Power Supplies for Mechatronics Systems

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Sources of power for DC motors

1. Batteries

2. AC Power Supply >> DC power Supply

Power supplies

1. Power from Batteries

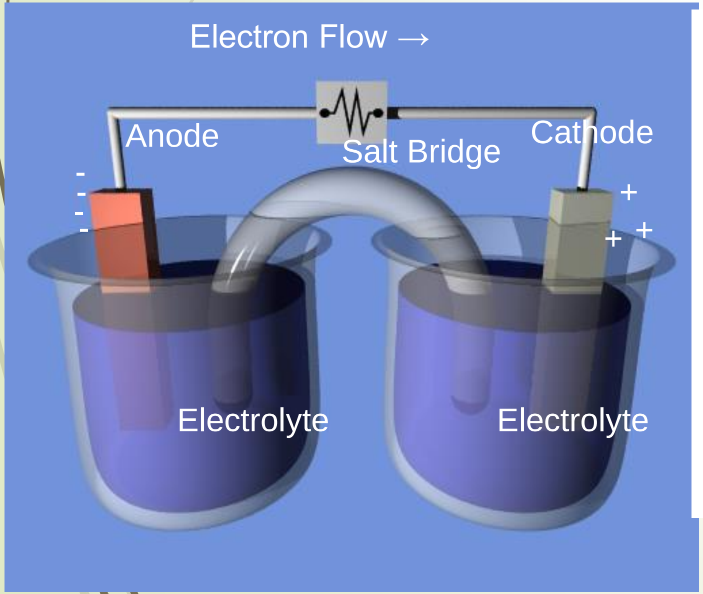
2. Power from supply mains: 100 V, 230 V 50 Hz or 60 Hz

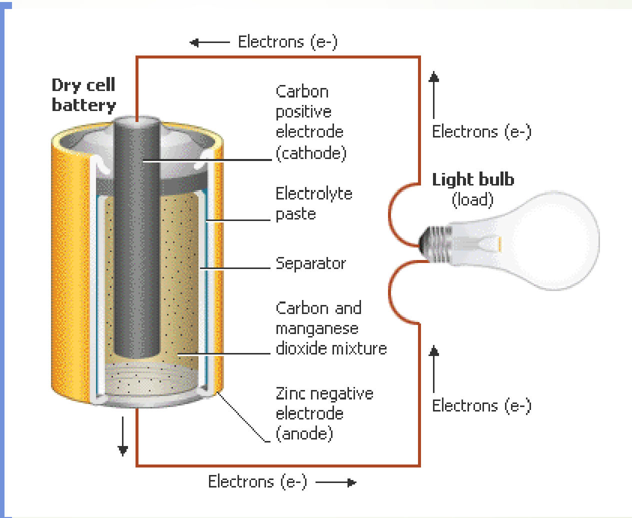
Output voltages: 3 V, 4.5 V, 6 V, 7.5 V, 9 V and 12 V

Batteries

How Electrochemical Batteries Work

- REDOX Reaction
  - Oxidation, the loss of electrons, occurs at the anode.
  - Reduction, the gain of electrons, occurs at the cathode.





- Primary Batteries – Disposable

  Secondary Batteries – Rechargeable

  emf – Electromotive force, voltage

  Ampere·hour (Ah) = 3600 coulombs, a measure of electric charge

  Watt ·hour (Wh) = 3600 joules, a measure of energy
- Ah = (Wh) / emf

The Electrochemical Cell

$$Zn \longrightarrow Zn^{2+} + 2e^- \quad (I.)$$

$$Cu^{2+} + 2e^- \longrightarrow Cu \quad (II.)$$

- **Zinc is (much) more easily oxidized than Copper**
- **Salt bridge only carries negative ions**
  - **This is the limiting factor for current flow**
  - **Pick a low-resistance bridge**

The Electrochemical Series

Most wants to reduce (gain electrons)

- Gold
- Mercury
- Silver
- Copper
- Lead
- Nickel
- Cadmium

- Iron
- Zinc
- Aluminum
- Magnesium
- Sodium
- Potassium
- *Lithium*

Most wants to oxidize (lose electrons)

History of battery:

- The Nickel-Cadmium Battery
  - Invented in 1899 by Waldmar Jungner.
- The common Alkaline Battery
  - Invented in 1955 by Lewis Urry
- The Nickel Metal-Hydrid Battery
  - NiMH batteries for smaller applications started to be on the market in 1989.
- Lithium and Lithium-ion Batteries
  - First lithium batteries sold in the 1970s
  - First lithium-ion batteries sold in 1991
  - First lithium-ion polymer batteries released in 1996

Battery Characteristics

- Size
  - Physical: button, AAA, AA, C, D, ...
  - Energy density (watts per kg or cm^3)
- Longevity
  - Capacity (Ah, for drain of C/10 at 20°C)
  - Number of recharge cycles
- Discharge characteristics (voltage drop)
- Cost
- Behavioral factors
  - Temperature range (storage, operation)
  - Self discharge
  - Memory effect
- Environmental factors
  - Leakage, gassing, toxicity
  - Shock resistance

Main specifications

	AAA	AA	9V	C	D
Capacity (Ah)	1.250	2.890	0.625	8.350	20.500
Voltage	1.5	1.5	9	1.5	1.5
Energy (Wh)	1.875	4.275	5.625	12.525	30.75

Batteries – a short description

Nickel Cadmium (NiCd) — mature and well understood but relatively low in energy density. The NiCd is used where long life, high discharge rate and economical price are important. Main applications are two-way radios, biomedical equipment, professional video cameras and power tools. The NiCd contains toxic metals and is environmentally unfriendly.

Nickel-Metal Hydride (NiMH) — has a higher energy density compared to the NiCd at the expense of reduced cycle life. NiMH contains no toxic metals. Applications include mobile phones and laptop computers.

Lead Acid — most economical for larger power applications where weight is of little concern. The lead acid battery is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems.

Lithium Ion (Li-ion) — fastest growing battery system. Li-ion is used where high-energy density and lightweight is of prime importance. The technology is fragile and a protection circuit is required to assure safety. Applications include notebook computers and cellular phones.

Lithium Ion Polymer (Li-ion polymer) — offers the attributes of the Li-ion in ultra-slim geometry and simplified packaging. Main applications are mobile phones.

Discharge of a battery:

C Rating Background

C Rate is derived from Coulomb's Law developed by French physicist Charles Augustin de Coulomb. The C-rate is the governing measurement of what current a battery is charged or discharged at. For example, the mAh of Ah of the battery is the 1C rating. If a battery is labelled 2000mAh, then its 1C rating is 2000mAh.

To make this simple, the battery should provide 1C current for one hour. In our example above that would be 2000mAh or 2A of current for one hour. The same applies for a 0.5C rating. Again using the 2000mAh battery, it would deliver 1000mAh or 1A of current for two hours.

Battery C Rating Examples

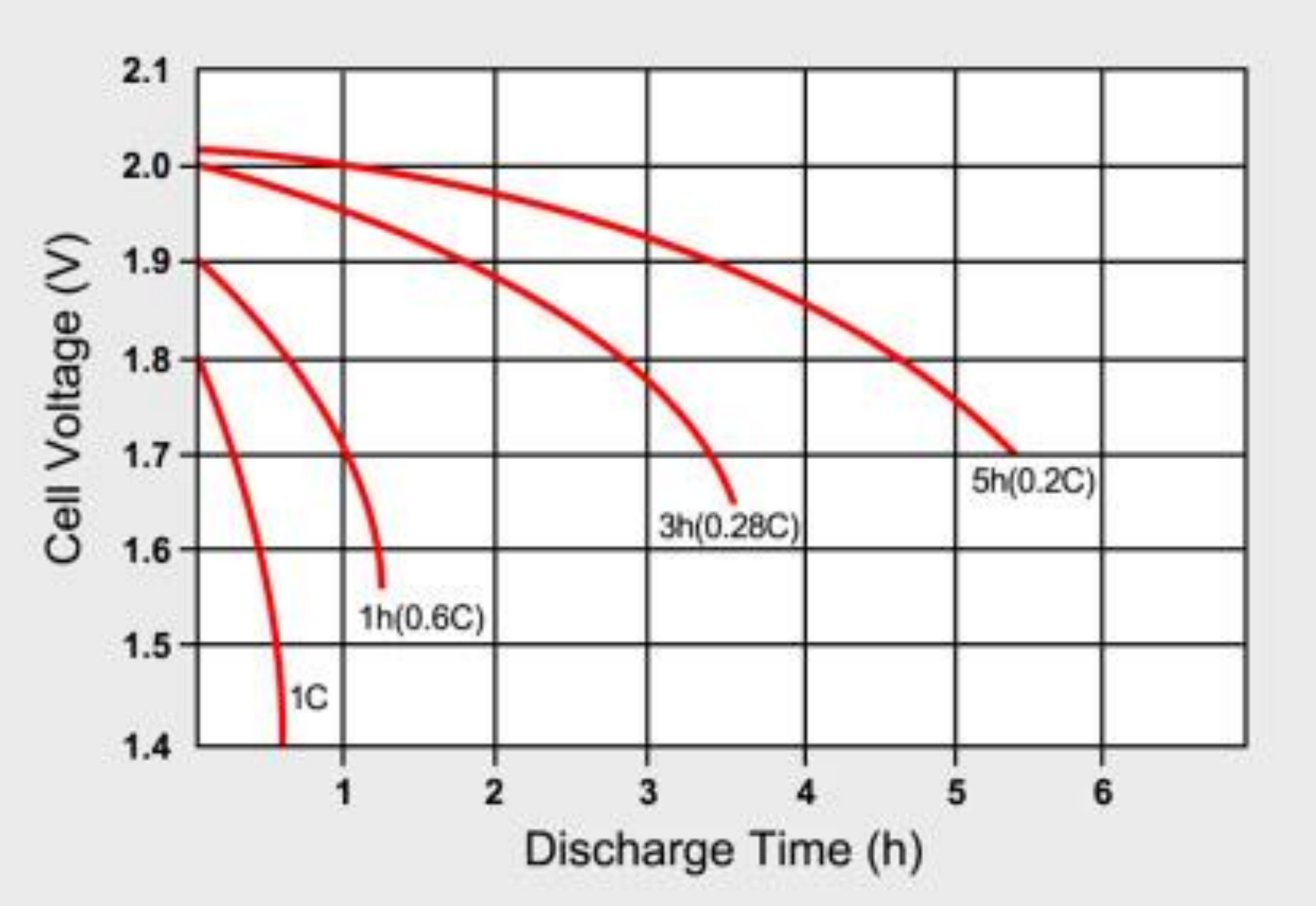
The formulas for the example are simple. 1600mAh battery with a 10C rating.

Continuous Discharge

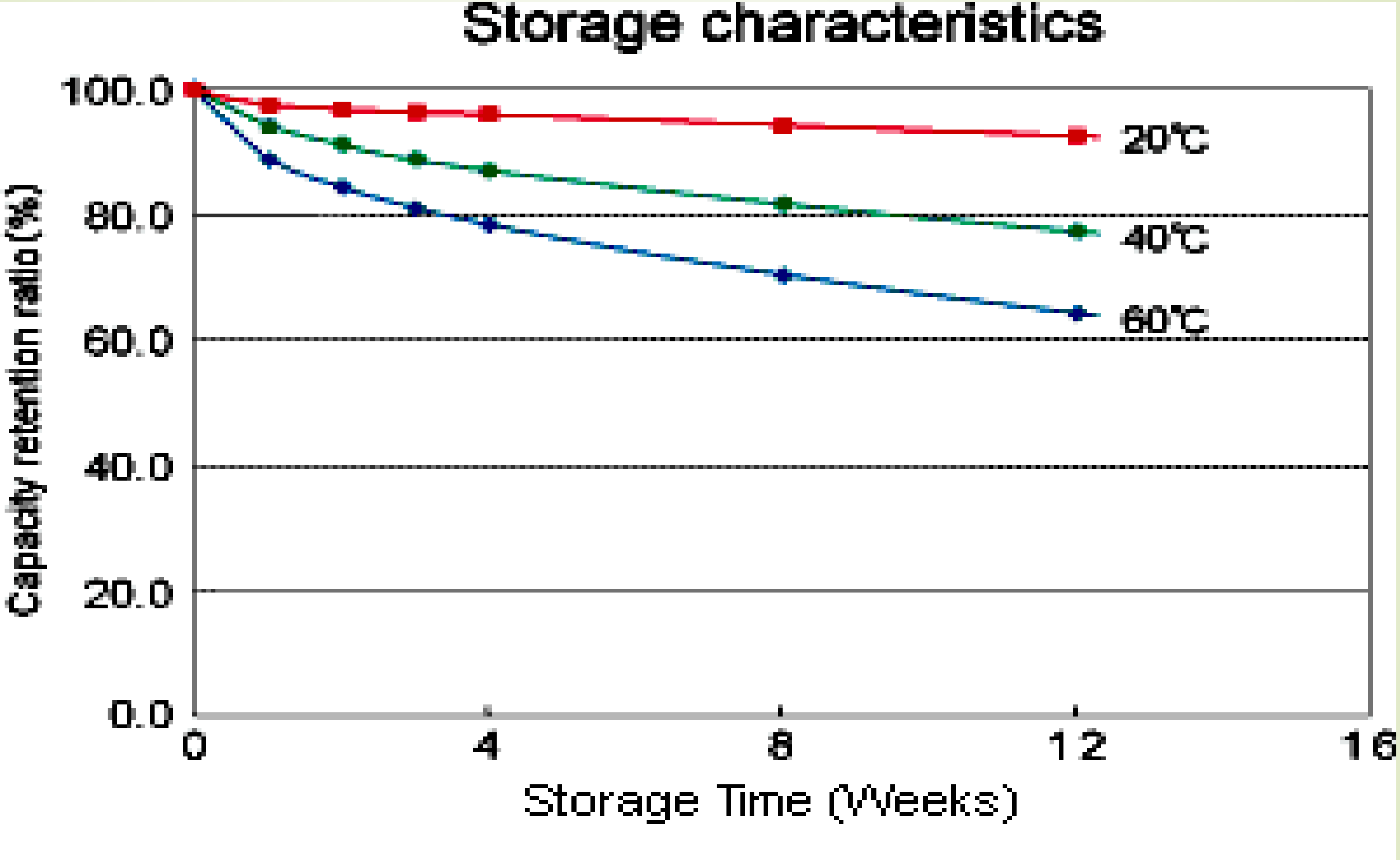
(mAh / 1000) x C Rate = Continuous Discharge Amperage
(1600 / 1000) x 10 = 16A

Run Time for Safe Continuous Discharge

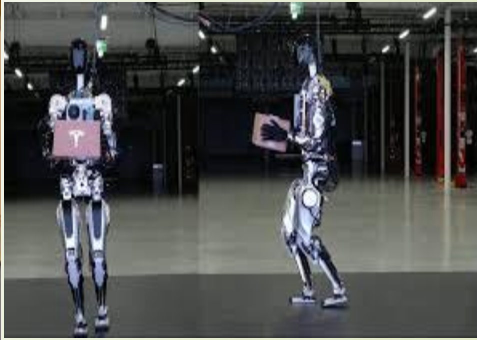
60mins / C-Rate = Run Time
60mins / 10C = Discharge 16A for 6mins



2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
Cell Voltage (V)
1C
1h(0.6C)
3h(0.28C)
5h(0.2C)
1
2
3
4
5
6
Discharge Time (h)


Storage characteristics
100.0
80.0
60.0
40.0
20.0
0.0
Capacity retention ratio (%)
20℃
40℃
60℃
0
4
8
12
16
Storage Time (Weeks)

Some applications of batteries



Calculation of Battery Capacity

- Assuming the current required = 0.75A
- Assume utilization efficiency is 75%.

Back-up Time (Hr(s))	Required Ah
1	1.0
2	2.0
4	4.0
8	8.0
12	12.0
24	24.0
48	48.0
72	72.0

Battery Discharging and Charging

Trying to calculate time for which i can watch 100W tv on a 150Ah battery

Power P = VI
P=100W &
voltage of battery V=12V
Therefore, I = 100/12 = 8.33A

Now charge stored Q is 150Ah
Q = It = 150
=> t = 150/I =150/8.33 = 18 hrs!

Considering utilisation less than 100%, the actual time of usage will be less than the calculated value of 18 hours.

Battery capacity is 1440mAh = 1.44Ah

charging current should be 10% of the Ah rating of battery

$$1.44Ah \times .10 = .144A$$

Due to some losses we it may take .14-.16

$$\frac{1.44Ah}{.15A} = 9.6h$$

it has been noted that **40% of losses** occurs in case of battery charging.

$$1.44Ah \times .40 = .576$$

$$1.44 + .576 = 2.016$$

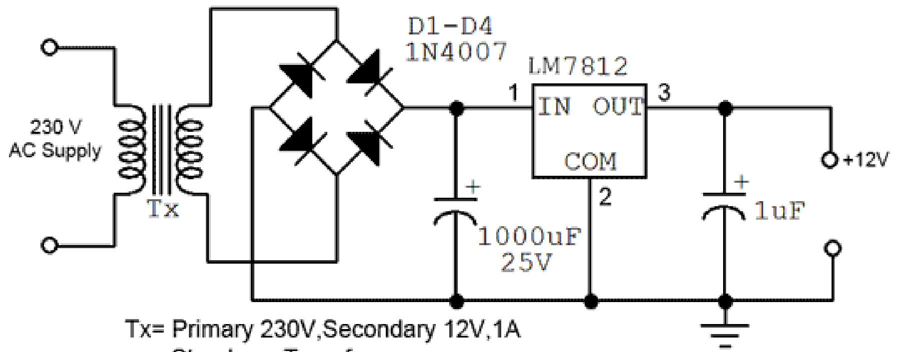
$$\frac{2.016}{.15} = 13.44\ hours$$

DC Power Supply

- All mechatronics systems need a power source to work.
- For electronic circuits made up of transistors and/or ICs, this power source must be a DC voltage of a specific value.
- A battery is a common DC voltage source for some small mechatronics equipment especially portables like toy cars, Roomba vacuum cleaners, drones etc.
- Most non-portable equipment uses power supplies that operate from the AC power line but produce one or more DC outputs.

A typical Power Supply for Low-power DC motors

- The input is the 230 volt 50 Hz AC supply.
- The power supply converts the AC into DC and provides one or more DC output voltages.
- Some modern electronic circuits need two or more different voltages.
- Common voltages are 48, 24, 15, 12, 9, 5, 3.3, 2.5, 1.8, 1.5, 1.2 and 1 volts.
- A good example of a modern power supply is the one inside a PC that furnishes 12, 5, 3.3 and 1.2 volts.

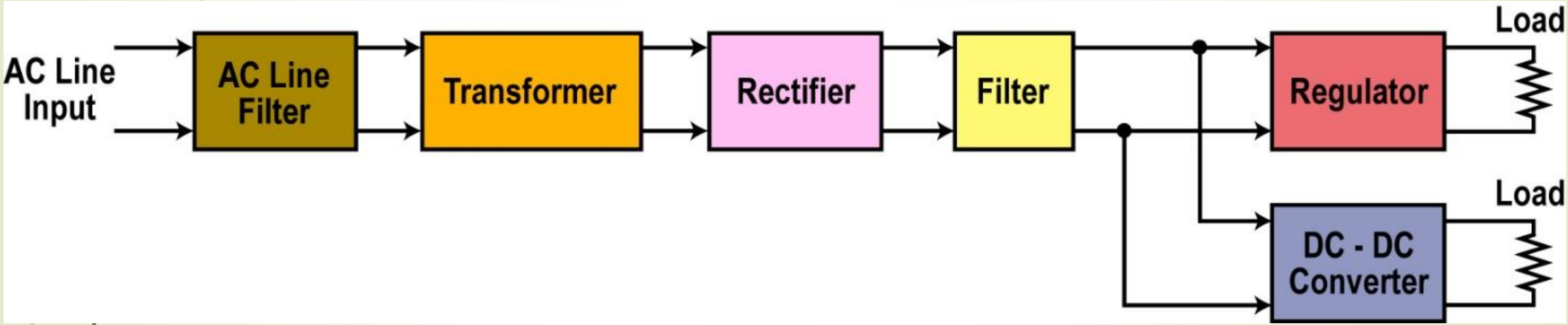


Tx= Primary 230V,Secondary 12V,1A
Stepdown Transformer

Wired power vs battery power?

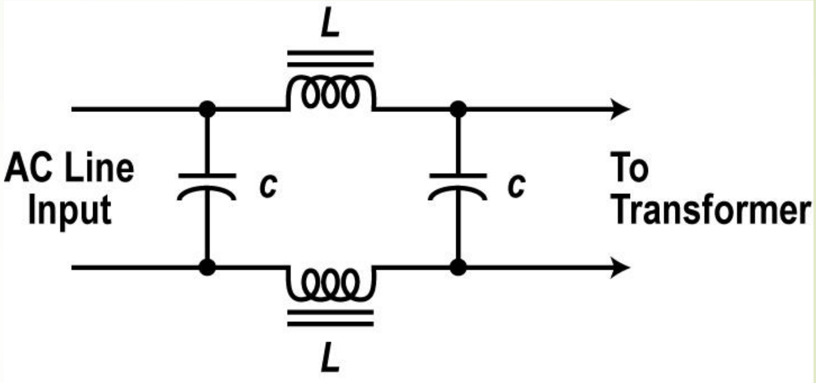
Components of a Power Supply

- Main circuits in most power supplies.

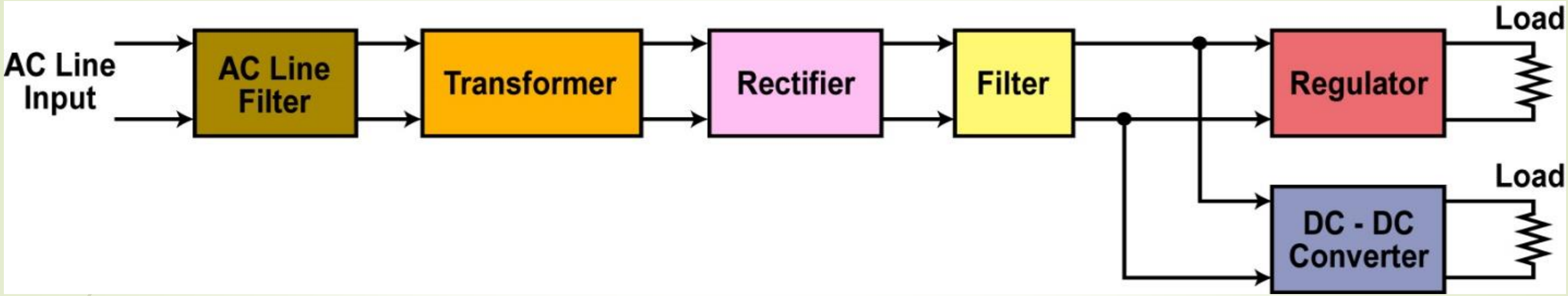


Line Filter

- The AC line is first passed through a low pass filter of the form shown in figure.
- This eliminates noise on the AC line from bothering the power supply circuits and prevents unwanted signals from the power supply from being transferred back into the AC line where they might interfere with other equipment.



Transformer

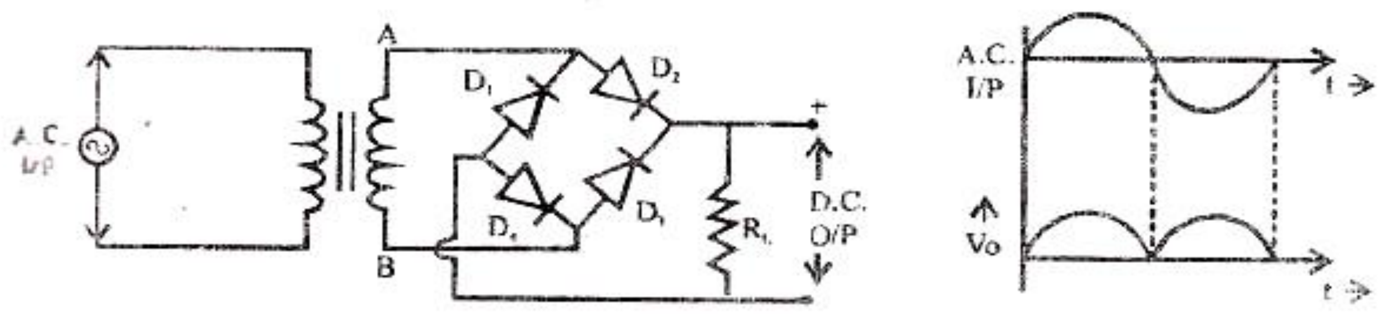


- A transformer is commonly used to step the input AC voltage level down or up. Most electronic circuits operate from voltages lower than the AC line voltage so the transformer normally steps the voltage down by its turns ratio to a desired lower level.

- For example, a transformer with a turns ratio of 20 to 1 would convert the 230 volt 50 Hz input sine wave into a 11.5 volt sine wave.

Rectifier

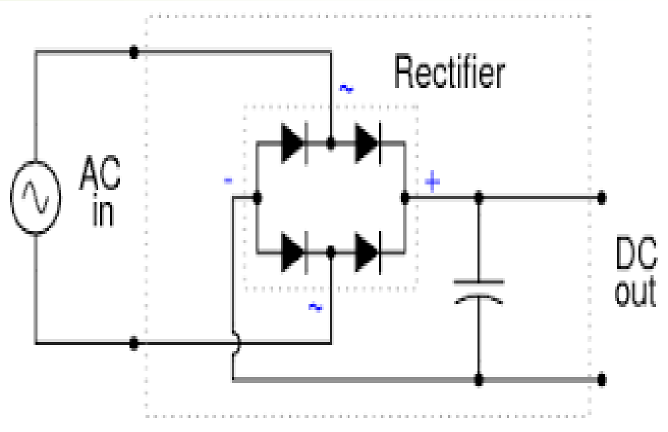
- The rectifier converts the AC sine wave into a pulsating DC wave.
- There are several forms of rectifiers used but all are made up of diodes.
- Rectifier types and operation depends on the design and configurations.

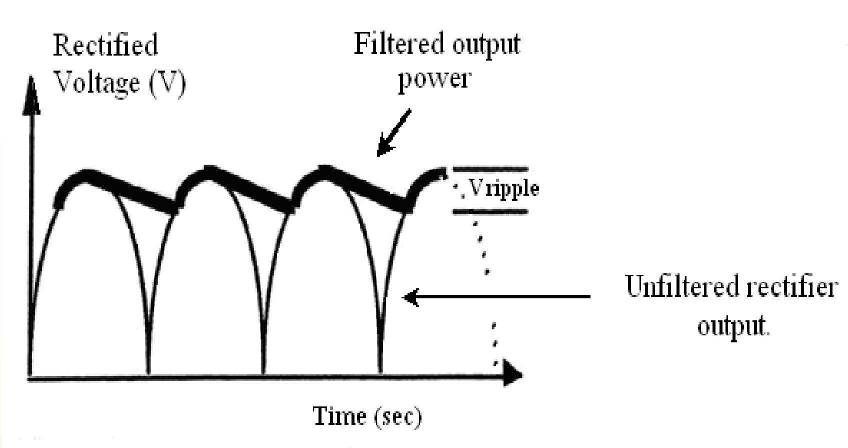


a) Bridge Rectifier b) Waveforms

Filter

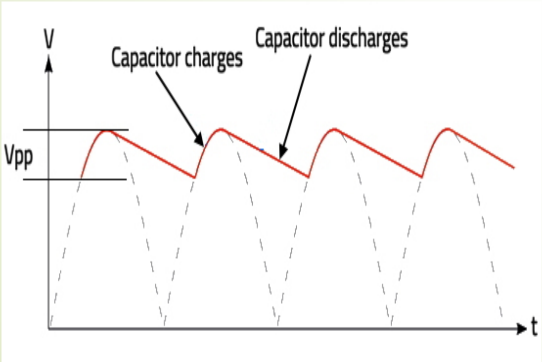
- The rectifier produces a DC output but it is pulsating rather than a constant steady value over time like that from a battery.
- A filter is used to remove the pulsations and create a constant output.
- The <u>most common filter</u> is a large <u>capacitor</u>.

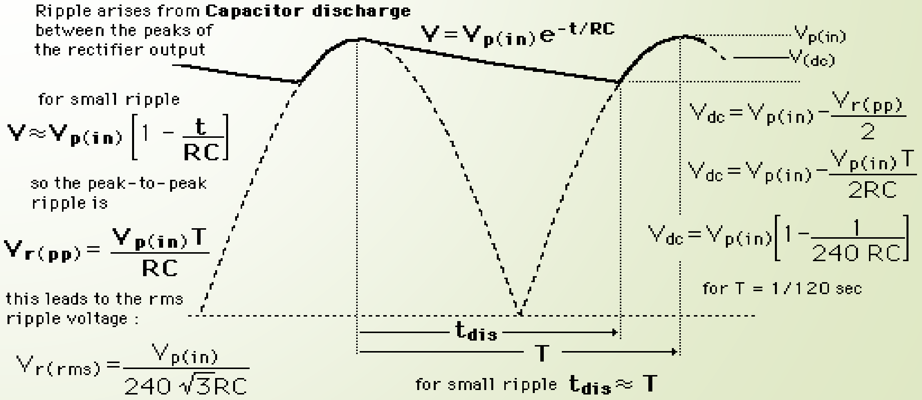




Ripple

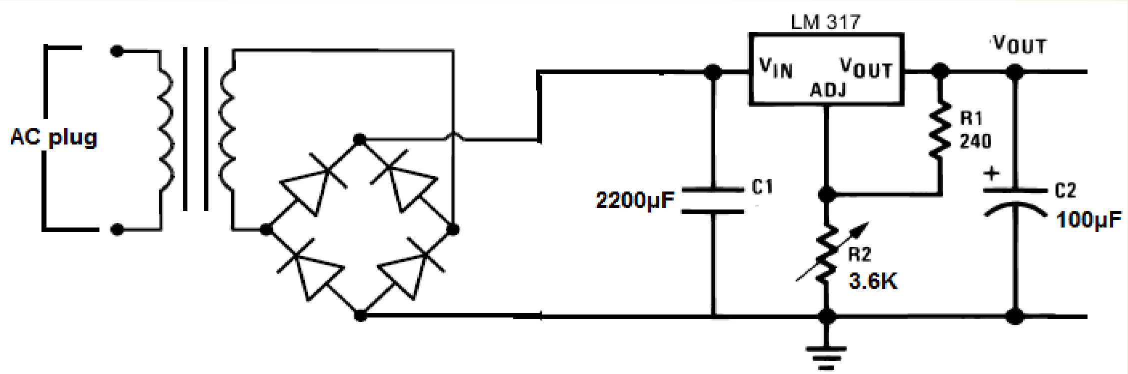
- The capacitor does smoothing the pulses from the rectifier into a more constant DC.
- A small variation occurs in the DC because <u>the capacitor discharges</u> a small amount between the positive and negative pulses. <u>Then it recharges</u>. This <u>variation is called ripple</u>.
- The ripple can be reduced further by making the capacitor larger.
- The ripple appears to be a sawtooth shaped AC variation riding on the DC output.
- A small amount of ripple can be tolerated in some circuits but the lower the better overall.





Regulator

- The regulator helps maintain a fixed or constant output voltage.
- Changes in the load or the AC line voltage will cause the output voltage to vary.
- Most electronic circuits cannot withstand the variations since they are designed to work properly with a fixed voltage.
- The regulator fixes the output voltage to the desired level then maintains that value despite any output or input variations.



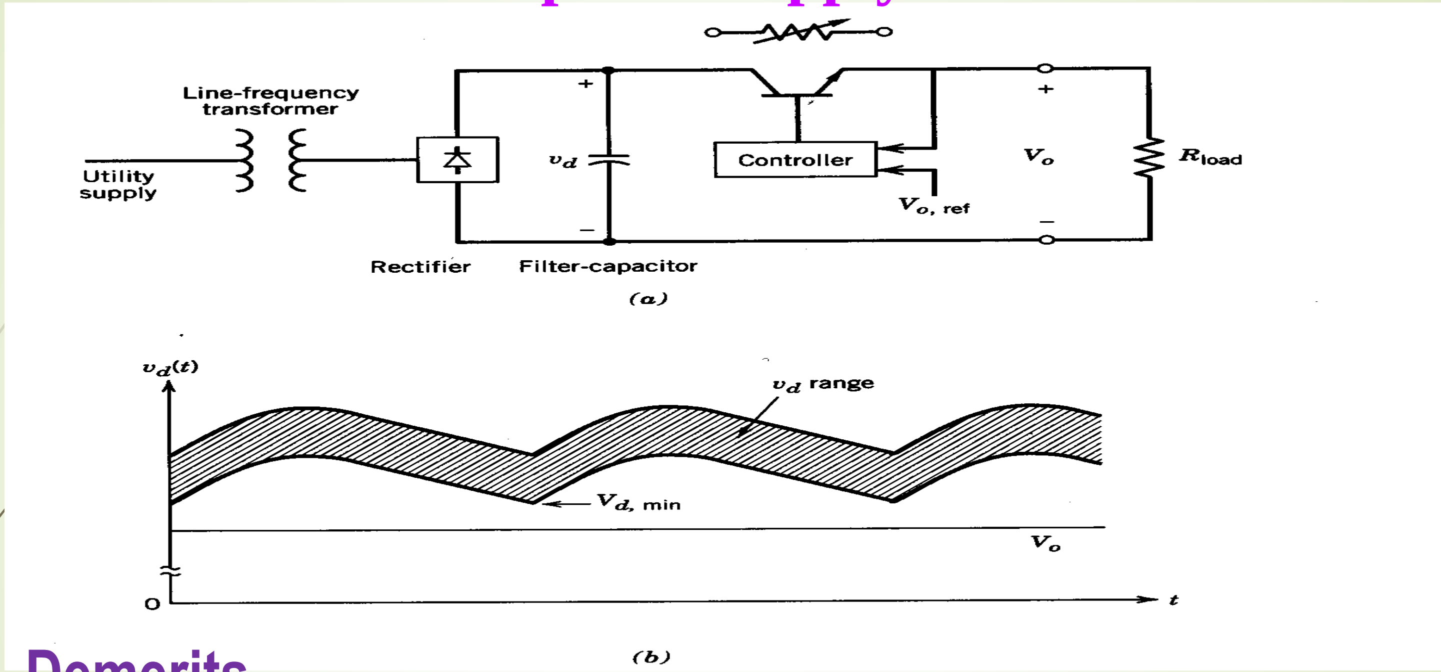
The Regulator

- Most regulators are ICs .
- These are feedback control circuits that actually monitor the output voltage to detect variations.
- If the output varies, for whatever reason, the regulator circuit automatically adjusts the output back to the set value.
- Regulators hold the output to the desired value.
- Since ripple represents changes in the output, the regulator also compensates for these variations producing a near constant DC output.

Issues of Rectified DC Power

- Size
- Efficiency
- Cost

Linear power supply



Demerits

* Series transistor as an adjustable resistor
* Low Efficiency
* Heavy and bulky

DC-DC Converter

- Most modern power supplies also contain one or more DC-DC converters
- Modern electronics often demand different voltages to function.
- A DC-DC converter changes one DC voltage to another, higher or lower DC voltage.
- A DC-DC converter is used with a power supply to prevent the need for a second AC-DC supply.

Switched Mode Power Supply

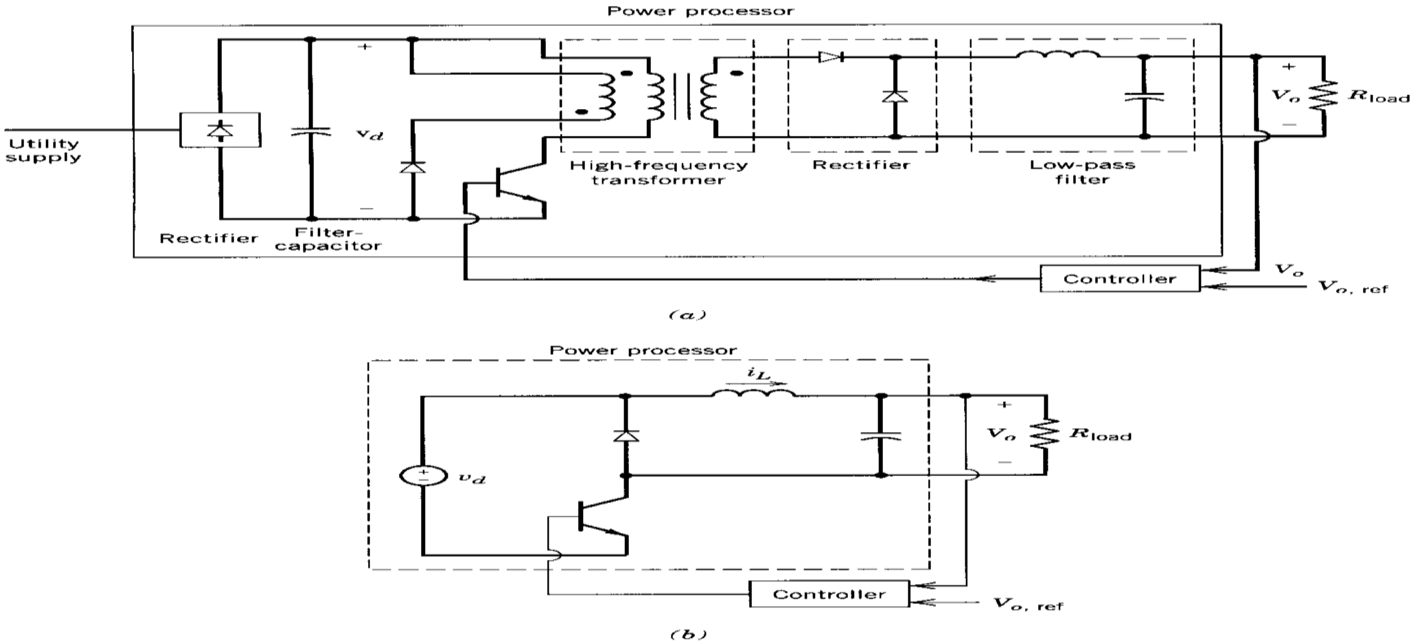


Figure 1-3 Switch-mode dc power supply.

- **Transistor as a switch**
- **High Efficiency**
- **High-Frequency Transformer**

Block Diagram of DC-DC Converters

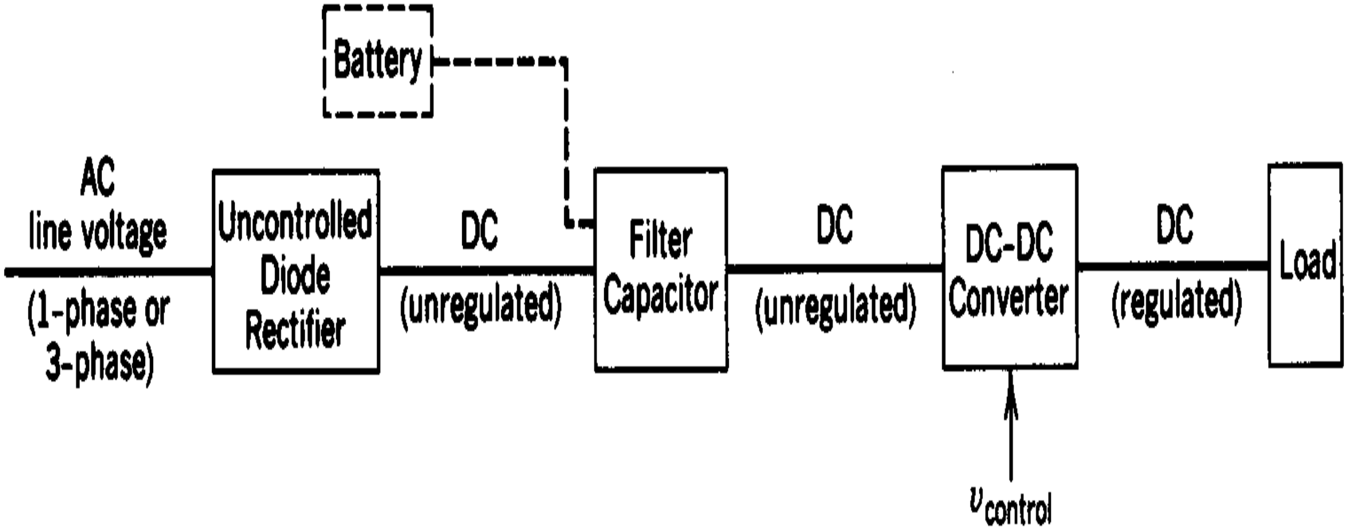


Figure 7-1 A dc–dc converter system.

Stepping down a dc voltage

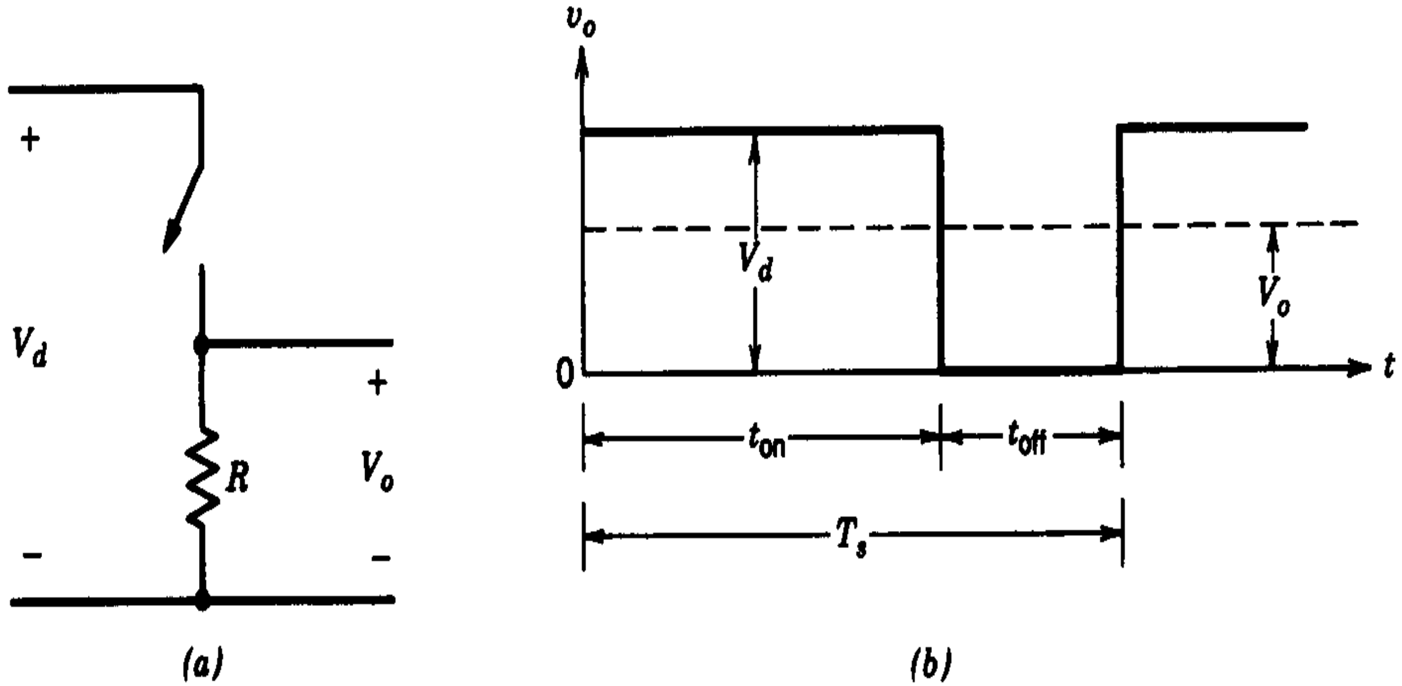


Figure 7-2 Switch-mode dc–dc conversion.

Pulse-Width Modulation in DC-DC Converters

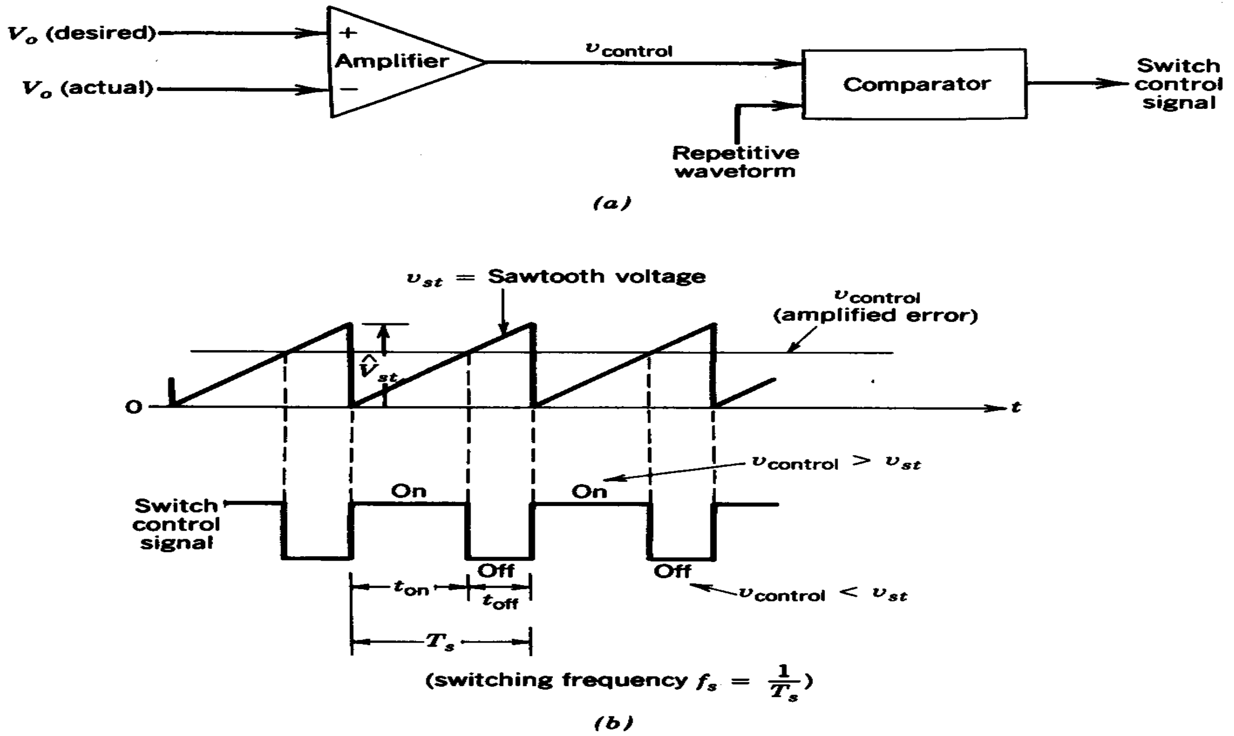


Figure 7-3 Pulse-width modulation: (*a*) block diagram; (*b*) comparator signals.

Role of PWM

Step-down DC to DC converter (BUCK)

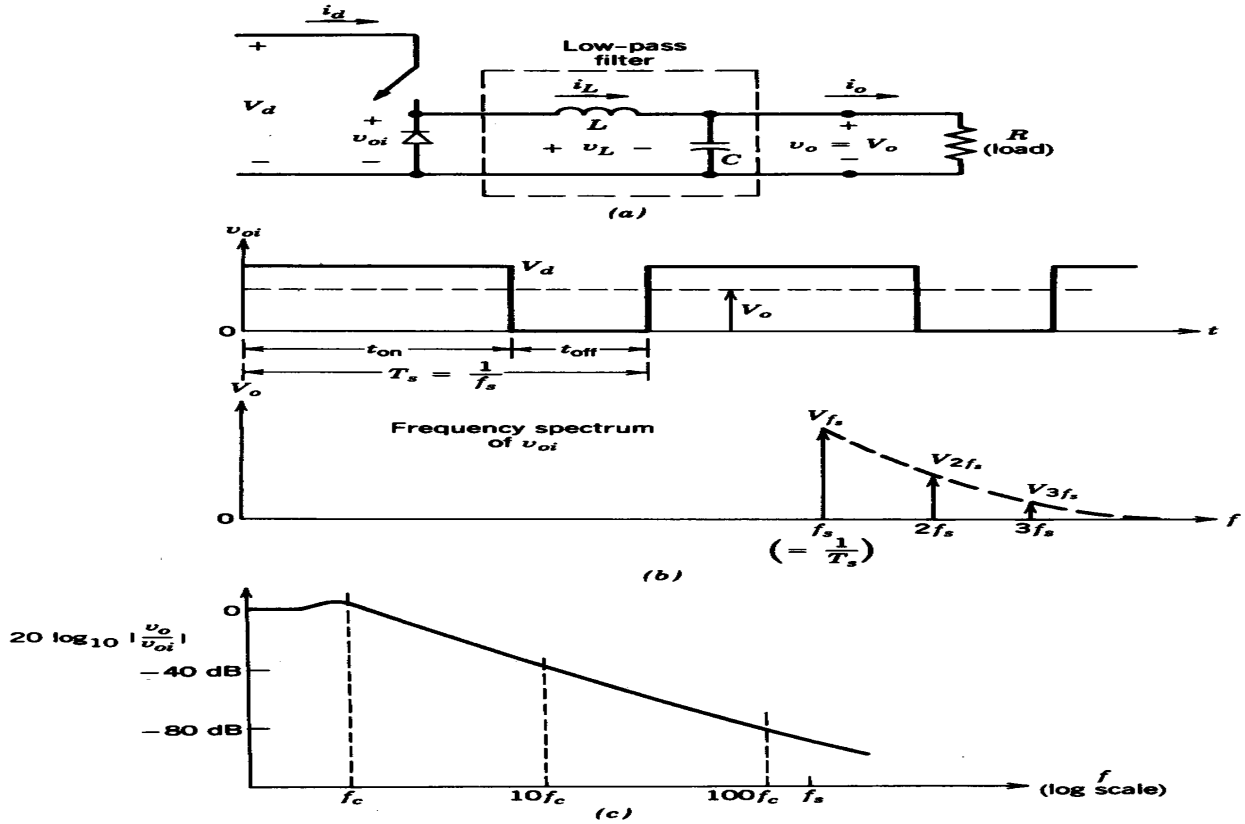


Figure 7–4 Step-down dc–dc converter.

- Pulsating input to the low-pass filter

BUCK converter: Waveforms

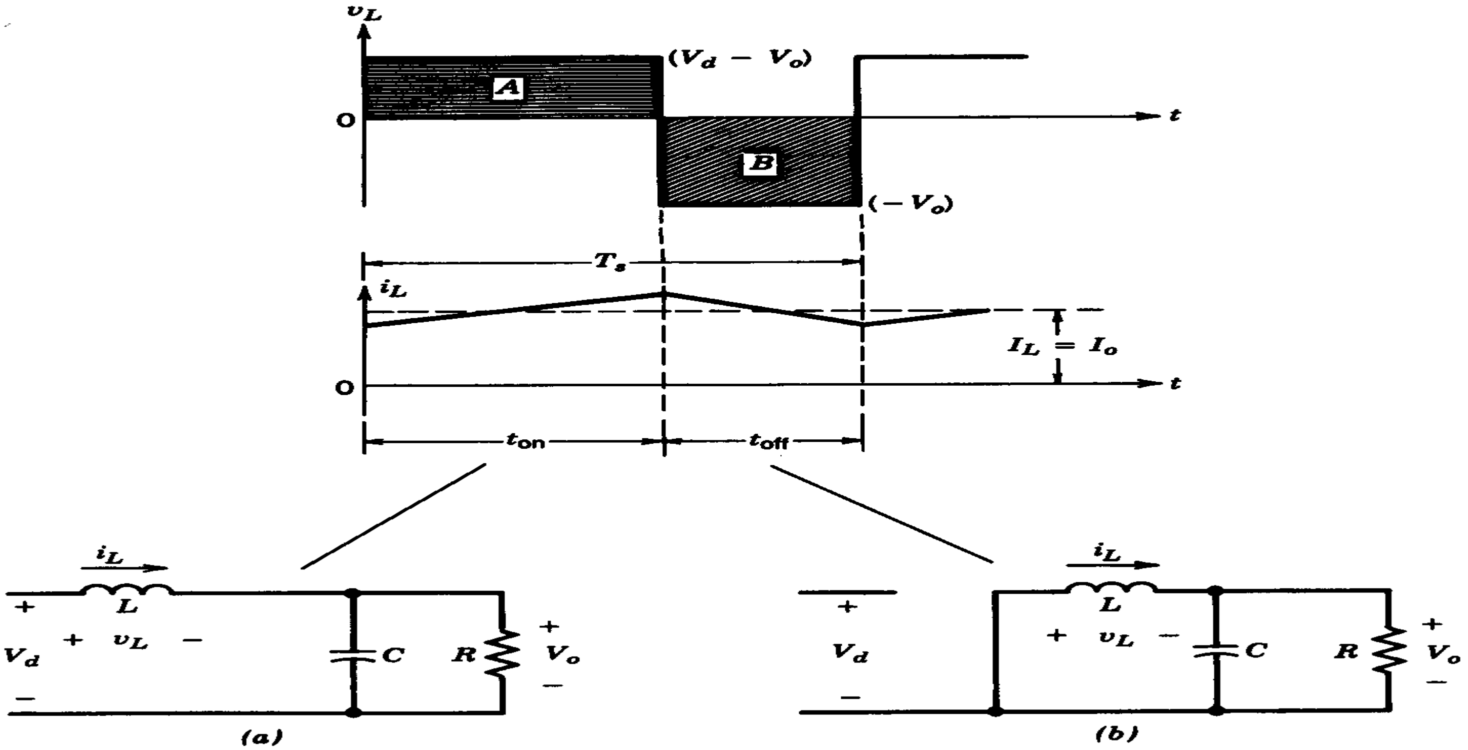
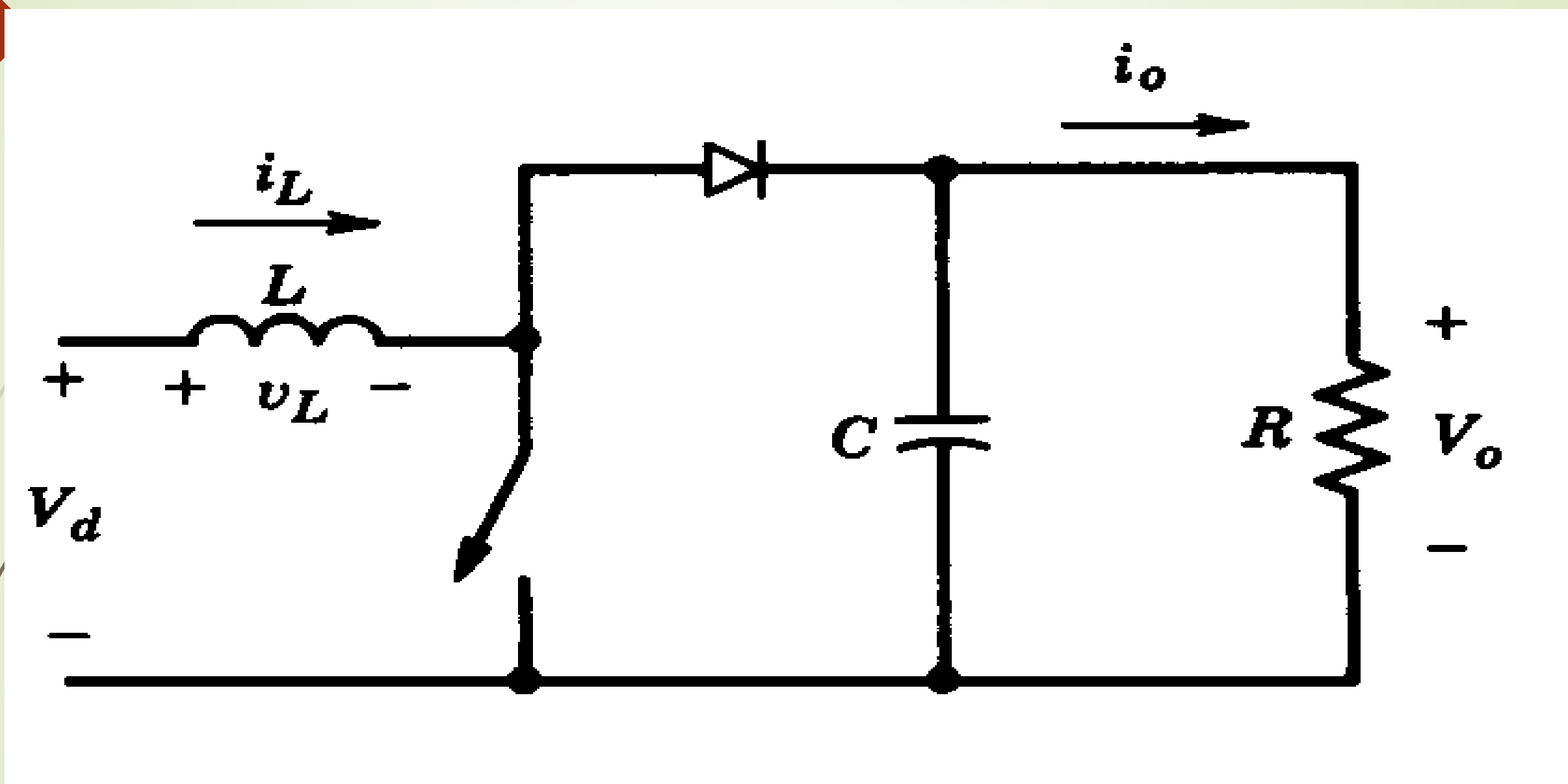


Figure 7-5 Step-down converter circuit states (assuming i_L flows continuously): (*a*) switch on; (*b*) switch off.

Steady state; inductor current flows continuously

Step-up DC to DC converter (Boost)



The output voltage must be greater than input voltage

BOOST converter: Waveforms

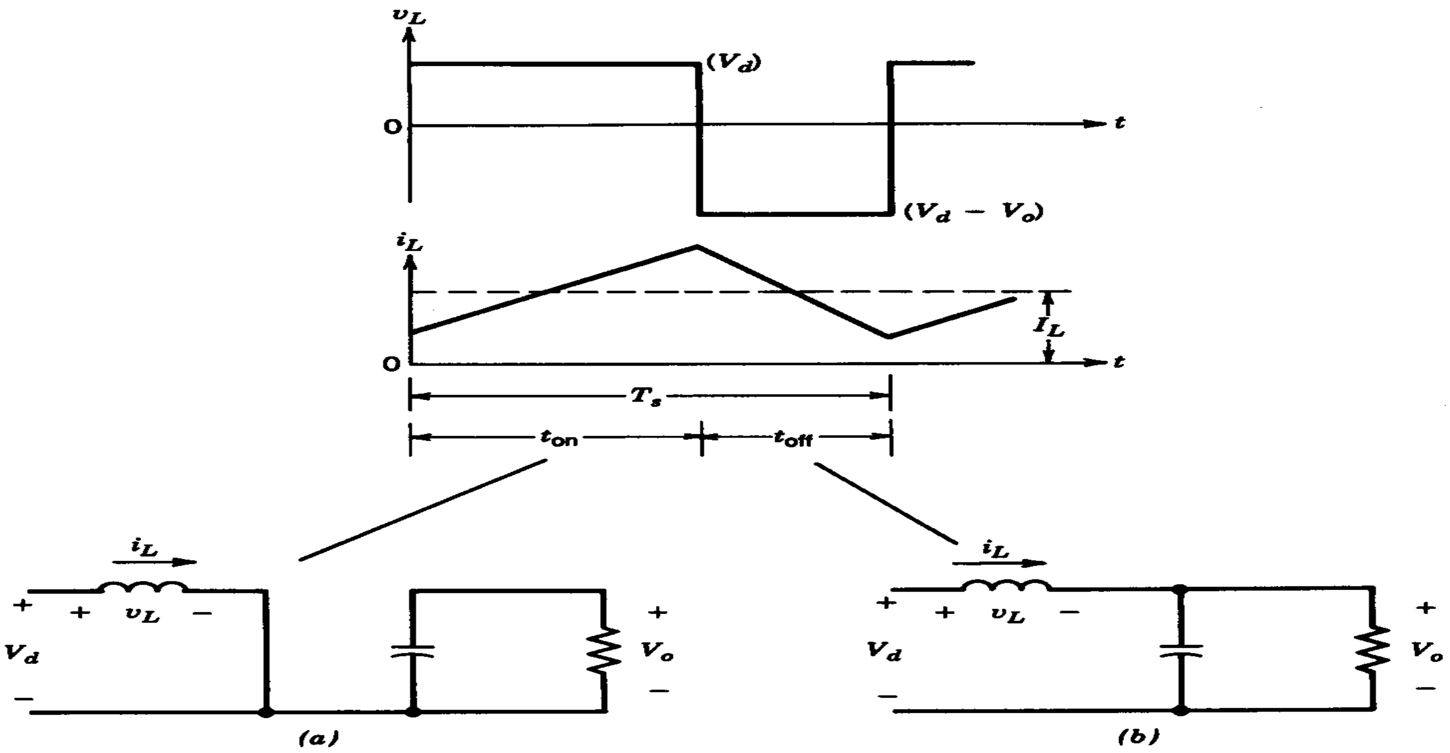
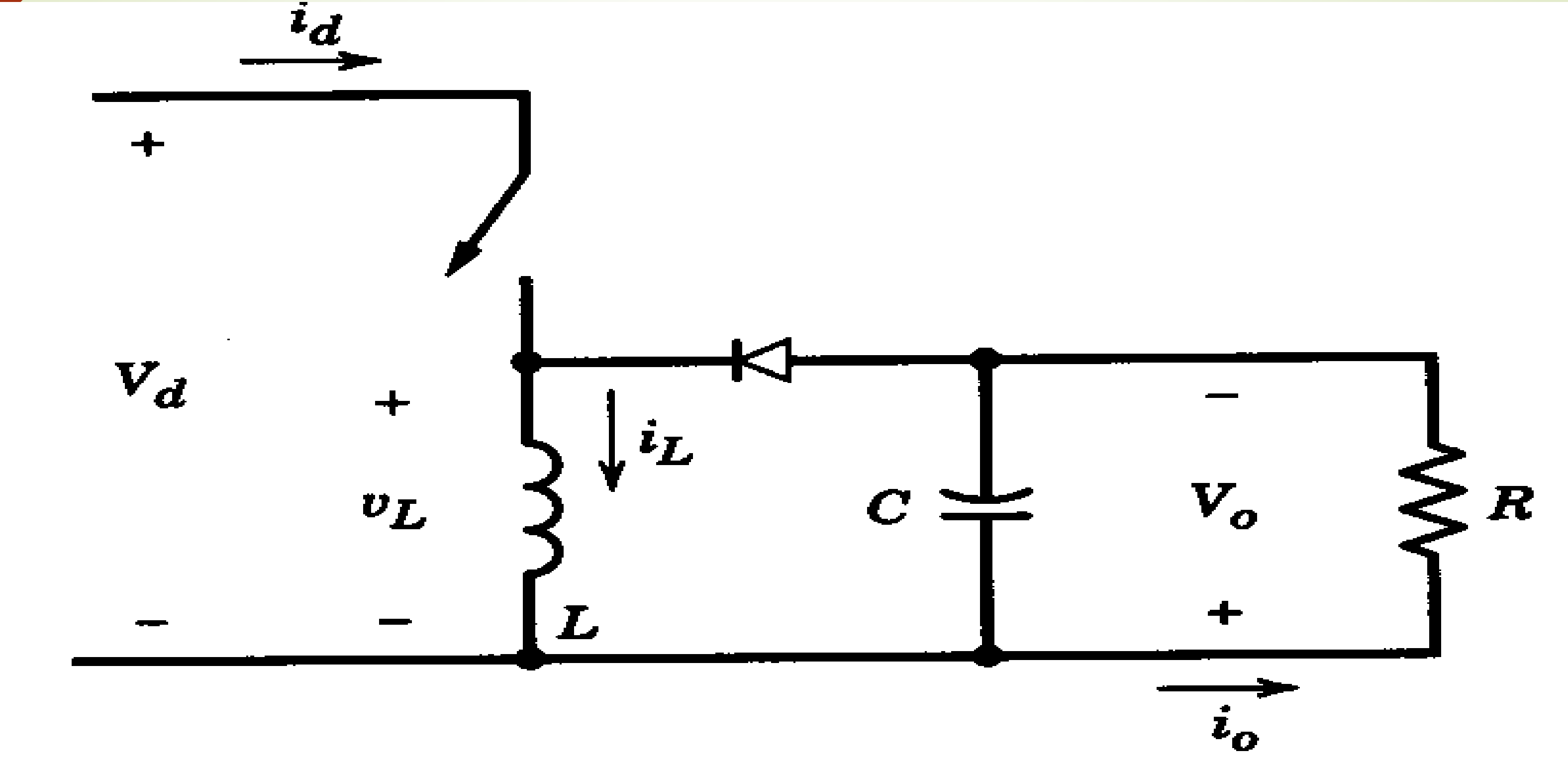


Figure 7-12 Continuous-conduction mode: (*a*) switch on; (*b*) switch off.

- **Continuous current conduction mode**

Step-up/down (Buck-Boost) DC to DC converter



The output voltage can be greater or lower than the input voltage

Buck-boost converter: waveforms

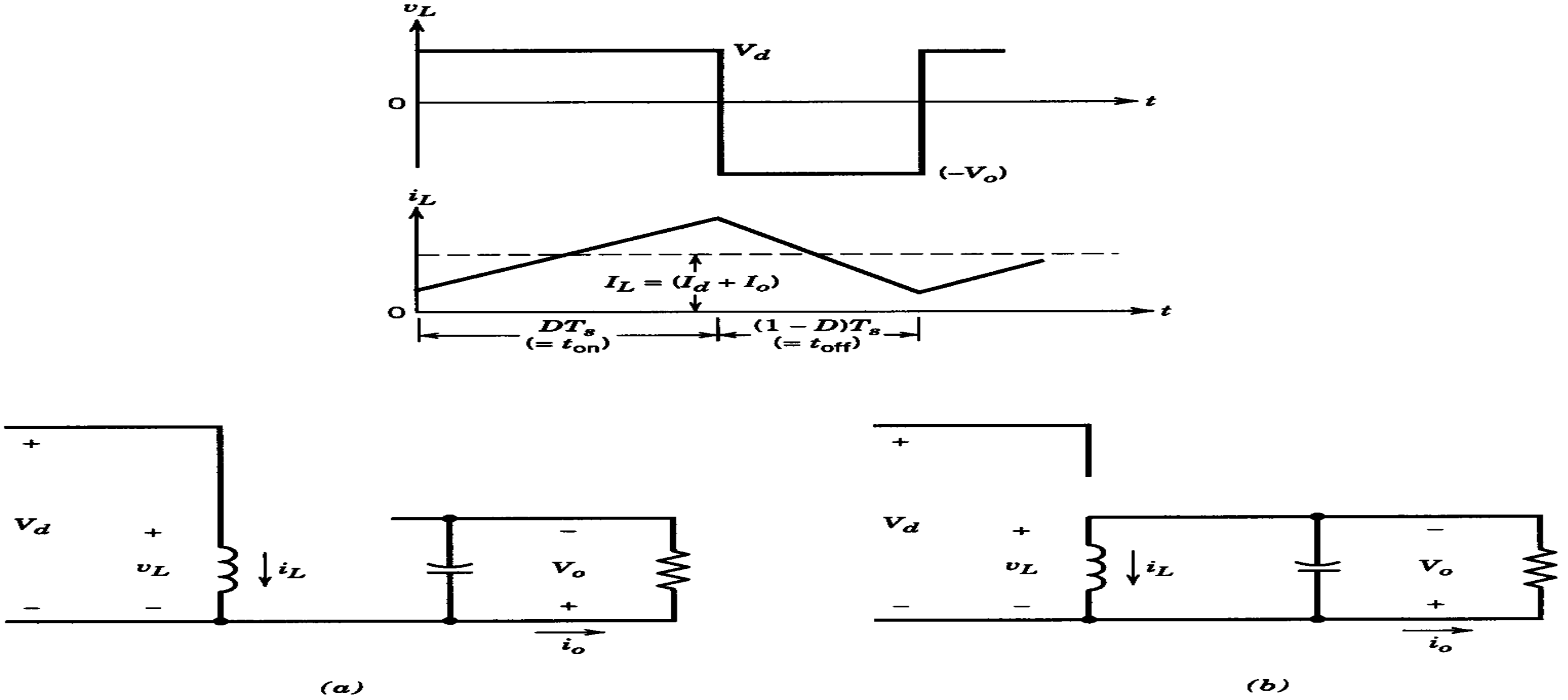
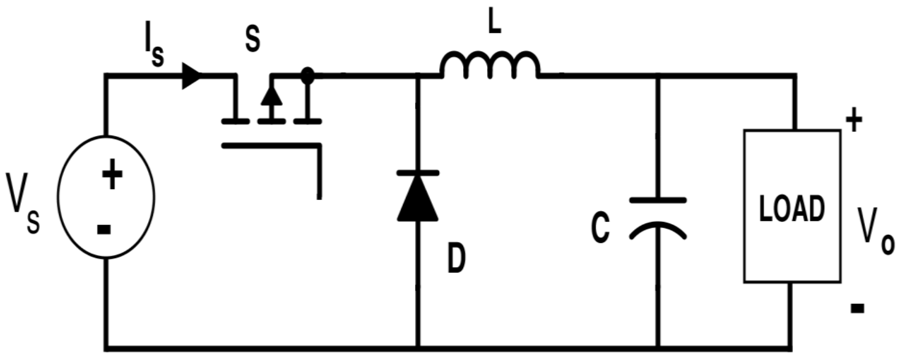


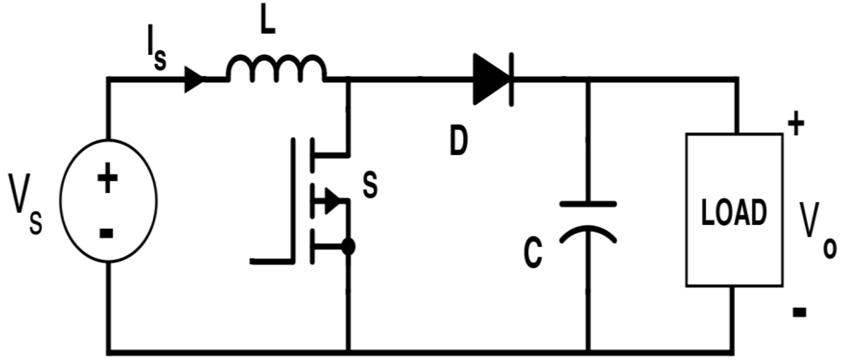
Figure 7-19 Buck—boost converter ($i_L > 0$): (a) switch on; (b) switch off.

Continuous conduction mode

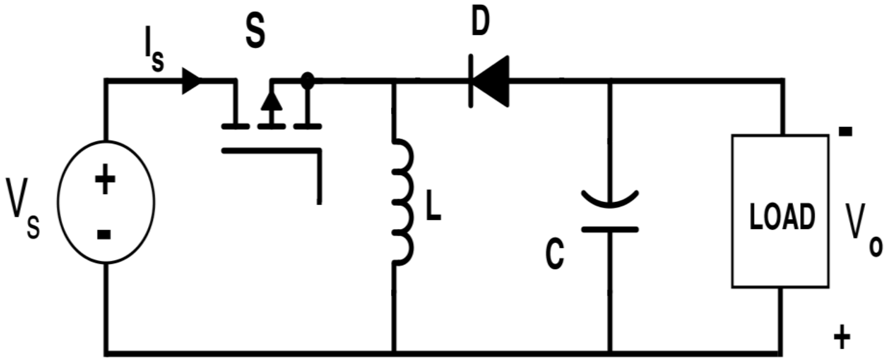
Power Circuit configuration of DC to DC Converters



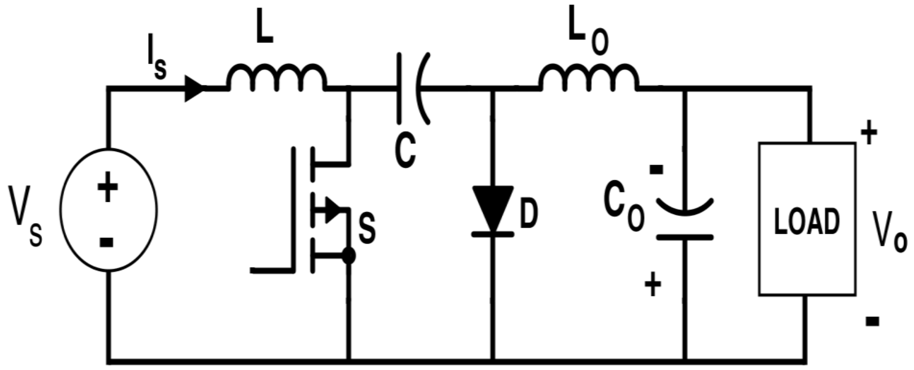
Buck Converter



Boost Converter



Buck-Boost Converter

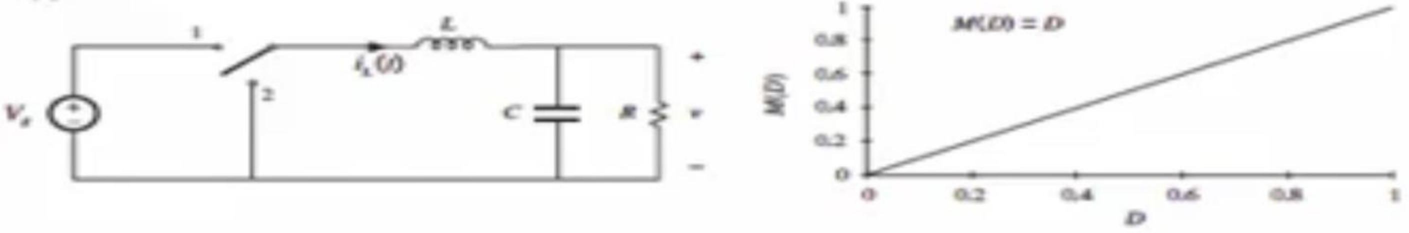


Cuk Converter

Three basic dc-dc converters

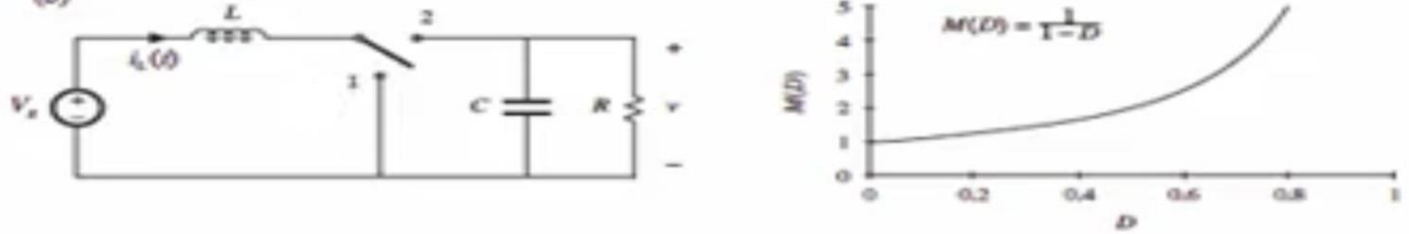
(a)

Buck



(b)

Boost



(c)

Buck-boost

Implementing Electrical Isolation in the Feedback Loop

Two ways are shown

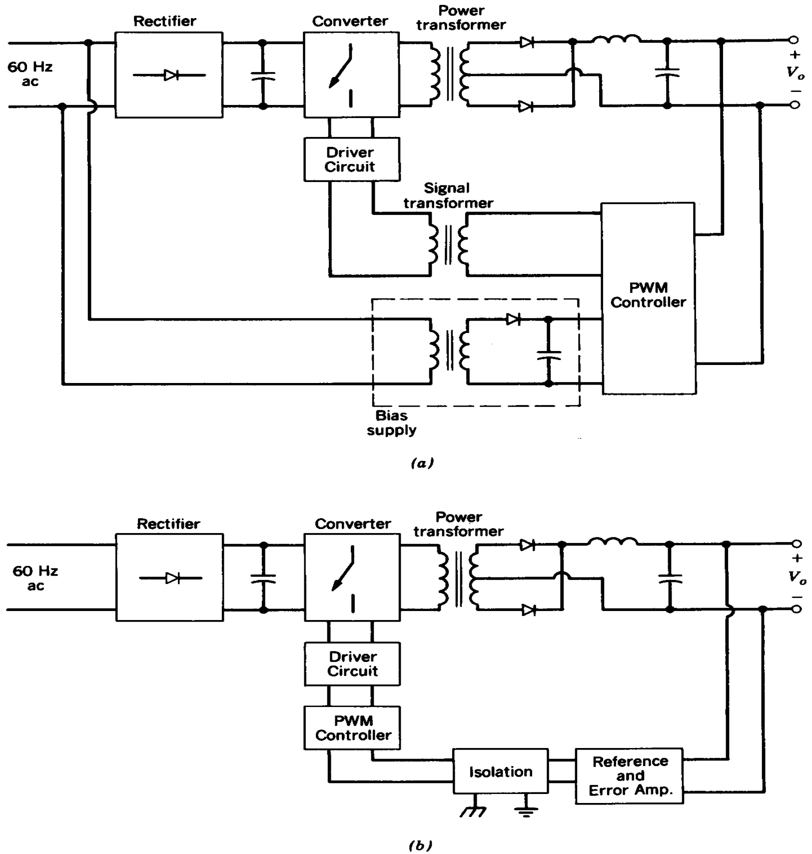


Figure 10-34 Electrical isolation in the feedback loop: (*a*) secondary-side control; (*b*) primary-side control.