Chapter 10

Switching DC Power Supplies

Chapter 10 Switching dc Power Supplies 301

- One of the most important applications of power electronics

Linear Power Supplies

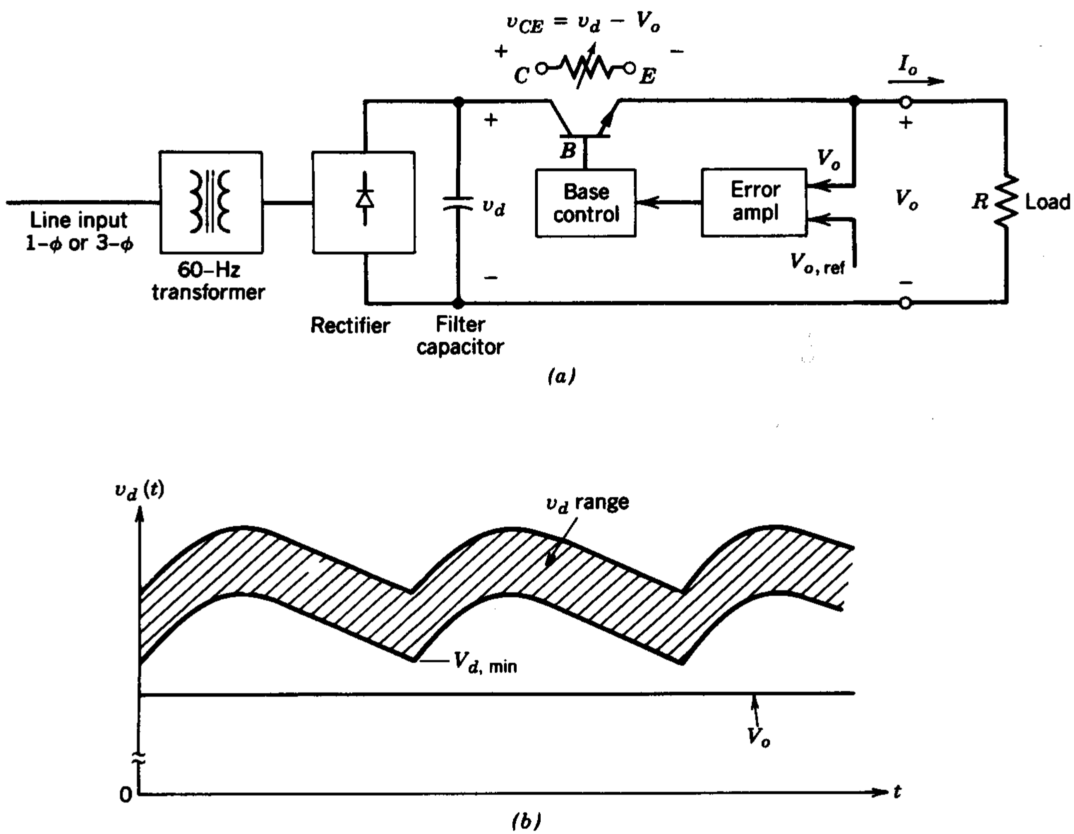


Figure 10-1 Linear power supply: (*a*) schematic; (*b*) selection of transformer turns ratio so that $V_{d,min} > V_o$ by a small margin.

- Very poor efficiency and large weight and size

Switching DC Power Supply: Block Diagram

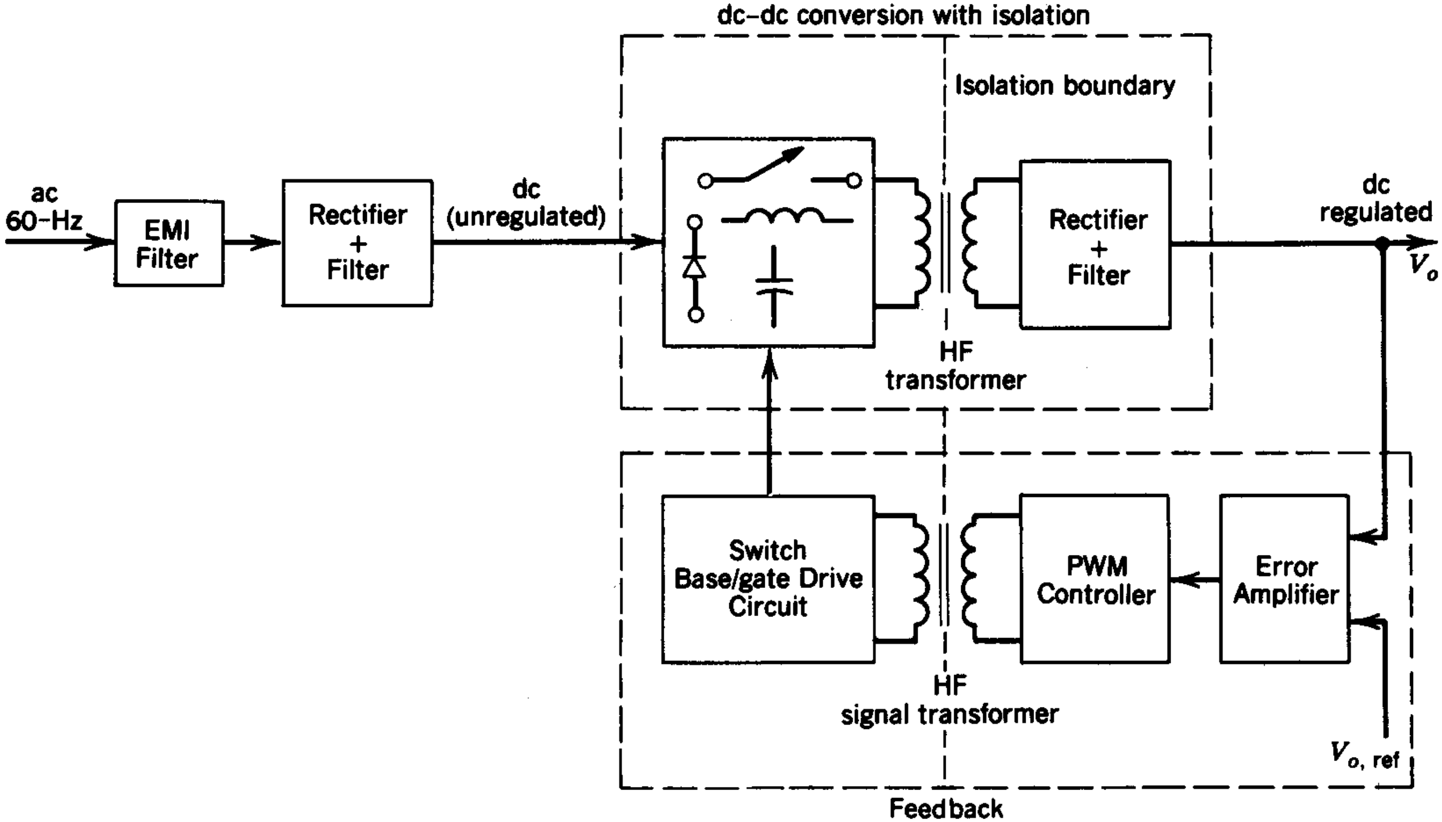


Figure 10-2 Schematic of a switch-mode dc power supply.

- High efficiency and small weight and size

Switching DC Power Supply: Multiple Outputs

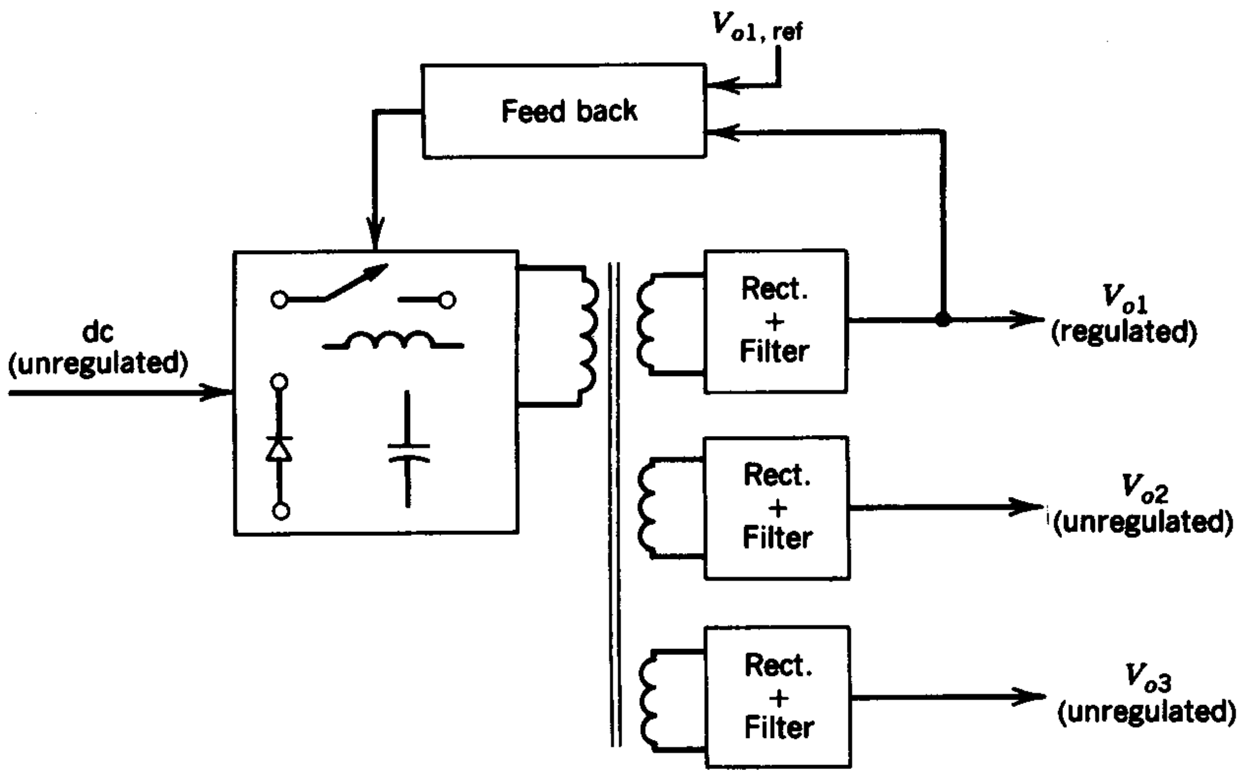


Figure 10-3 Multiple outputs.

- In most applications, several dc voltages are required, possibly electrically isolated from each other

Transformer Analysis

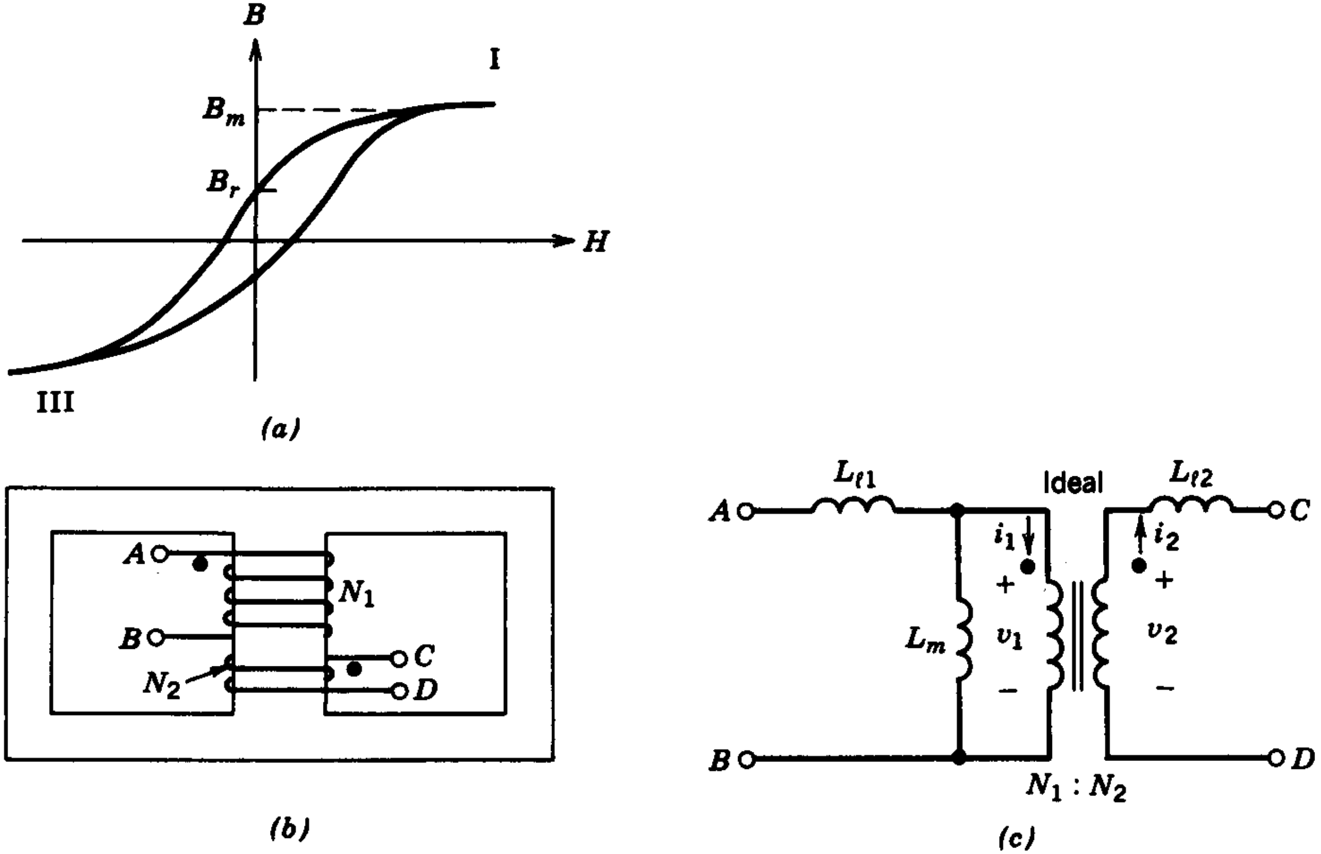


Figure 10-4 Transformer representation: (*a*) typical *B–H* loop of transformer core; (*b*) two-winding transformer; (*c*) equivalent circuit.

- Needed to discuss high-frequency isolated supplies

PWM to Regulate Output

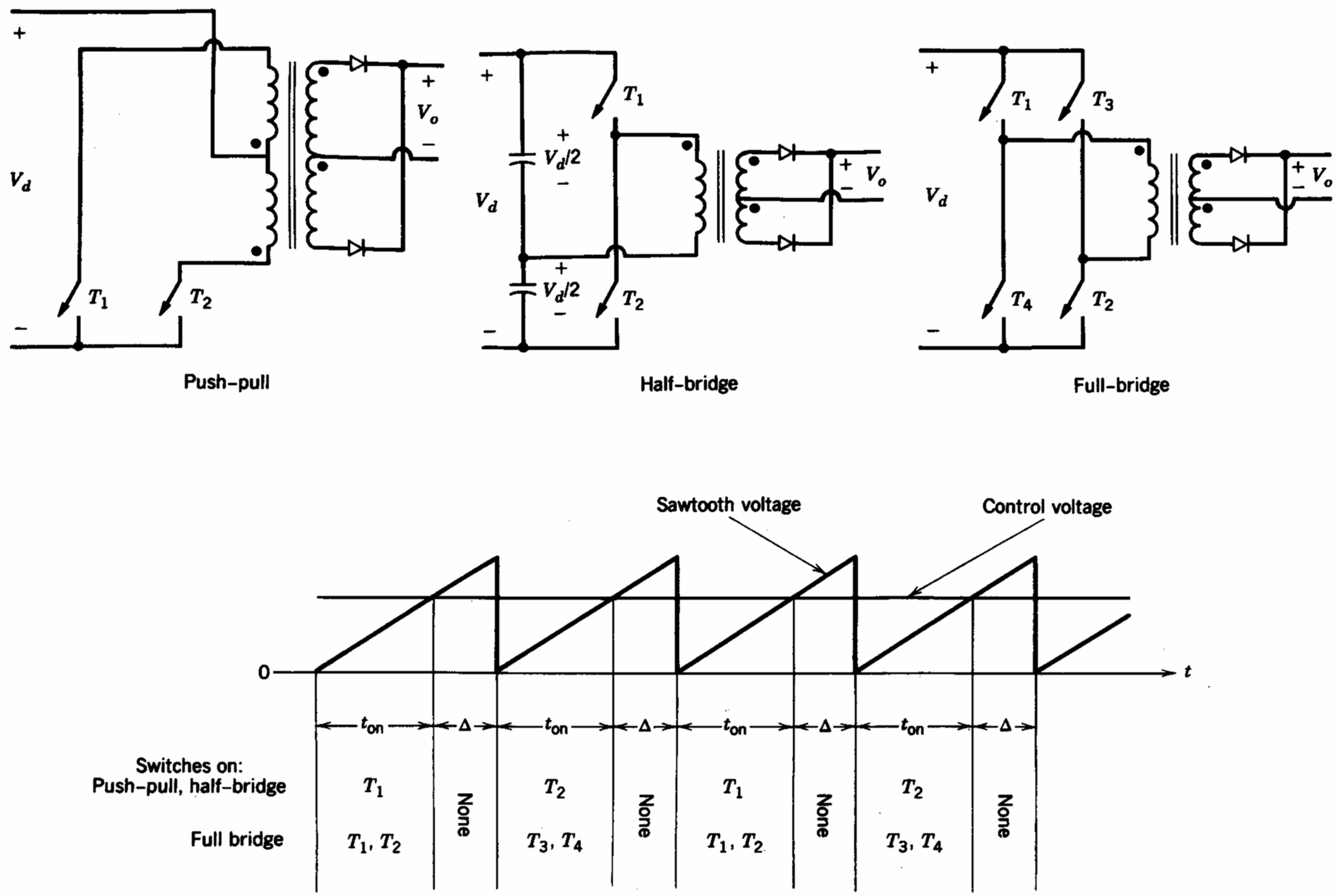


Figure 10-5 PWM Scheme used in dc–dc converters, where the converter output is rectified to produce a dc output.

- Basic principle is the same as discussed in Chapter 8

Flyback Converter

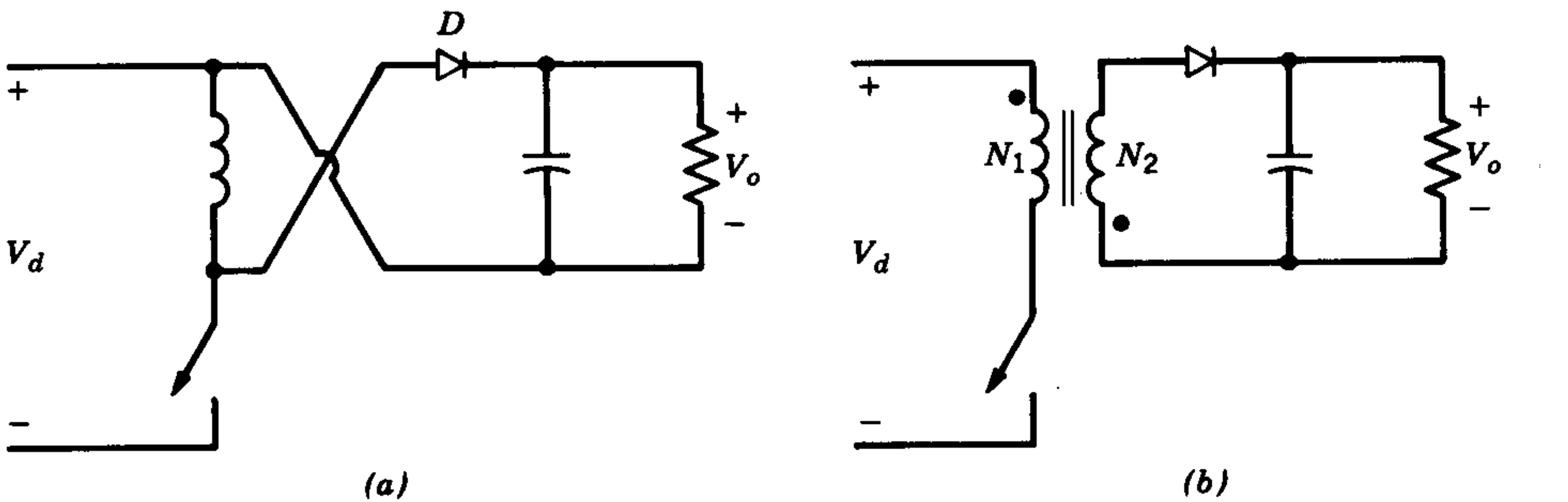


Figure 10-6 Flyback converter.

- Derived from buck-boost; very power at small power (> 50 *W*) power levels

Flyback Converter

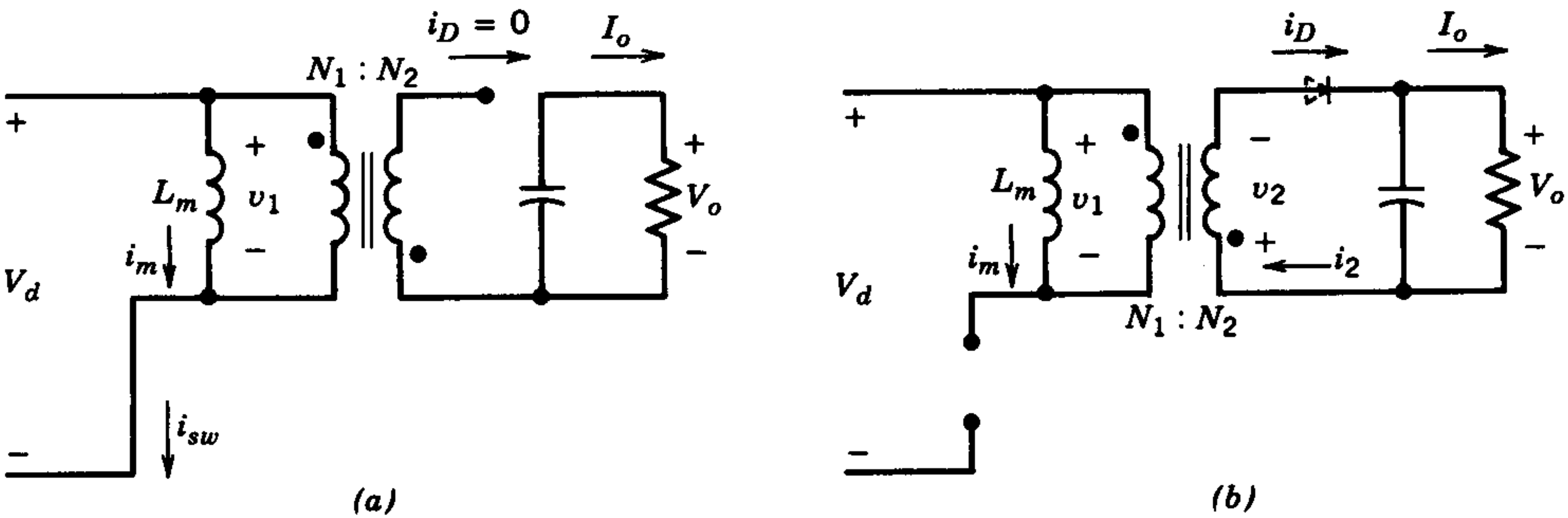


Figure 10-7 Flyback converter circuit states: (*a*) switch on; (*b*) switch off.

- Switch on and off states (assuming incomplete core demagnetization)

Flyback Converter

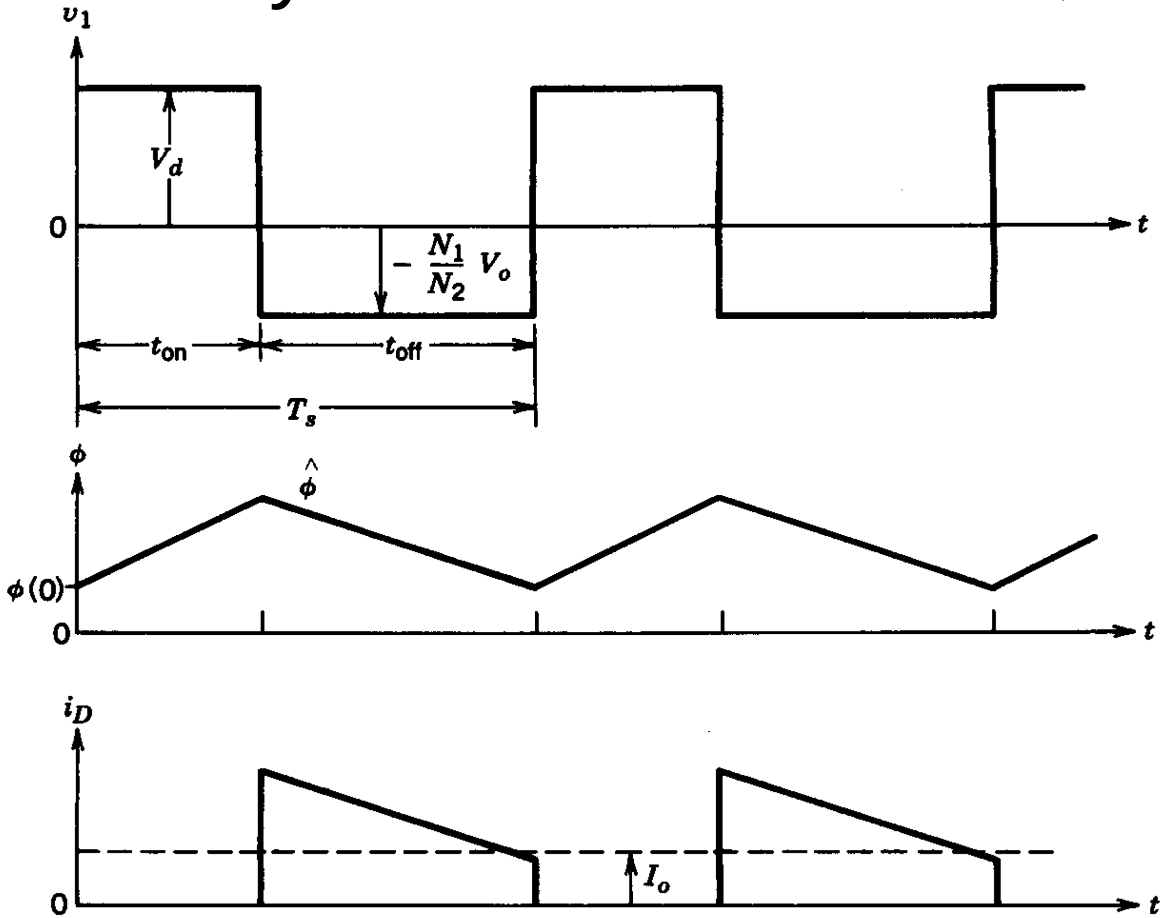


Figure 10-8 Flyback converter waveforms.

- Switching waveforms (assuming incomplete core demagnetization)

Other Flyback Converter Topologies

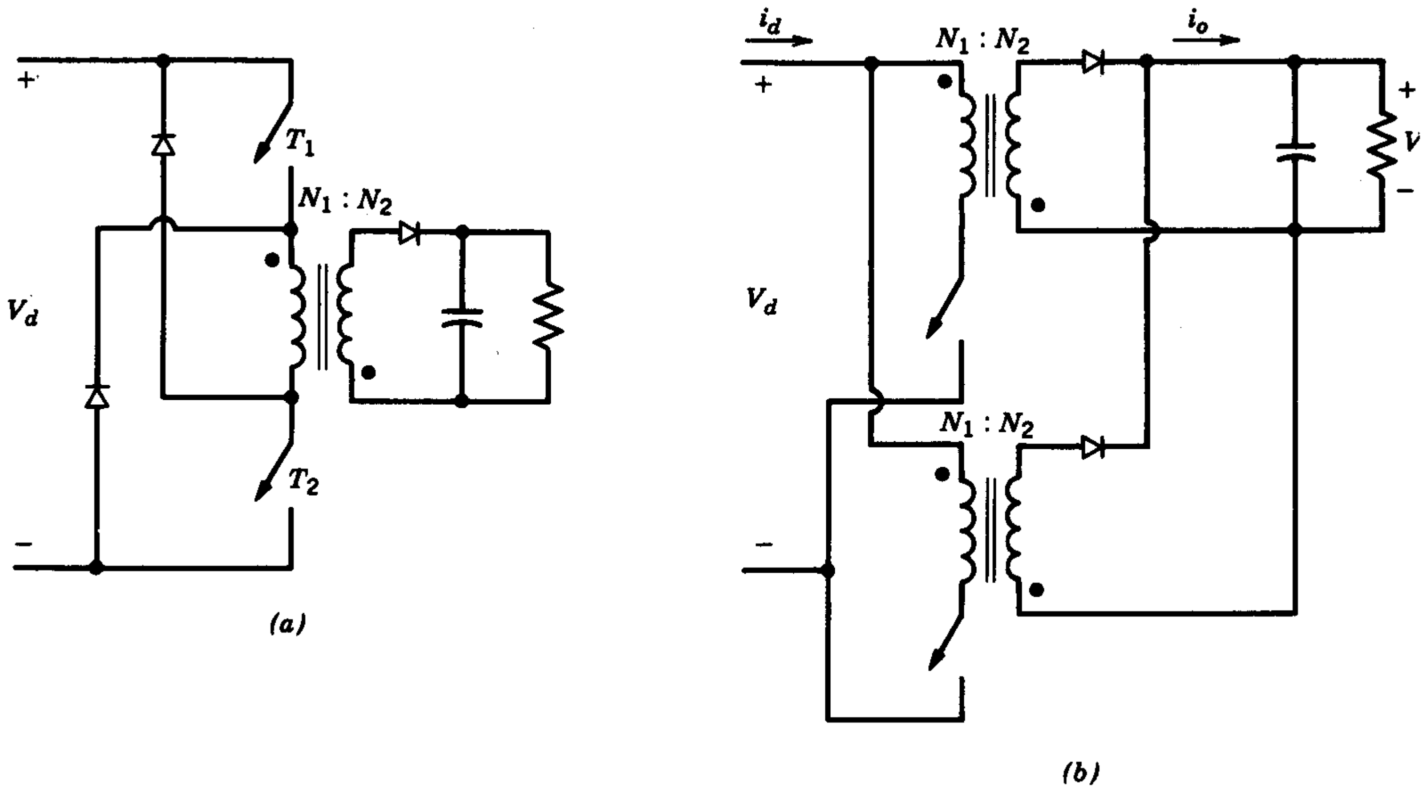


Figure 10-9 Other flyback topologies: (*a*) two-transistor flyback converter; (*b*) parallelled flyback converters.

- Not commonly used

Forward Converter

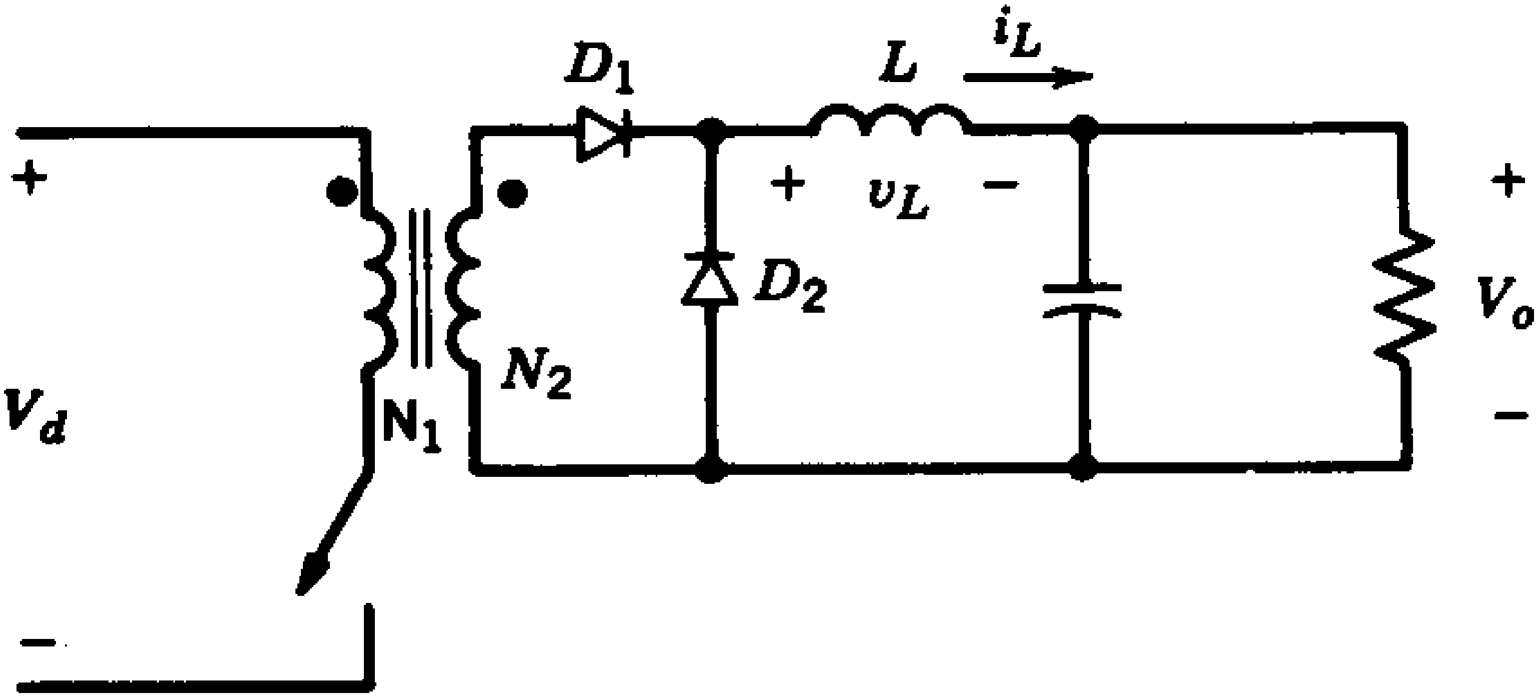


Figure 10-10 Idealized forward converter.

- Derived from Buck; idealized to assume that the transformer is ideal (not possible in practice)

Forward Converter: in Practice

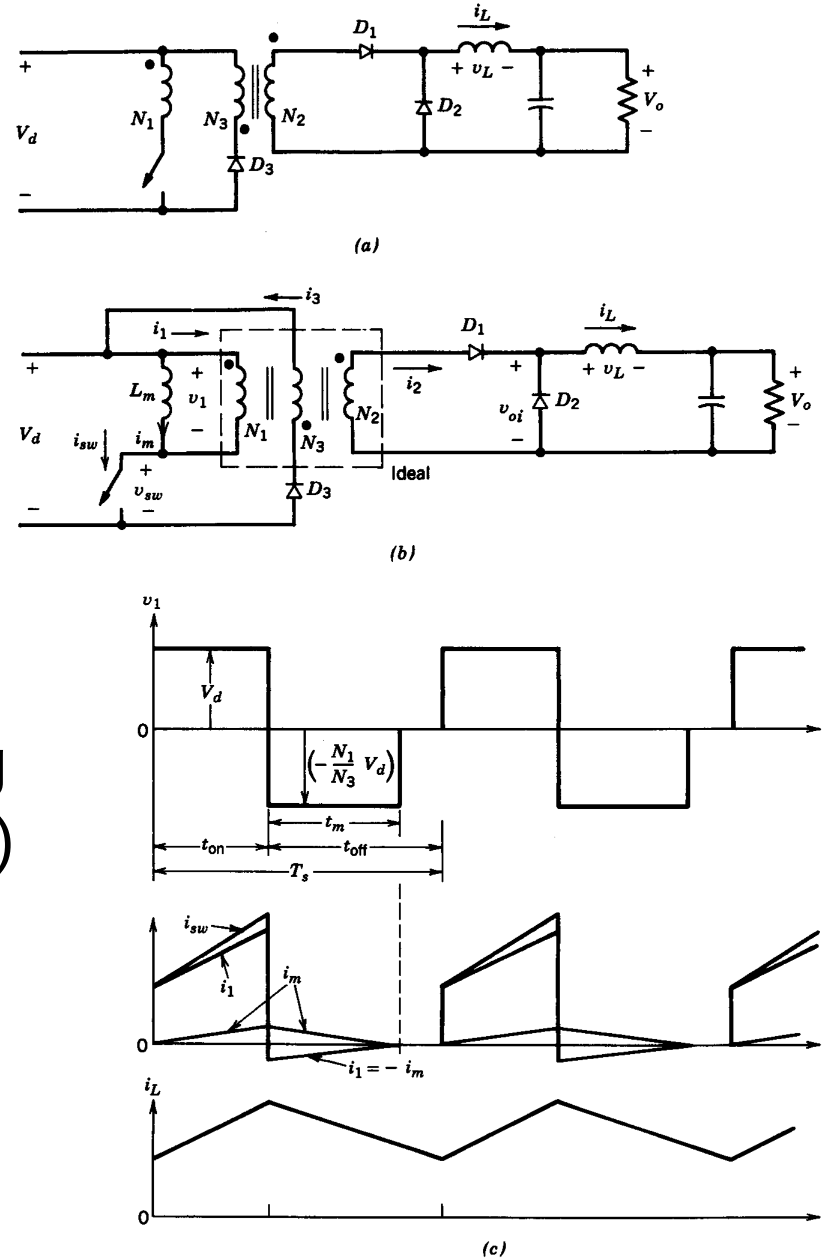


Figure 10-11 Practical forward converter.

- Switching waveforms (assuming incomplete core demagnetization)

Forward Converter: Other Possible Topologies

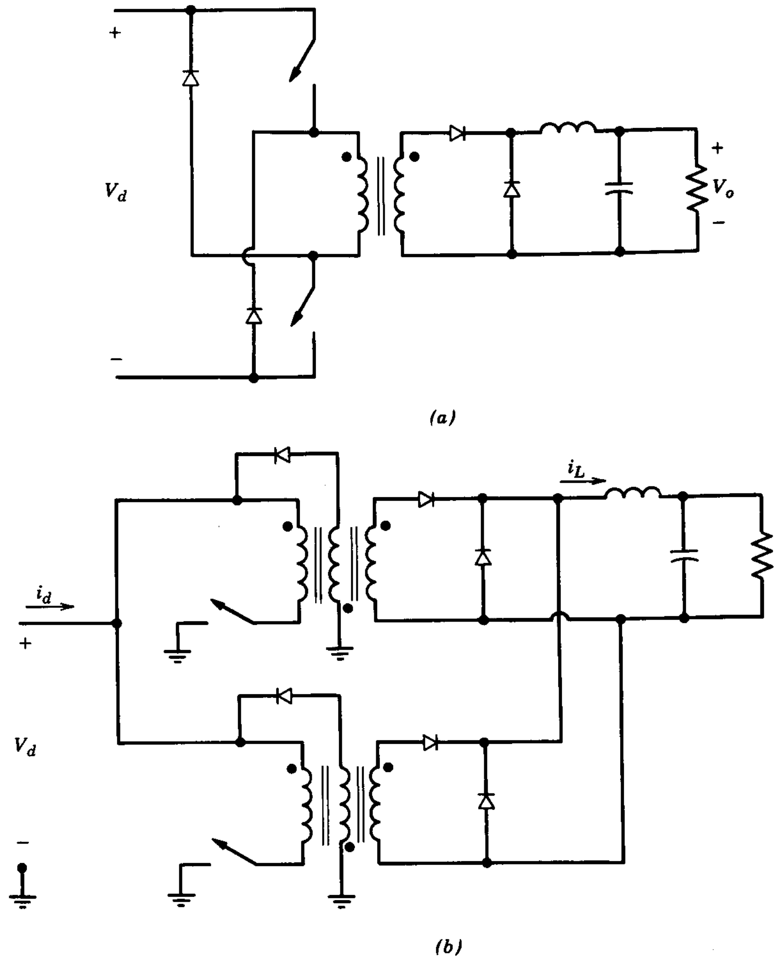


Figure 10-12 Other topologies of forward converter: (*a*) two-switch forward converter; (*b*) parallelled forward converters.

- Two-switch Forward converter is very commonly used

Push-Pull Inverter

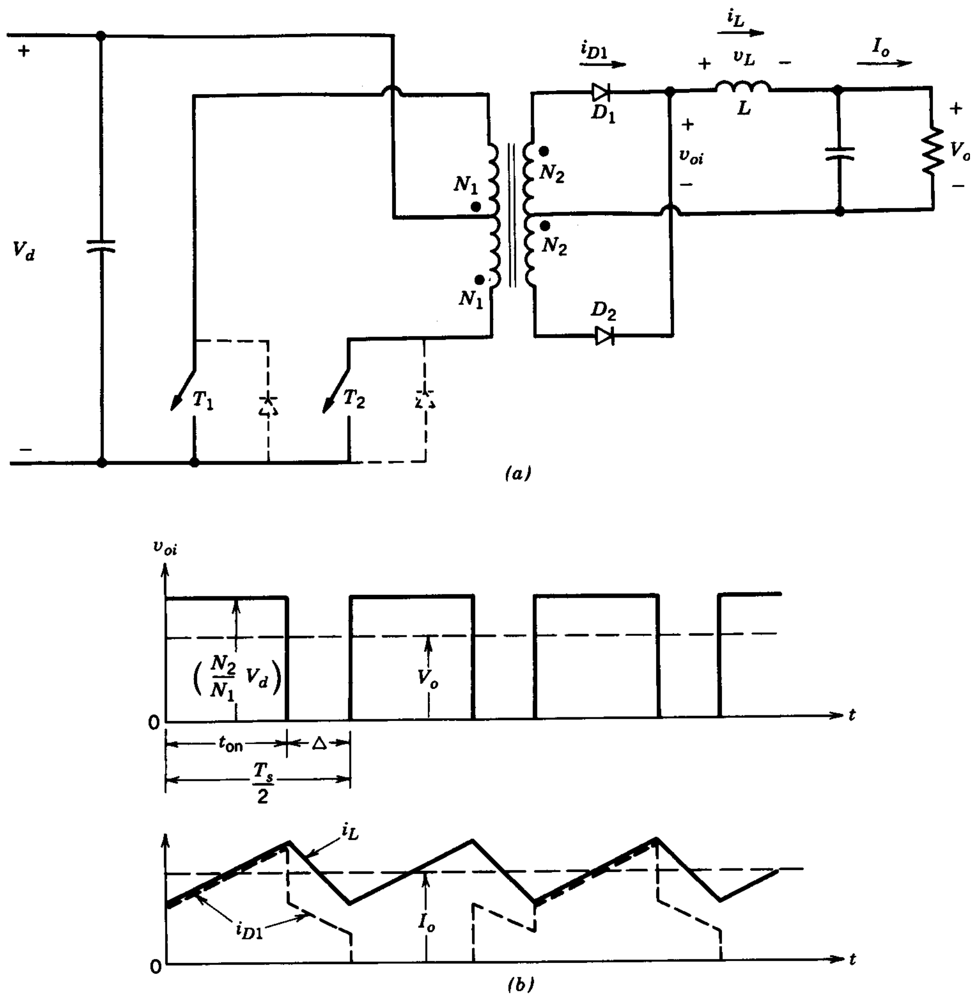


Figure 10-13 Push–pull converter.

- Leakage inductances become a problem

Half-Bridge Converter

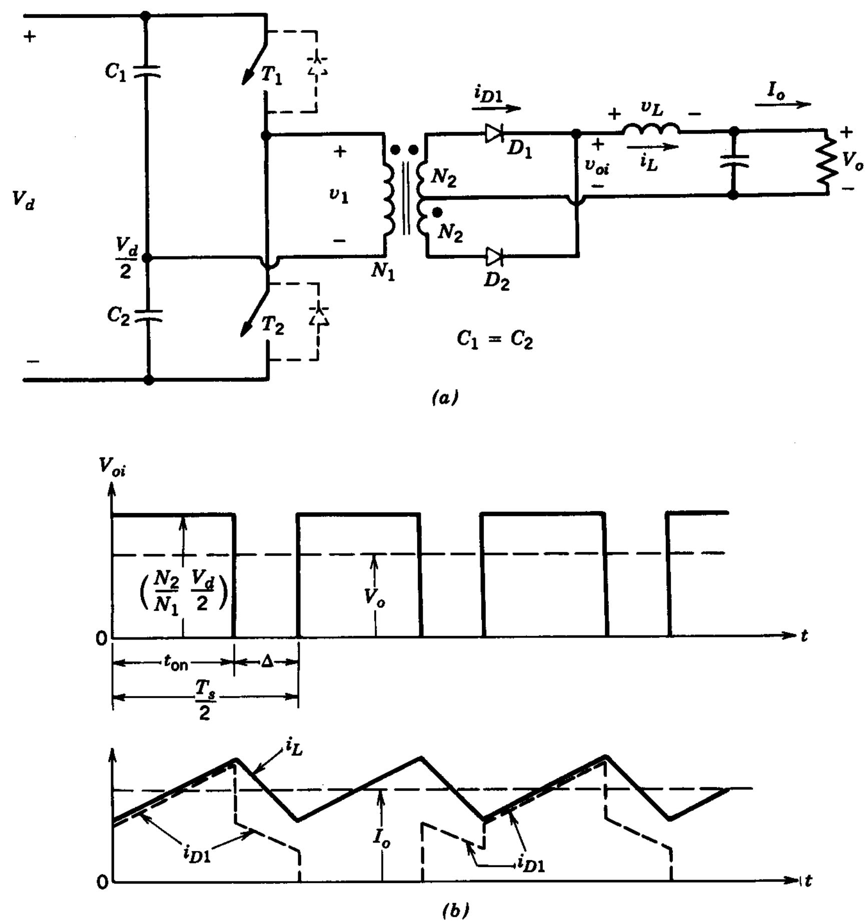


Figure 10-14 Half-bridge dc–dc converter.

- Derived from Buck

Full-Bridge Converter

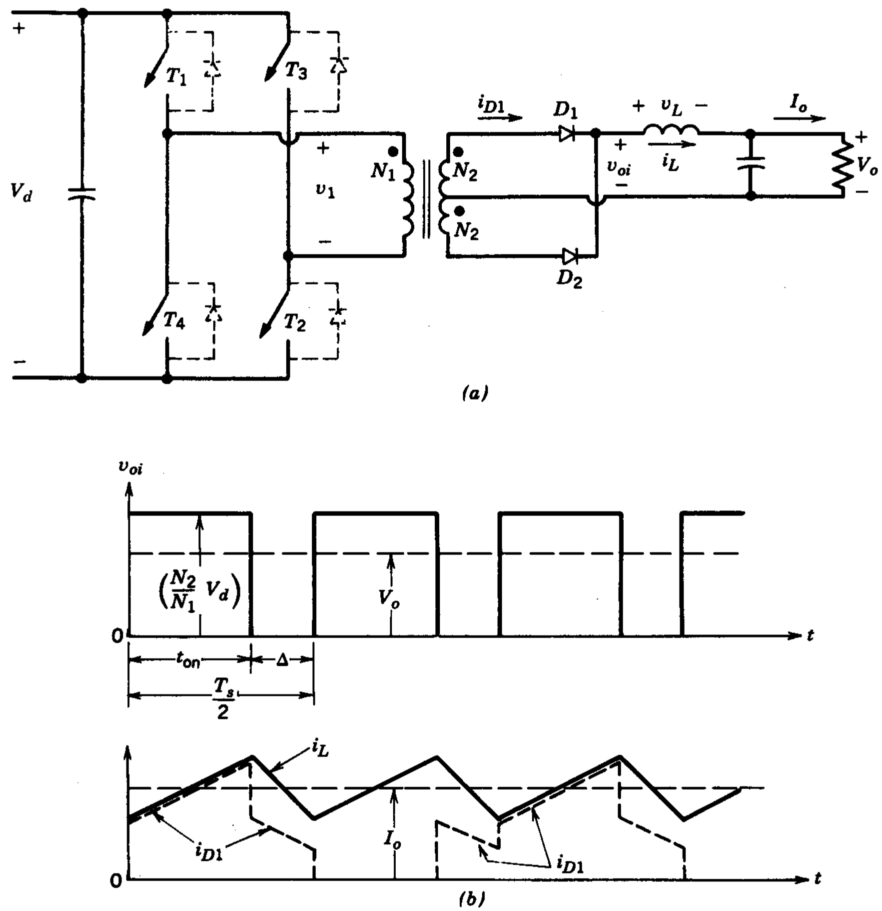


Figure 10-15 Full-bridge converter.

- Used at higher power levels (> 0.5 *kW*)

Current-Source Converter

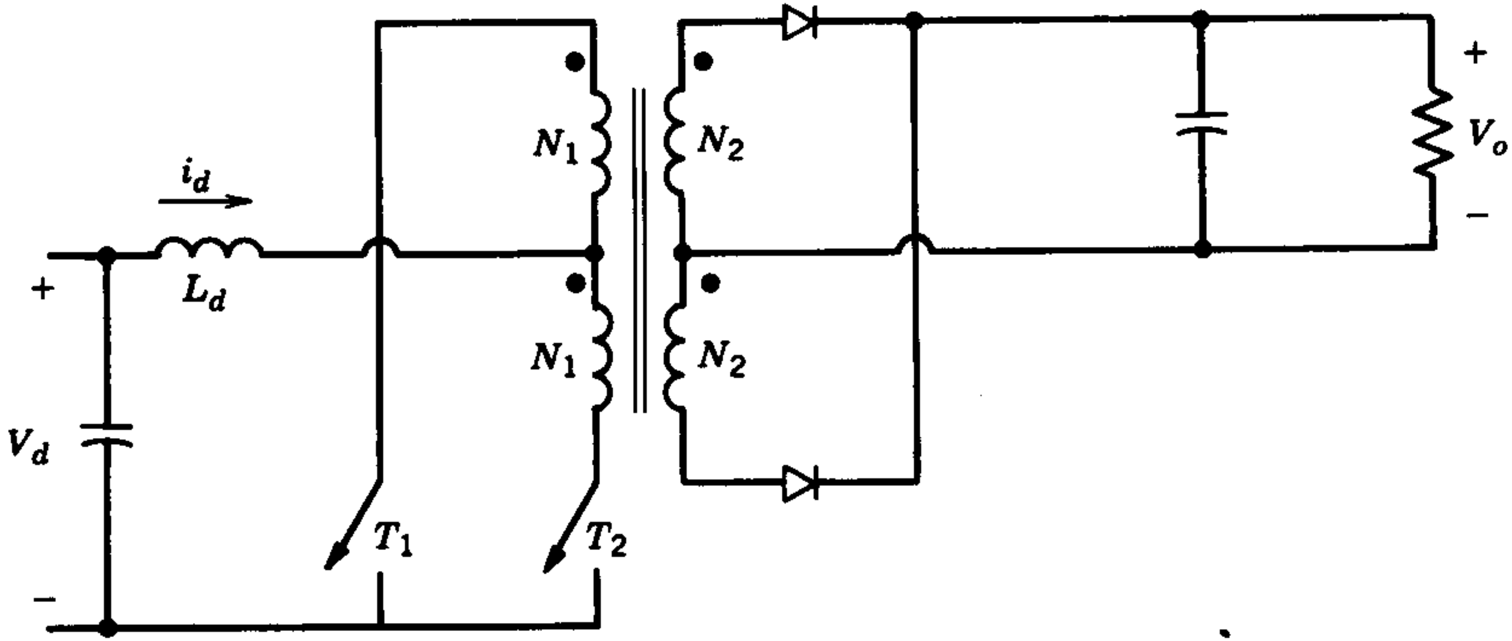


Figure 10-16 Current source converter ($D > 0.5$).

• More rugged (no shoot-through) but both switches must not be open simultaneously

Ferrite Core Material

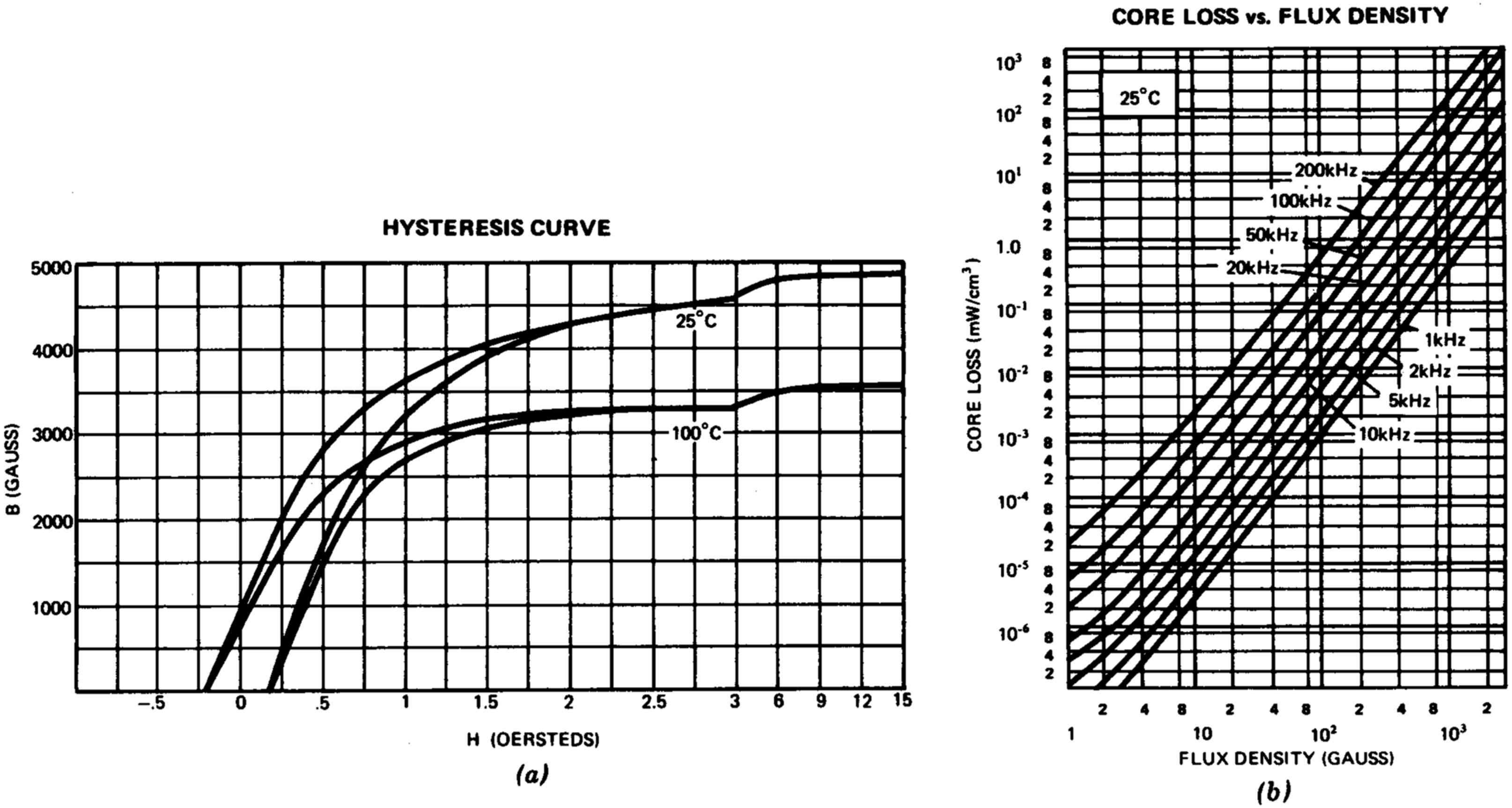


Figure 10-17 3C8 ferrite characteristic curves: (*a*) B–H loop; (*b*) core loss curves. (*Courtesy of Ferroxcube Division of Amperex Electronic Corporation.*)

- Several materials to choose from based on applications

Core Utilization in Various Converter Topologies

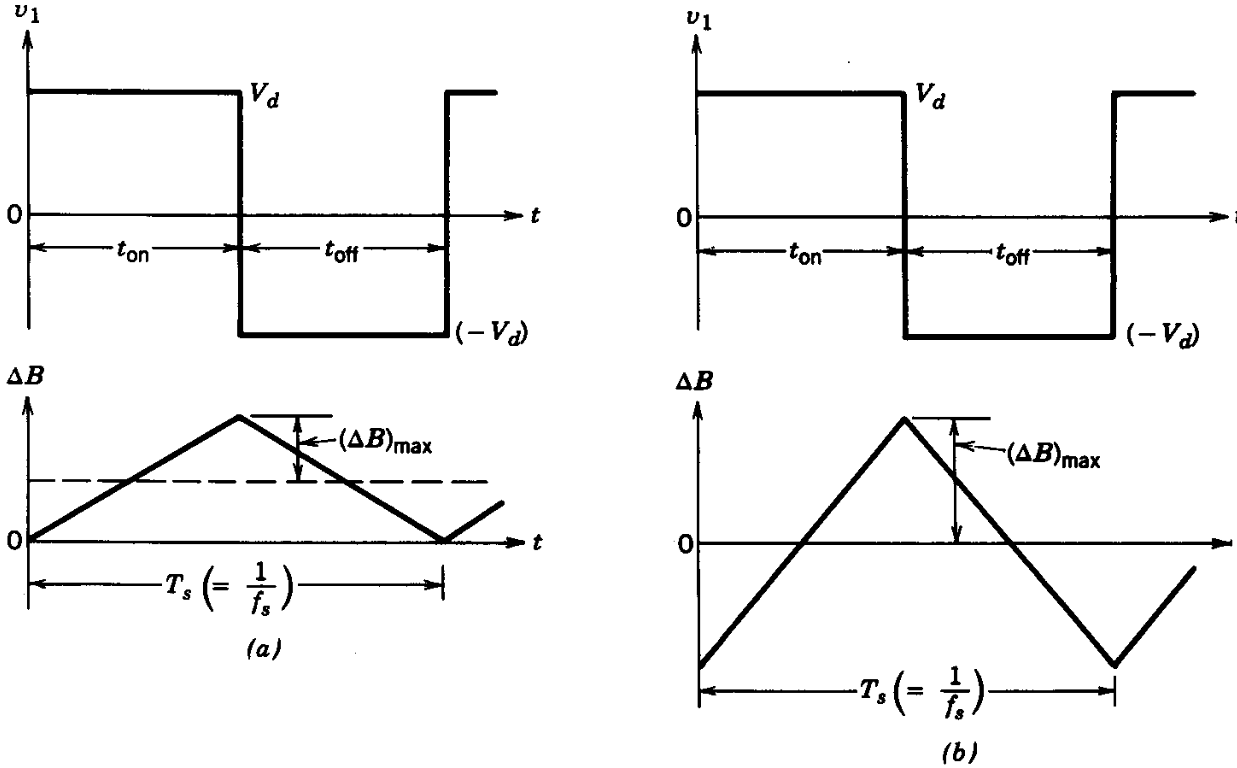


Figure 10-18 Core excitation: (*a*) forward converter, $D = 0.5$; (*b*) full-bridge converter, $D = 0.5$.

- At high switching frequencies, core losses limit excursion of flux density

Control to Regulate Voltage Output

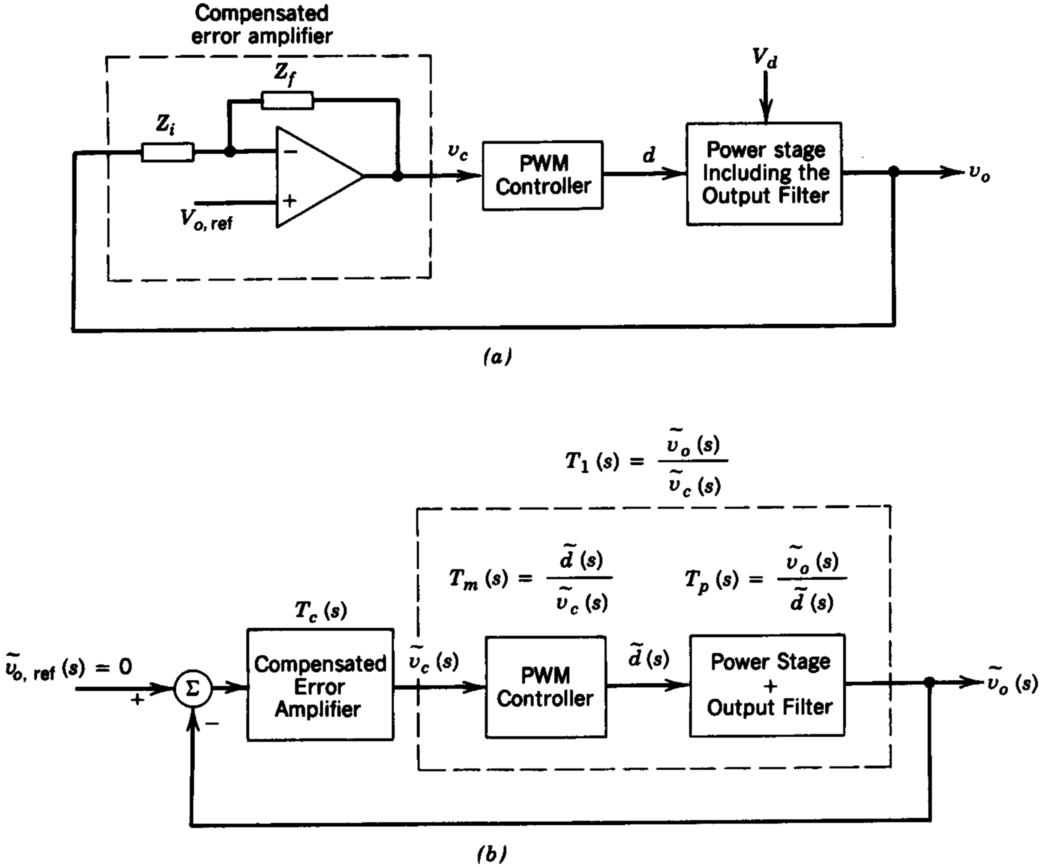


Figure 10-19 Voltage regulation: (*a*) feedback control system; (*b*) linearized feedback control system.

- Linearized representation of the feedback control system

Forward Converter: An Example

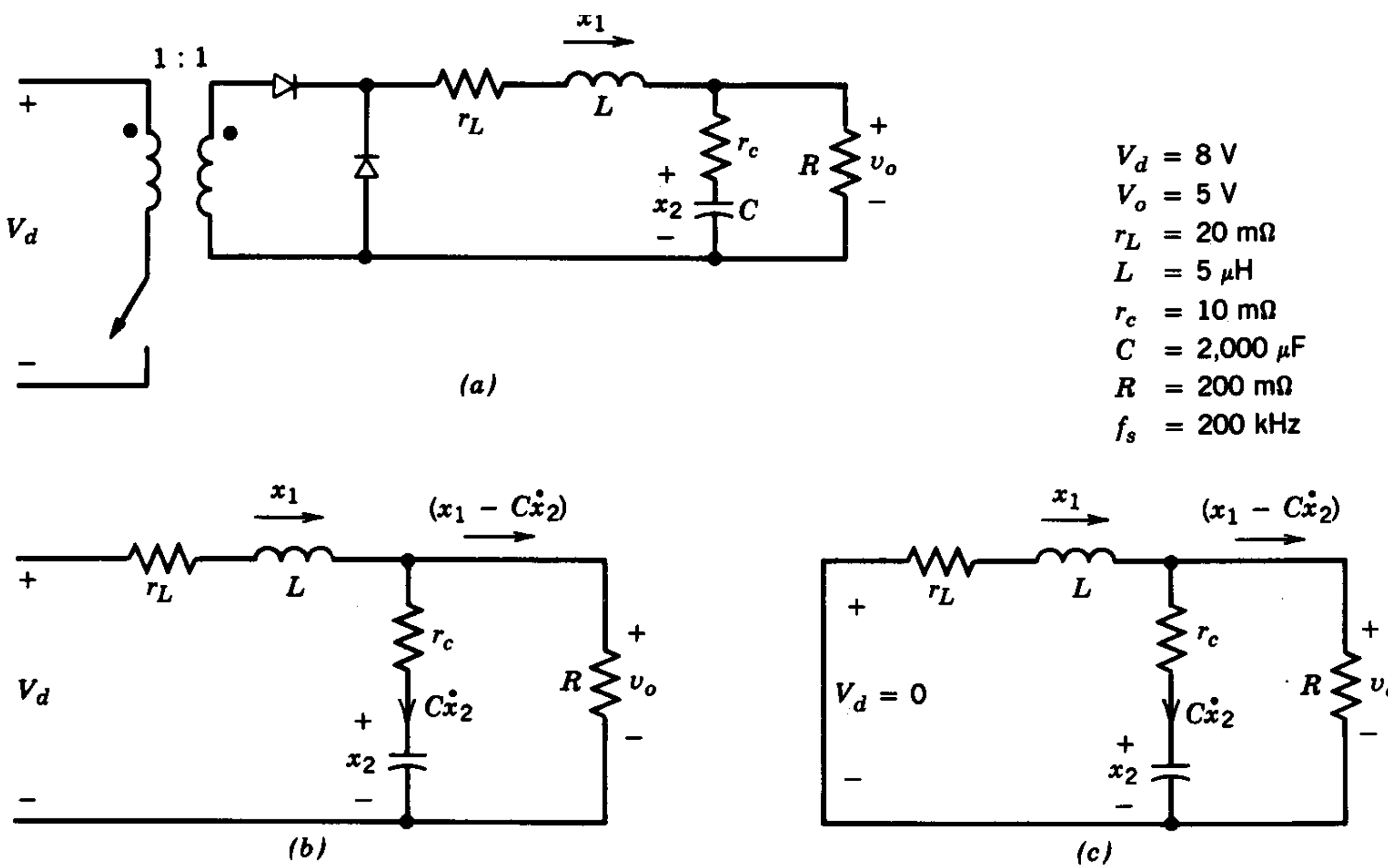
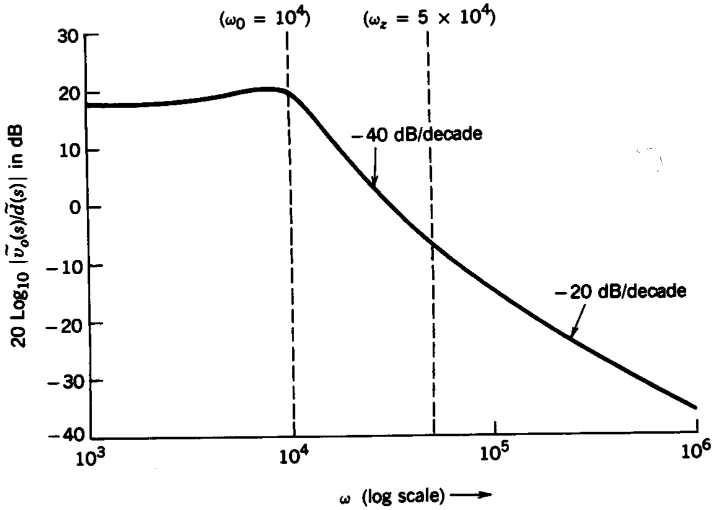


Figure 10-20 Forward converter: (*a*) circuit; (*b*) switch on; (*c*) switch off.

- The switch and the diode are assumed to be ideal

Forward Converter:Transfer Function Plots



- Example considered earlier

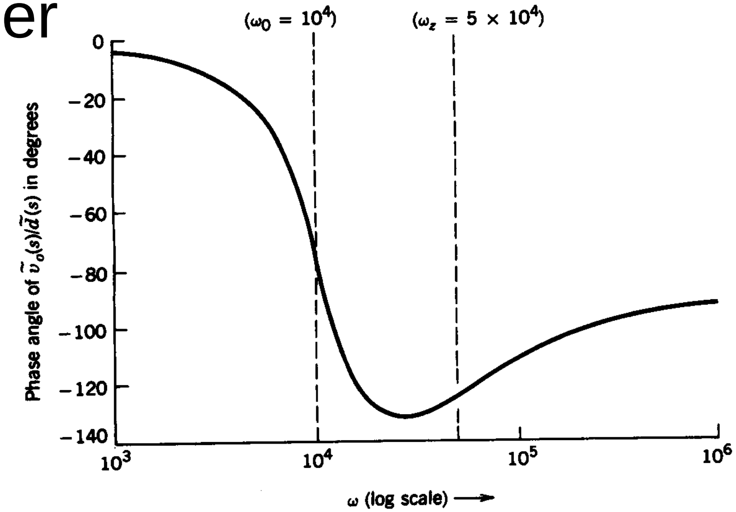


Figure 10-21 (*a*) Gain plot of the forward converter in Fig. 10-20*a*. (*b*) Phase plot of the forward converter in Fig. 10-20*a*.

Flyback Converter:Transfer Function Plots

- An example

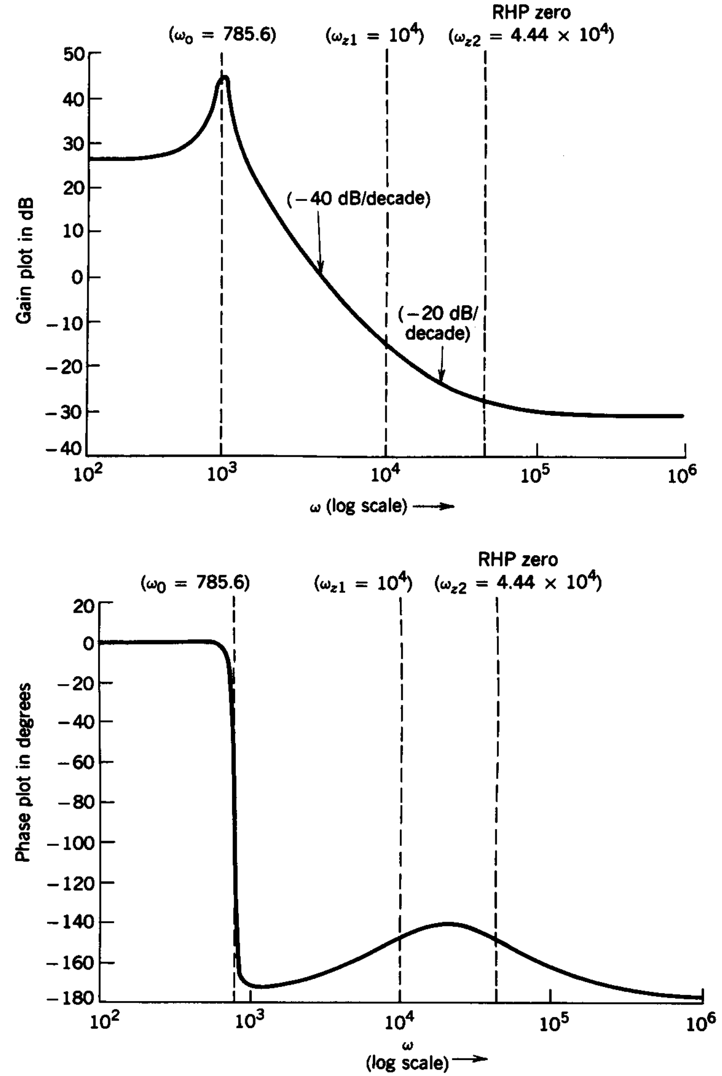


Figure 10-22 (*a*) Gain plot for a flyback converter. (*b*) Phase plot for a flyback converter.

Linearizing the PWM Block

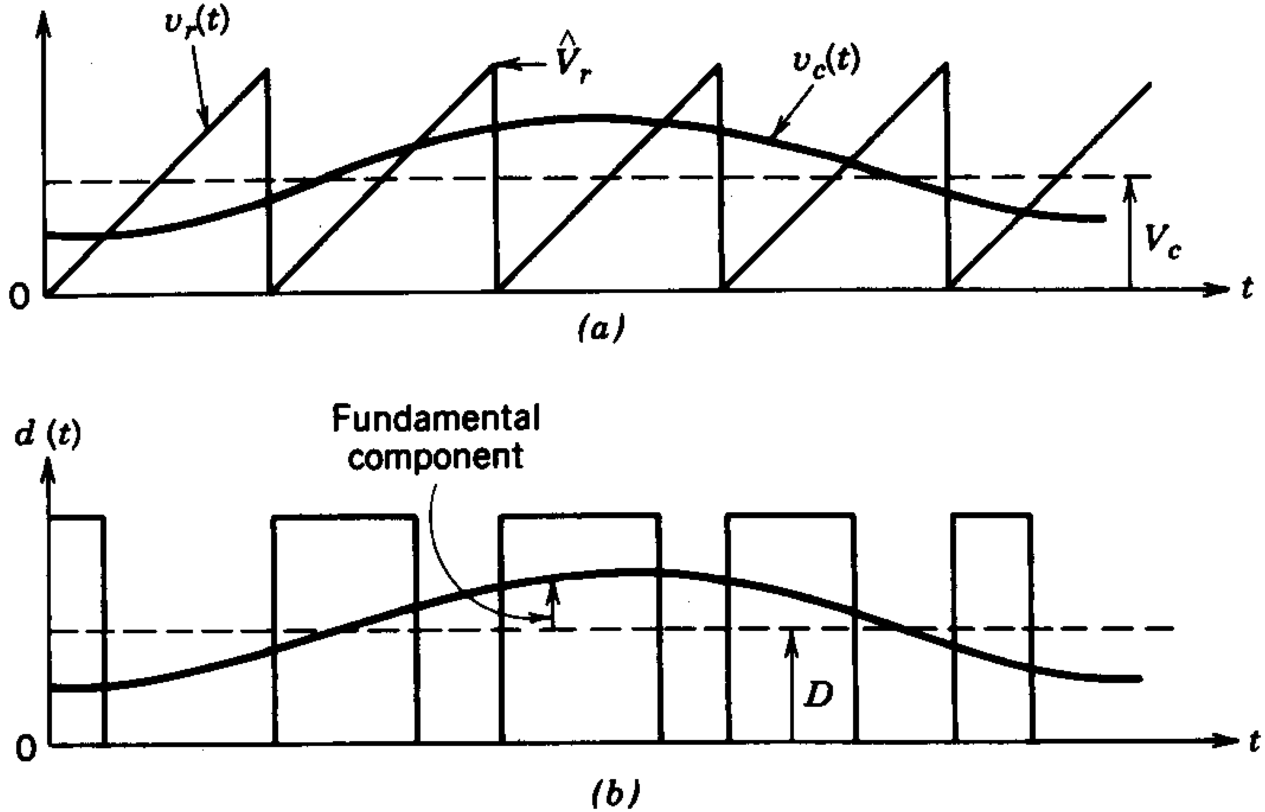


Figure 10-23 Pulse-width modulator.

- The transfer function is essentially a constant with zero phase shift

Gain of the PWM IC

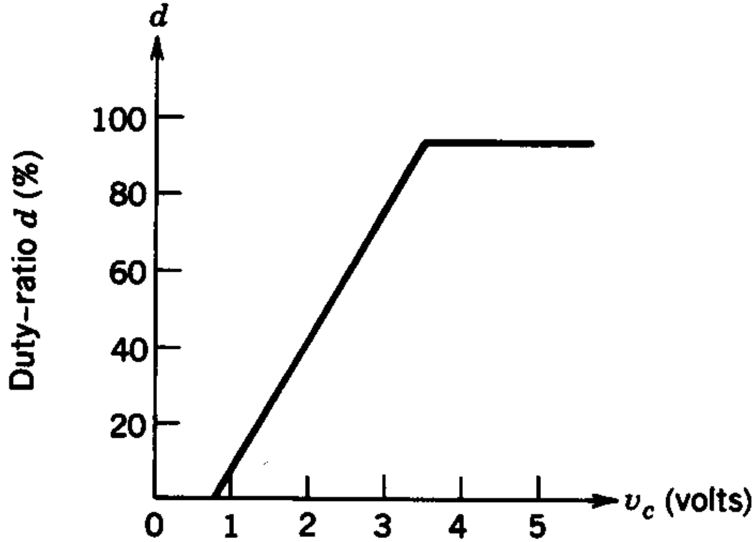


Figure 10-24 Pulse-width modulator transfer function.

- It is slope of the characteristic

Typical Gain and Phase Plots of the Open-Loop Transfer Function

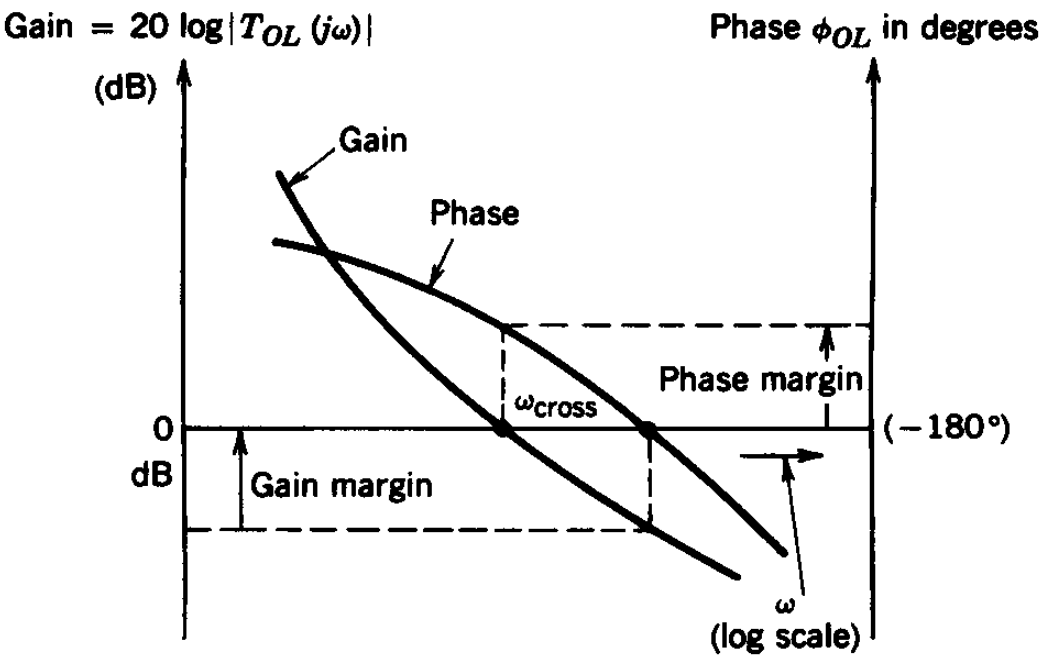


Figure 10-25 Gain and phase margins.

- Definitions of the crossover frequency, phase and gain margins

A General Amplifier for Error Compensation

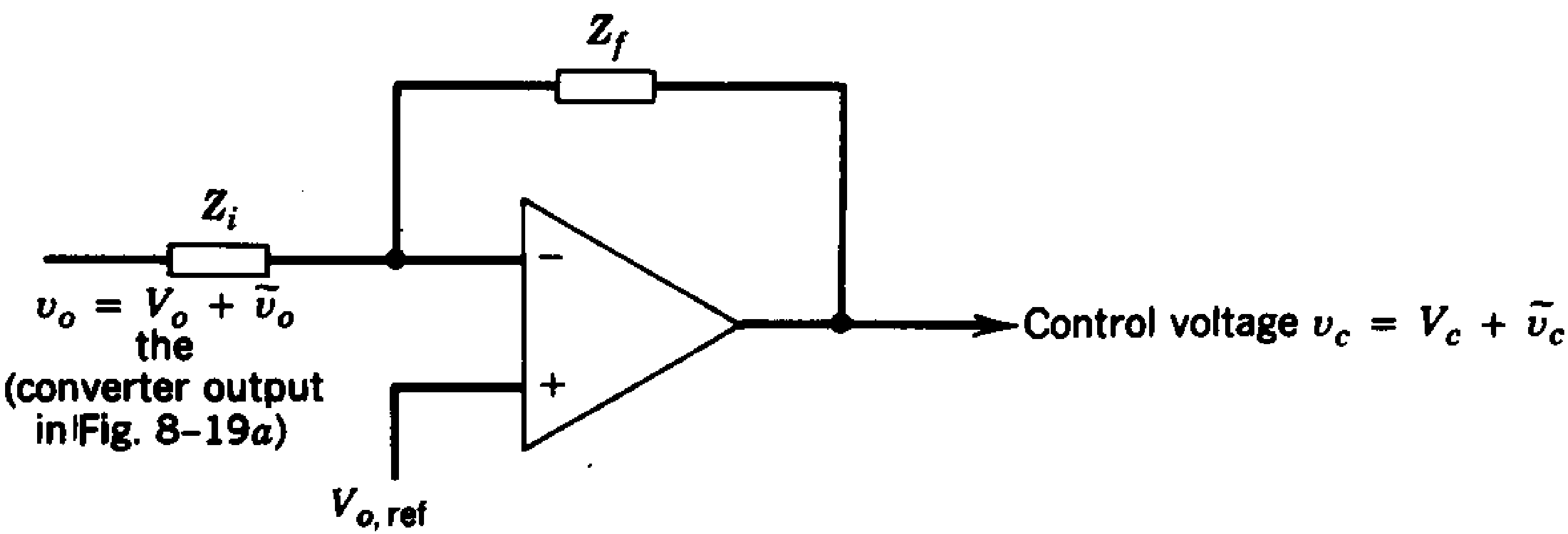


Figure 10-26 A general compensated error amplifier.

- Can be implemented using a single op-amp

Type-2 Error Amplifier

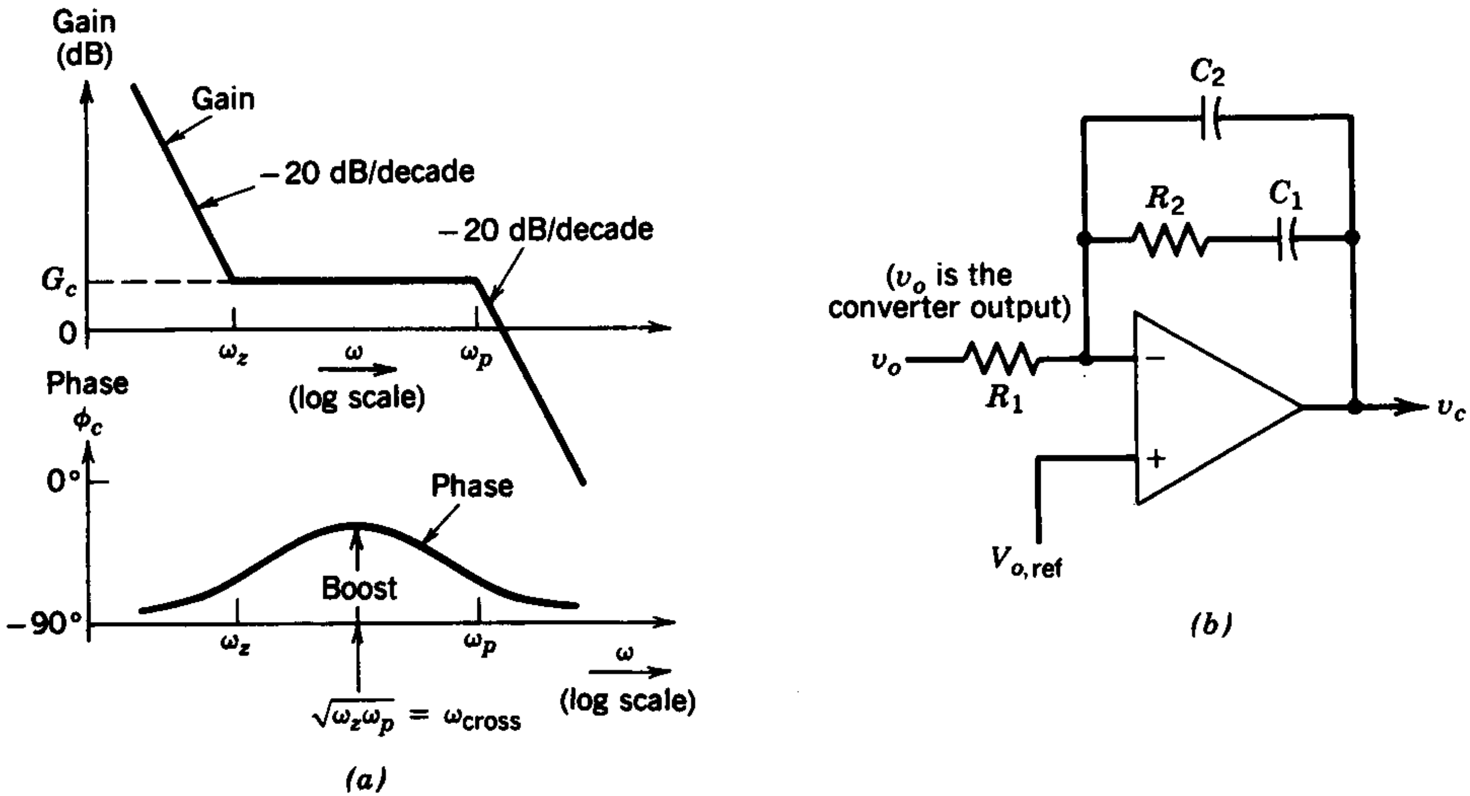


Figure 10-27 Error amplifier.

- Shows phase boost at the crossover frequency

Voltage Feed-Forward

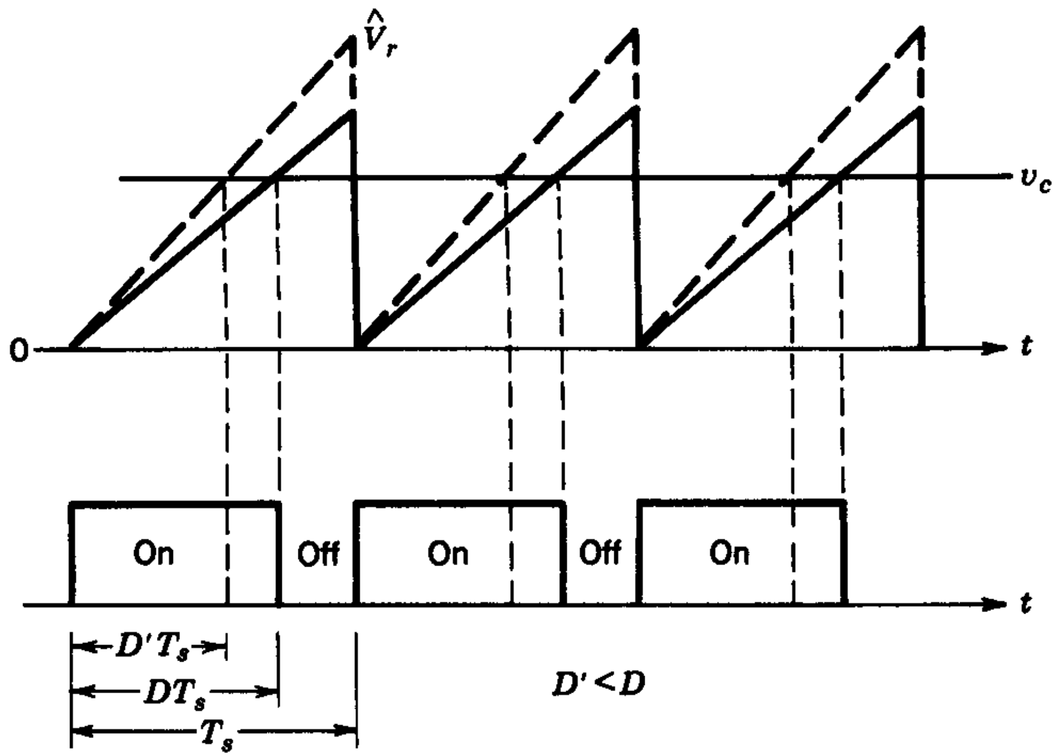


Figure 10-28 Voltage feed-forward: effect on duty ratio.

- Makes converter immune from input voltage variations

Voltage versus Current Mode Control

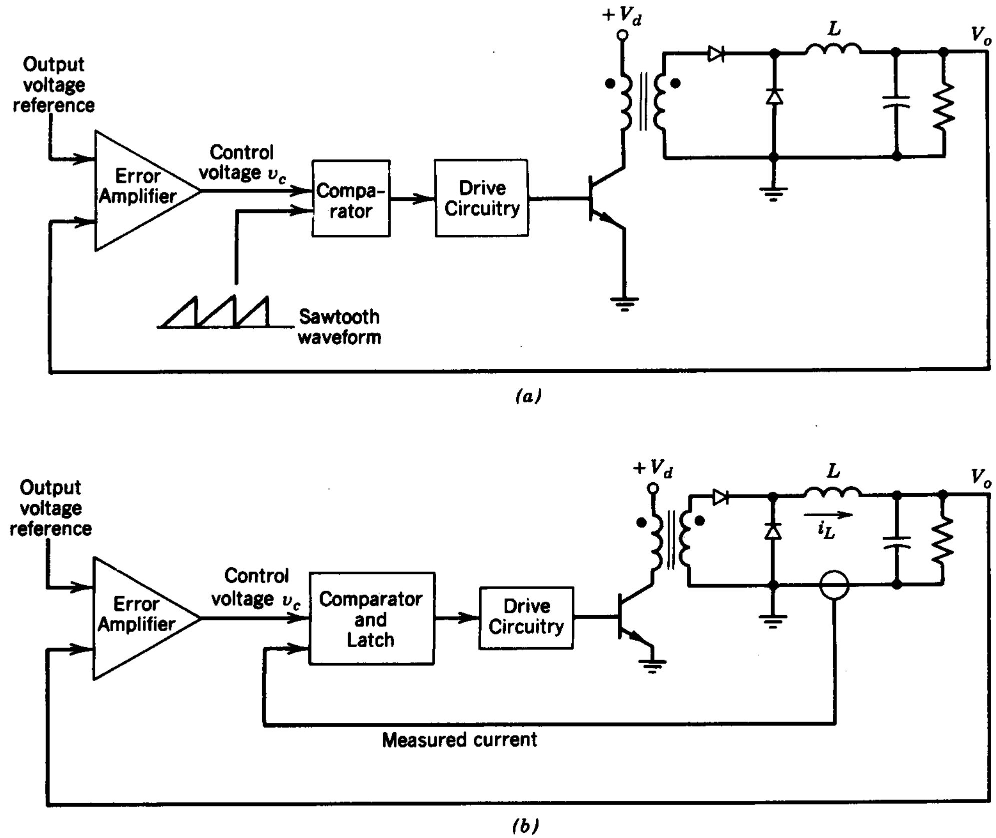


Figure 10-29 PWM duty ratio versus current-mode control: (*a*) PWM duty ratio control; (*b*) current-mode control.

- Regulating the output voltage is the objective in both modes of control

Various Types of Current Mode Control

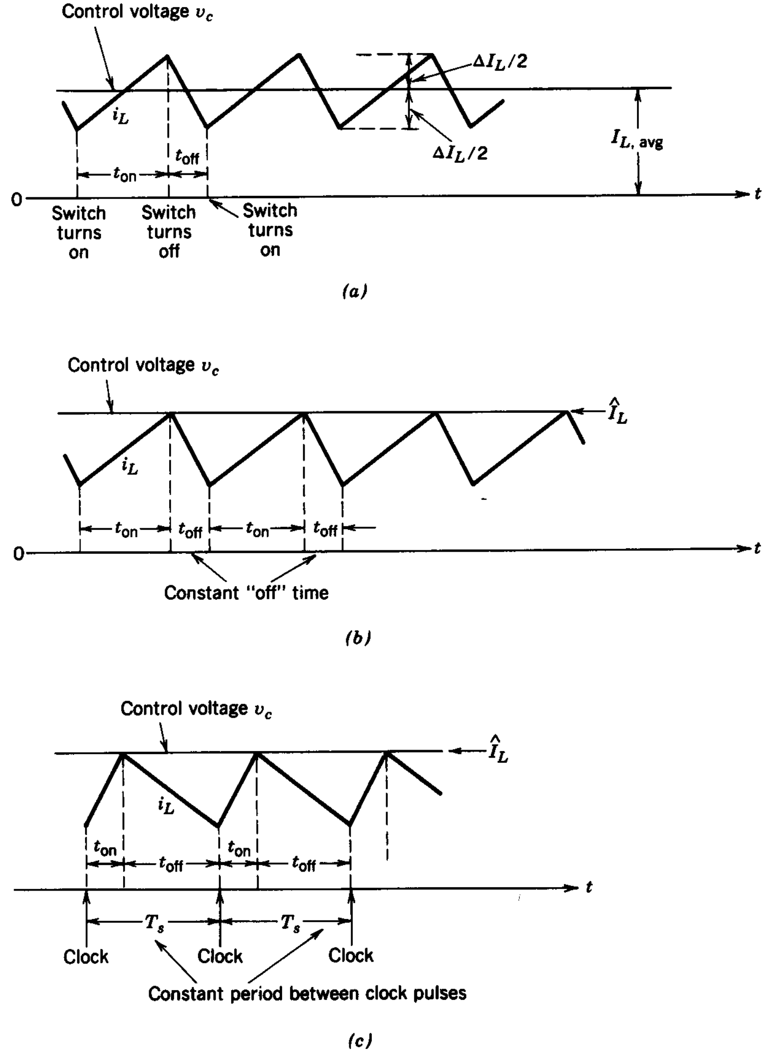


Figure 10-30 Three types of current-mode control: (*a*) tolerance band control; (*b*) constant-off-time control; (*c*) constant frequency with turn-on at clock time.

- Constant frequency, peak-current mode control is used most frequently

Peak Current Mode Control

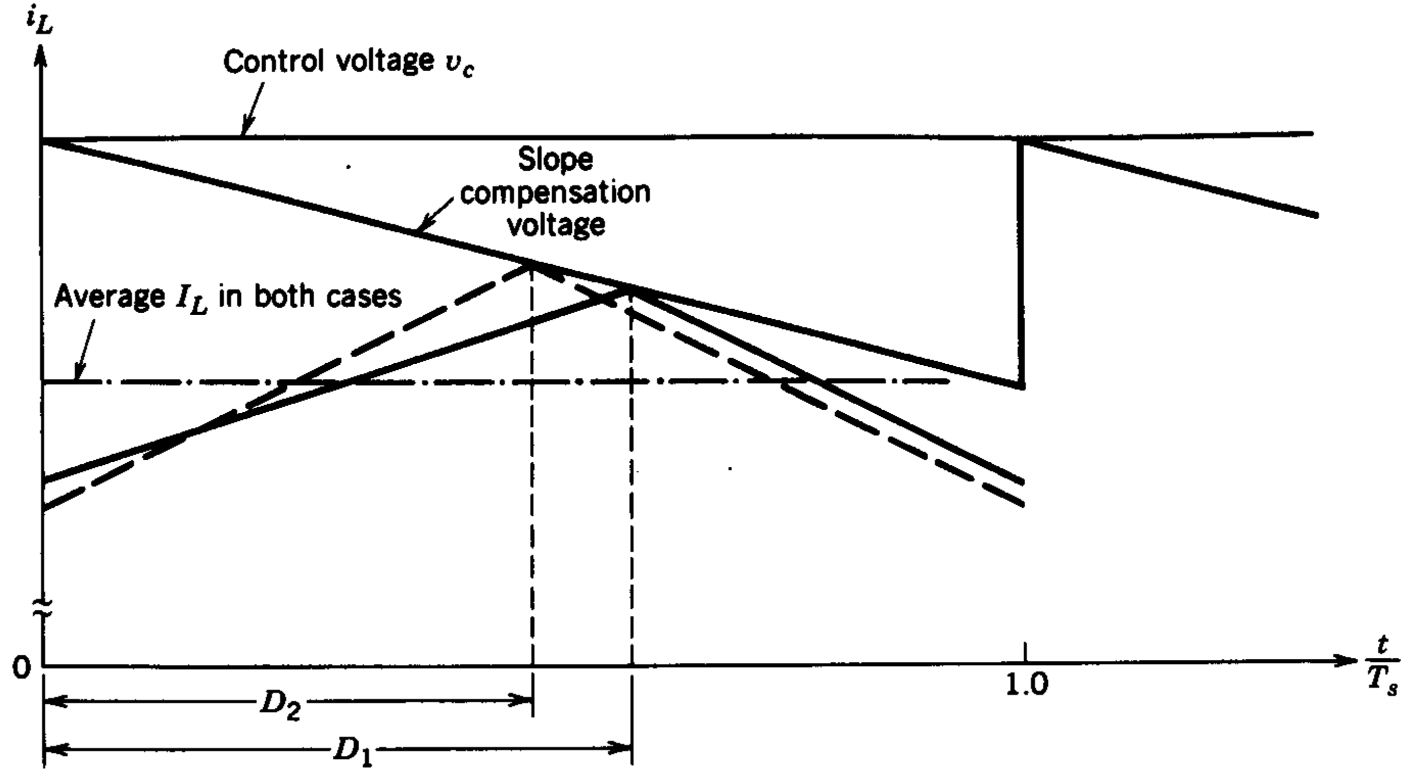


Figure 10-31 Slope compensation in current-mode control (D_2 is smaller for a higher input voltage with a constant V_o).

- Slope compensation is needed

A Typical PWM Control IC

- Many safety control functions are built in

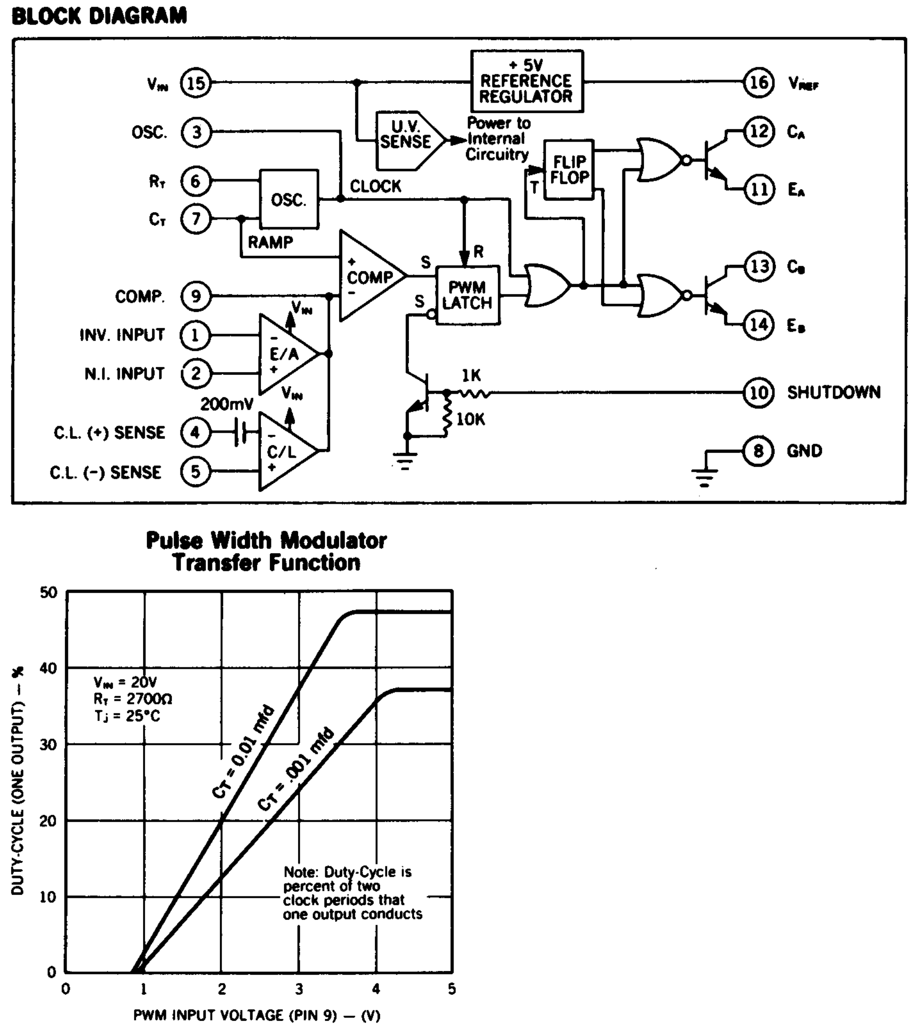


Figure 10-32 Pulse-width modulator UC1524A: (*a*) block diagram; (*b*) transfer function. (*Courtesy of Unitrode Integrated Circuits Corp.*)

Current Limiting

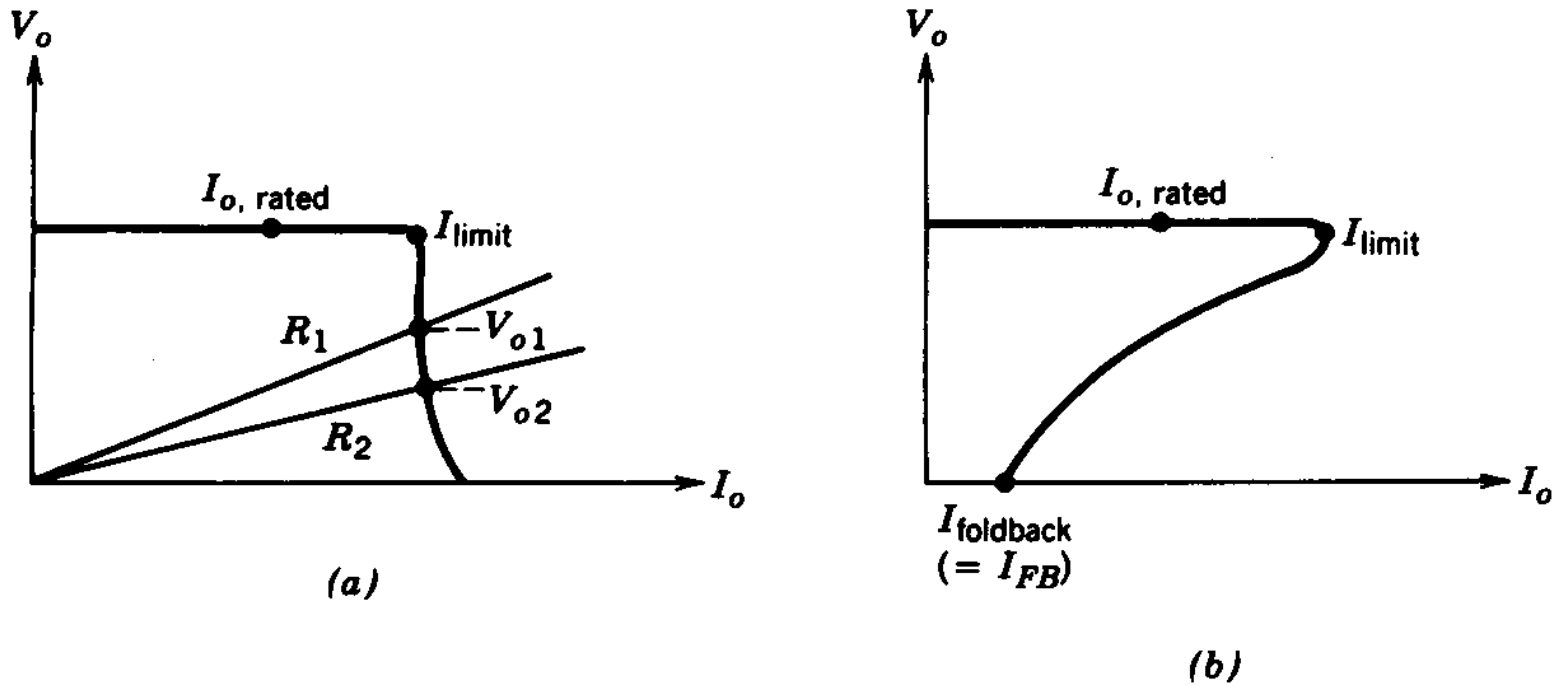
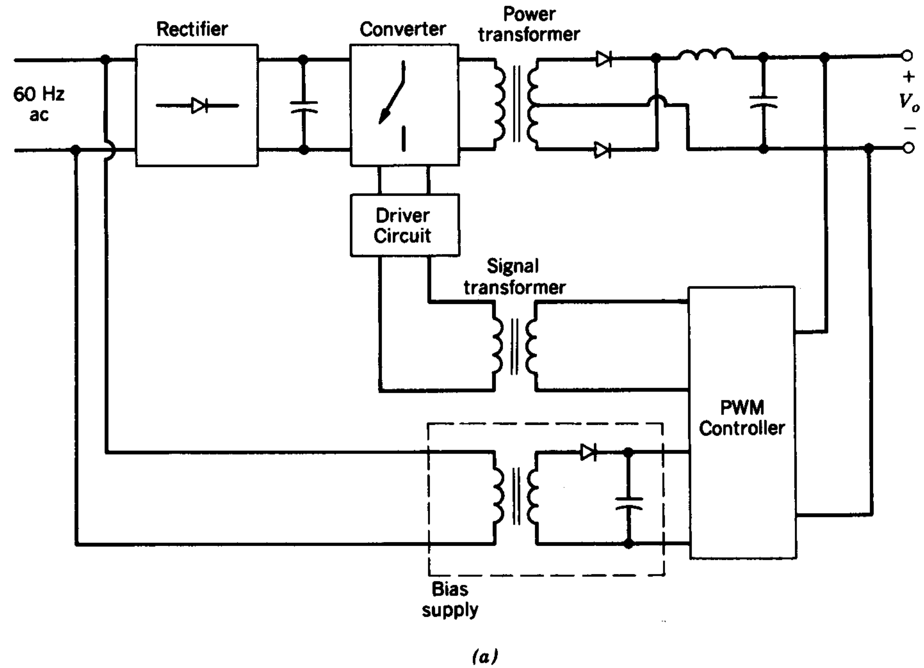


Figure 10-33 Current limiting: (a) constant current limiting; (b) foldback current limiting.

- Two options are shown

Implementing Electrical Isolation in the Feedback Loop

- Two ways are shown



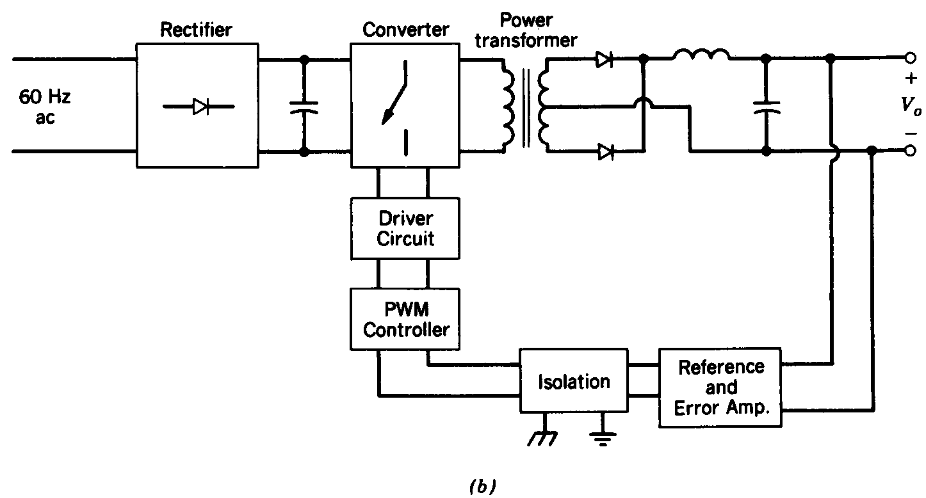


Figure 10-34 Electrical isolation in the feedback loop: (*a*) secondary-side control; (*b*) primary-side control.

Implementing Electrical Isolation in the Feedback Loop

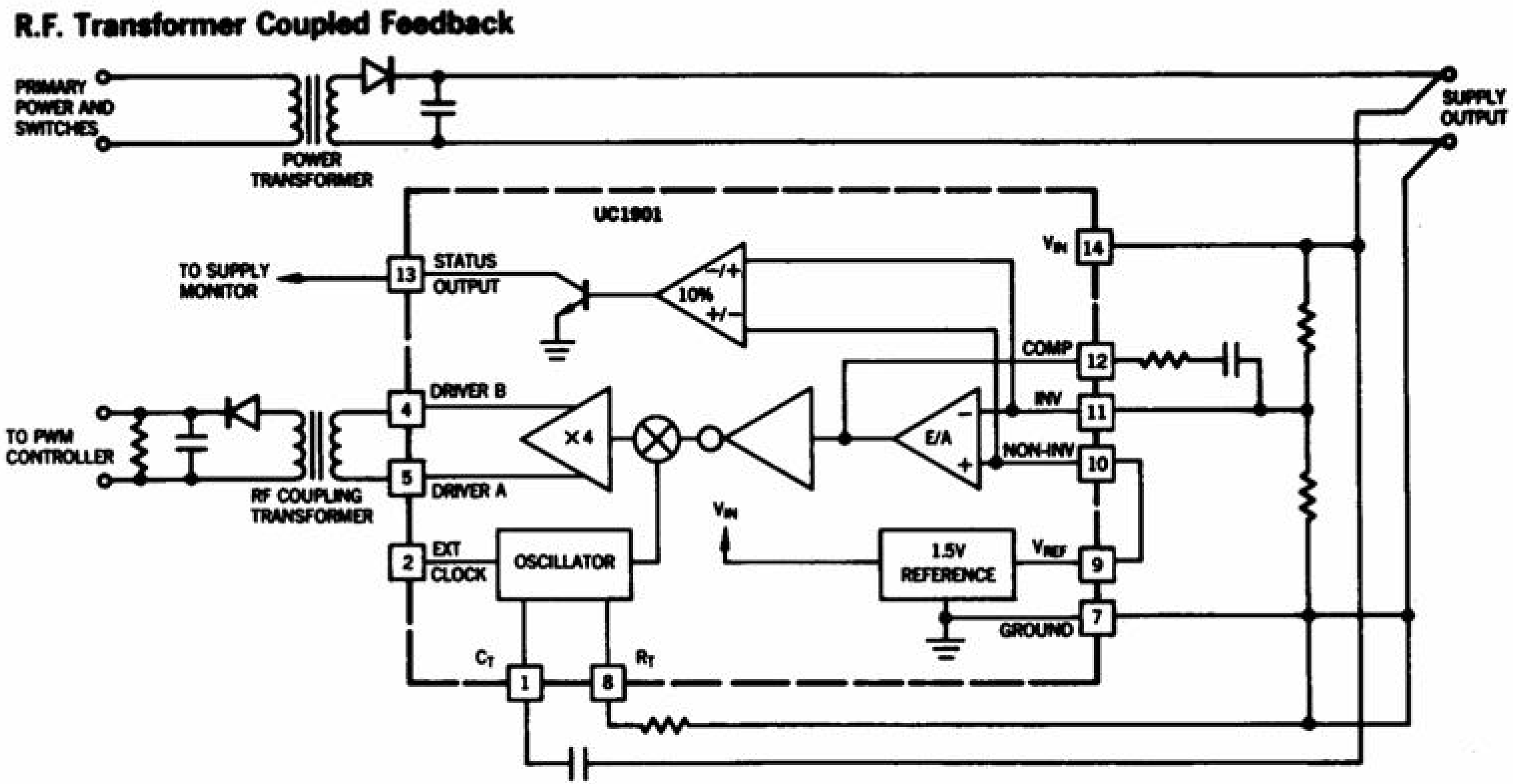


Figure 10-35 Isolated feedback generator UC1901. (*Courtesy of Unitrode Integrated Circuits Corp.*)

- A dedicated IC for this application is available

Input Filter

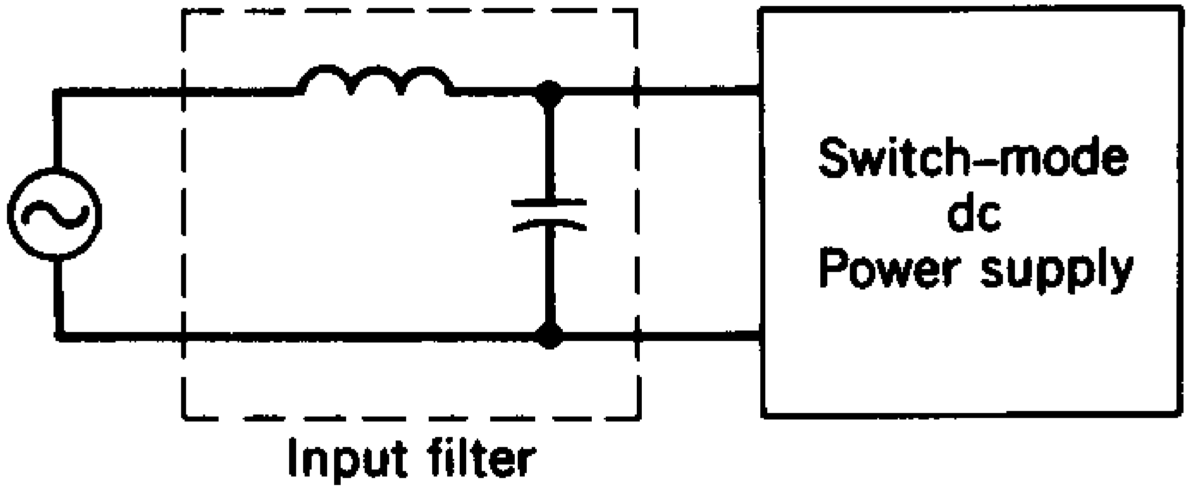


Figure 10-36 Input filter.

- Needed to comply with the EMI and harmonic limits

ESR of the Output Capacitor

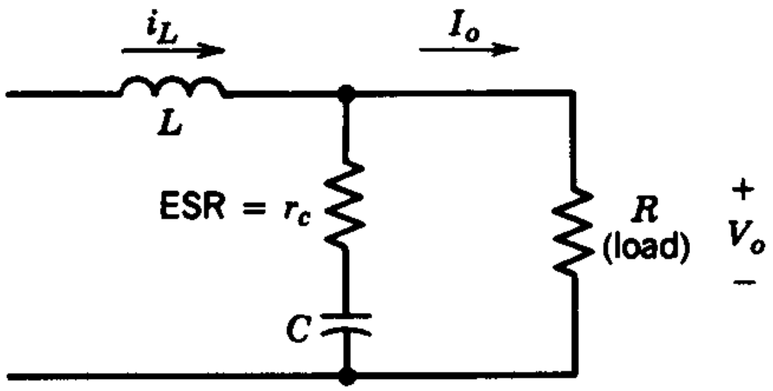


Figure 10-37 ESR in the output capacitor.

- ESR often dictates the peak-peak voltage ripple