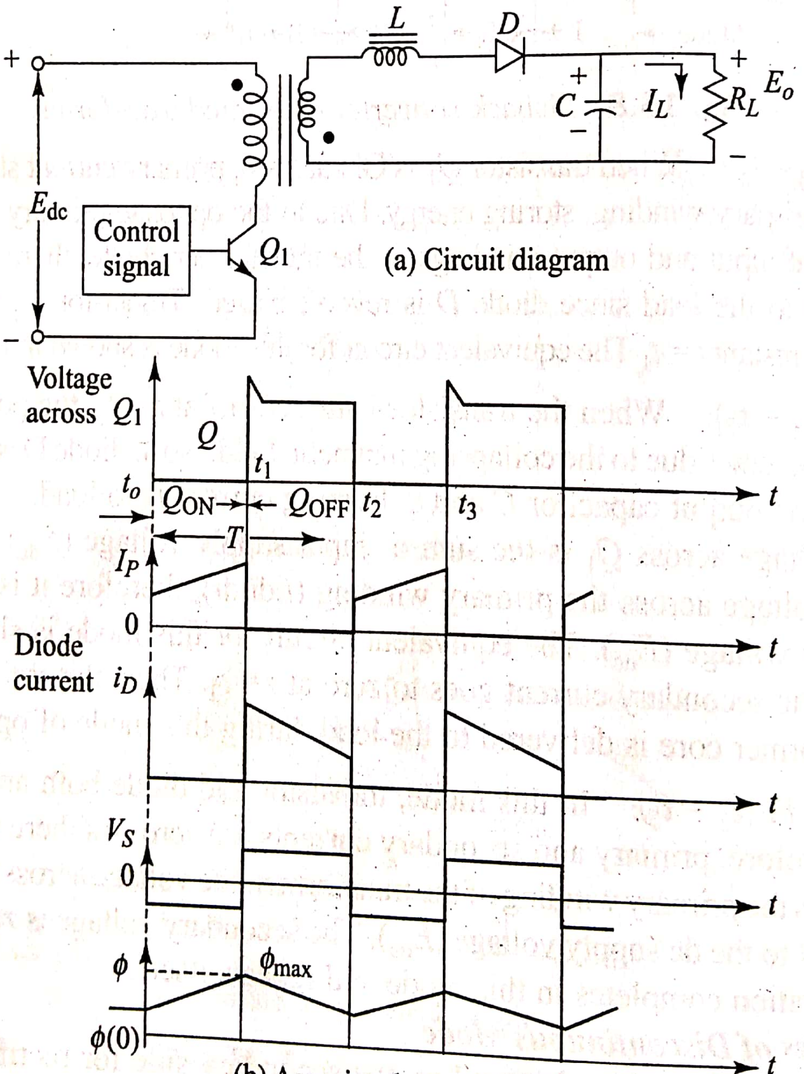
(iii) An additional filter inductance is not required on the secondary side.
(iv) Fast transient response.

Disadvantages

(i) Peak current rating of both devices is high.
(ii) Large size filter capacitor is required.
(iii) The maximum value of duty cycle is limited to 50% to avoid core saturation.

16.3.1.2 Continuous Mode Flyback Converter

The circuit diagram for the flyback converter operating in a continuous mode is as shown in Fig. 16.9(a) and its associated waveforms are shown in Fig. 16.9(b). The circuit diagram and the basic principle of operation is same as that of the flyback converter operating in the discontinuous mode. However, in continuous mode, the energy stored in core is completely transferred to the load, transistor Q1 is turned-on again as shown in Fig. 16.9(b). The flyback converter operates in the continuous conduction mode if converter is operating on full-load and if the supply voltage is minimum. Under this condition, the duty cycle is increased to meet the load voltage and current demand. This increases the on-time of the pulse and decreases the off-time of the pulse. Flyback converters are used in computers, printers, video games, CATV, etc.



(a) Circuit diagram

(b) Associated waveforms

Fig. 16.9 *Flyback converter continuous mode.*

(i) Advantages of Continuous Mode:

(i) The size of the filter capacitor required for this mode in the secondary side is nearly half the size of the filter capacitor used in discontinuous mode.

(ii) The peak current rating of the diode and the transistor reduces to 50% of that used in the discontinuous mode.

(ii) Disadvantages of Continuous Mode:

(i) Rectifier diodes should be nearly four times faster than discontinuous current mode (typical t_{rr} = 25–100 ns).

(ii) Size of the transformer is larger than that of the discontinuous mode.

(iii) Expression for Voltage Transfer Ratio:

Let, E_{dc} be the dc input voltage to the converter,
N_1/N_2 be the transformer turns ratio,
E_0 be the output voltage and
α be the duty ratio of the transistor.

As shown in Fig. 16.9, the inductor core flux increases linearly from its initial value $\phi(0)$, which is finite and positive and is given by

$$\phi_{(t)} = \phi_{(0)} + \frac{E_{dc}}{N_1} t, \text{ for } 0 < t < t_{on} \tag{16.6}$$

The value of peak flux at the end of this interval is given by

$$\phi_{max} = \phi(t_{on}) = \phi_{(0)} + \frac{E_{dc}}{N_1} t_{on} \tag{16.7}$$

Transistor is turned-off after t_{on} and the energy stored in the transformer core causes the current to flow in the secondary winding. The voltage across the secondary $e_2 = -E_0$, and therefore the flux decreases linearly during the off-time of switch, i.e. t_{off}.

$$\therefore \quad \phi_{(t)} = \phi_{max} - \frac{E_o}{N_2}(t - t_{on}) \text{ for } t_{on} < t < T \tag{16.8}$$

and

$$\phi_{(T)} = \phi_{max} - \frac{E_o}{N_2}(T - t_{on}) \tag{16.9}$$

Substituting ϕ_{max} from (16.7) in (16.9), we get

$$\phi_{(T)} = \phi_{(0)} + \frac{E_{dc}}{N_1} t_{on} - \frac{E_o}{N_2}(T - t_{on}) \tag{16.10}$$

In steady state, since the net change of flux through the core over one time period must be zero,

$\phi_{(T)} = \phi_{(0)}$, substitute in Eq. (16.10),

$$\therefore \quad \phi_{(0)} = \phi_{(0)} + \frac{E_{dc}}{N_1} t_{on} - \frac{E_o}{N_2}(T - t_{on})$$

$$\frac{E_{dc}}{N_1} t_{on} = \frac{E_o}{N_2} (T - t_{on})$$

$$\therefore \quad \frac{E_o}{E_{dc}} = \frac{t_{on}}{(T - t_{on})} \frac{N_2}{N_1} = \frac{t_{on}/T}{(1 - t_{on}/T)} \frac{N_2}{N_1}$$

but, $\alpha = t_{on}/T$,

$$\therefore \quad \frac{E_o}{E_{dc}} = \frac{\alpha}{1-\alpha} \frac{N_2}{N_1} \tag{16.11}$$

Equation (16.11) shows that the voltage transfer ratio in flyback converter depends on α in an identical manner as in the buck-boost converter.

(iv) Selection Criteria for Switching Transistor:

(a) The switching transistor used in the flyback converter must be chosen to handle peak collector voltage at turn-off and peak collector currents at turn-on. The peak collector voltage which the transistor must sustain at turn-off is

$$V_{CE,max} = \frac{E_{dc}}{1 - \alpha_{max}} \tag{16.12}$$

From Eq. (16.12), it becomes clear that in order to limit the collector voltage to a safe value, the duty cycle must be kept relatively low, normally below 50 per cent, i.e. $\alpha_{max} < 0.5$.

In practice, α_{max} is taken at about 0.4, which limits the peak collector voltage $V_{CE,max} < 2.2\ E_{dc}$ and, therefore, transistors with working voltages above 800 V are usually used in the off-line flyback converter designs.

(b) The Selected transistor must have,

$$I_c = \frac{I_L}{n} = I_p \tag{16.13}$$

where I_p is the primary transformer-choke peak current,
n is the primary to secondary turns ratio,
and I_L is the output load current.

(v) Selection of Transformer-Choke:

Since the transformer-choke of the flyback converter is driven in one direction only of the B-H characteristics curve, it has to be designed so that it will not saturate. Therefore, a core with a relatively large volume and air-gap must be used. The effective transformer-choke volume is given by

$$\text{Volume } (V) = \frac{\mu_o \cdot \mu_e \cdot I_{L,max}^2 \cdot L_{out}}{\beta_{max}^2} \tag{16.14}$$

where, $I_{L,max}$ = determined by load current.
μ_e = relative permeability of the chosen core material.
β_{max} = maximum flux density of the core.