ĐHBK Tp HCM-Khoa Đ-ĐT
BMĐT
GVPT: Hồ Trung Mỹ
Môn học: Dụng cụ bán dẫn

Chương 4
Chuyển tiếp PN
(PN Junction)

Nội dung chương 4

1. Chuyển tiếp PN – Giới thiệu các khái niệm
2. Điều kiện cân bằng nhiệt
3. Miền nghèo
4. Điện dung miền nghèo
5. Đặc tuyến dòng-áp
6. Các mô hình của diode bán dẫn
7. Điện tích chứa và quá trình quá độ
8. Đánh thủng chuyển tiếp
9. Chuyển tiếp dị thể (Heterojunction)
10. Các diode bán dẫn khác
11. Giới thiệu các ứng dụng của diode bán dẫn

Các ứng dụng của diode bán dẫn

Các ứng dụng thực tế của các mạch diode

Các mạch chỉnh lưu (Rectifier Circuits)

- Chuyển từ điện AC sang DC cho các mạch điện tử
- Các mạch nạp điện cho pin hay accu (Battery charging circuits)

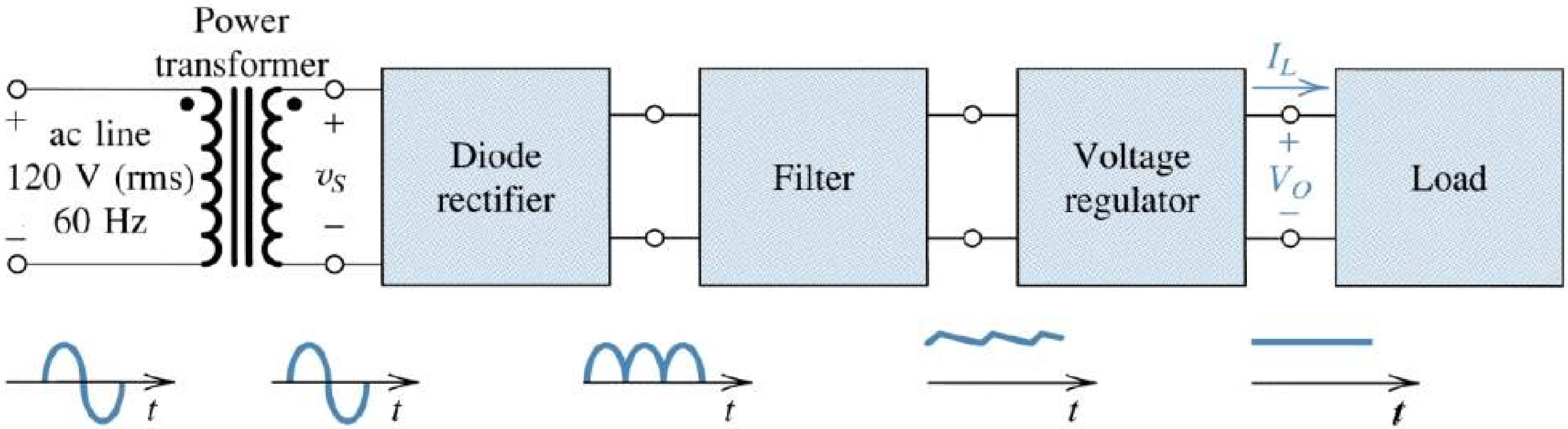
Các mạch diode đơn giản

- Mạch xén, mạch kẹp
- Mạch bảo vệ chống:
  - o Quá dòng
  - o Mắc ngược cực tính
  - o Quá áp trên khóa điện tử trong mạch lái rờ-le (relay)
- Các cổng logic

Các mạch Zener

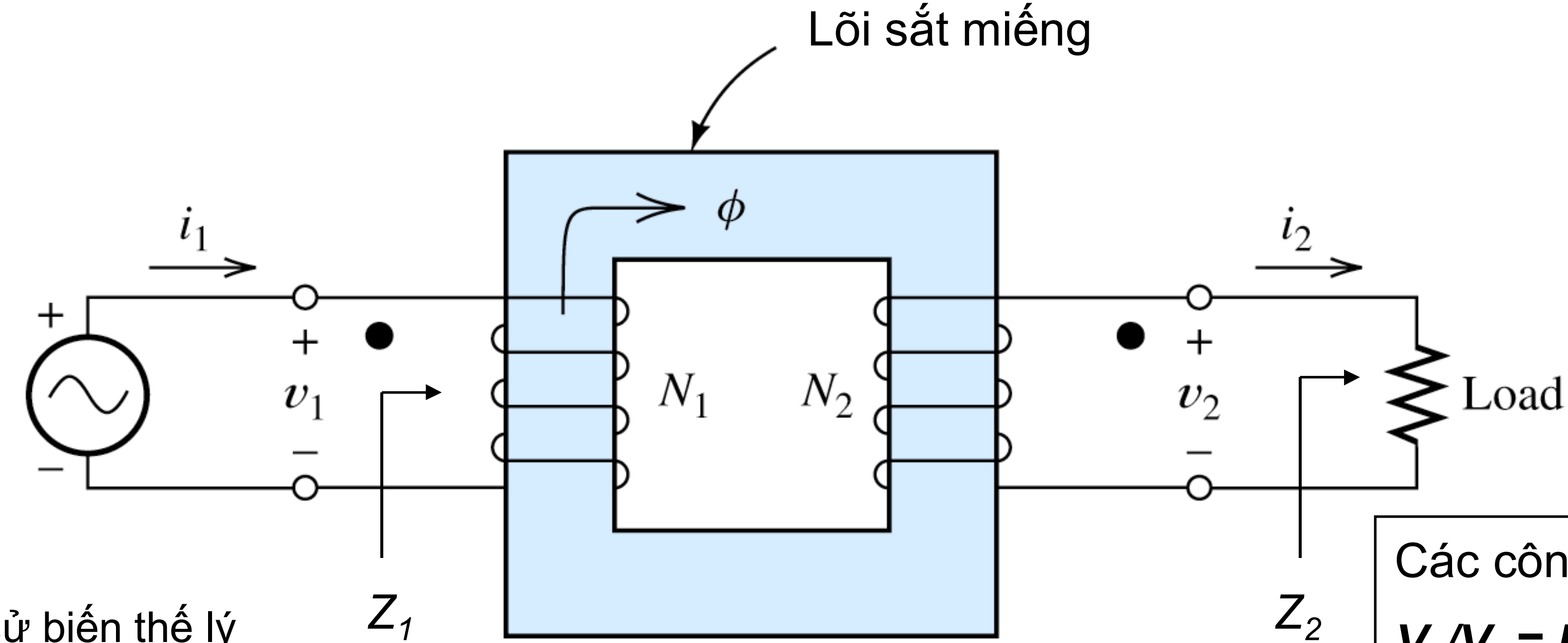
- Bảo vệ quá áp
- Tạo các điện áp chuẩn (Reference Voltages)

Sơ đồ khối của
một bộ nguồn cấp điện DC



Chú thích:
- Ac line = đường dây [điện] xoay chiều
- Power transformer = biến thế (hay biến áp) công suất
- Diode rectifier = Mạch chỉnh lưu dùng diode
- Filter = mạch lọc
- Voltage regulator = mạch ổn áp
- Load = Tải

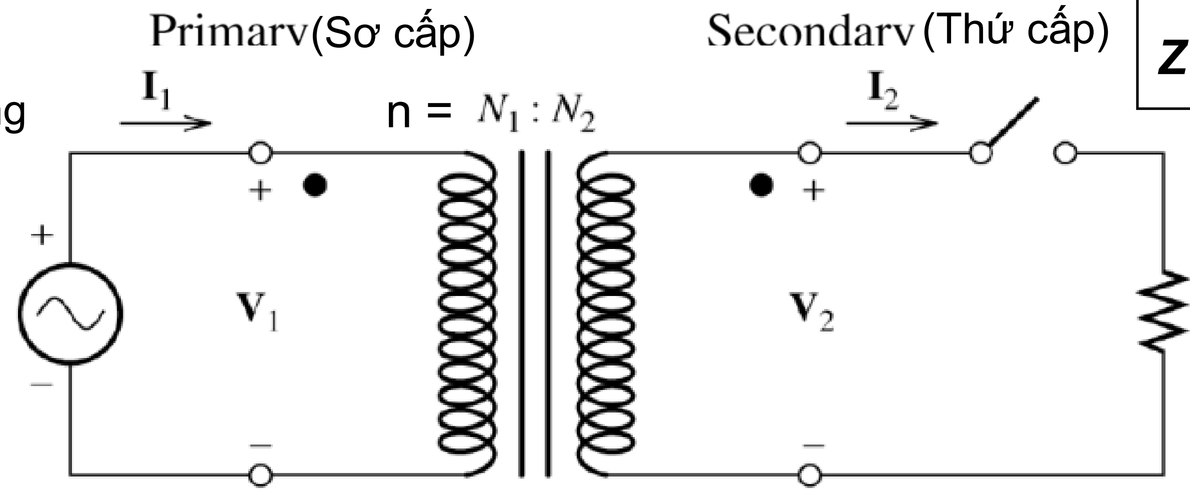
Máy biến thế cấp điện



Giả sử biến thế lý tưởng:

- Không có tổn hao

→ Công suất ra bằng công suất vào



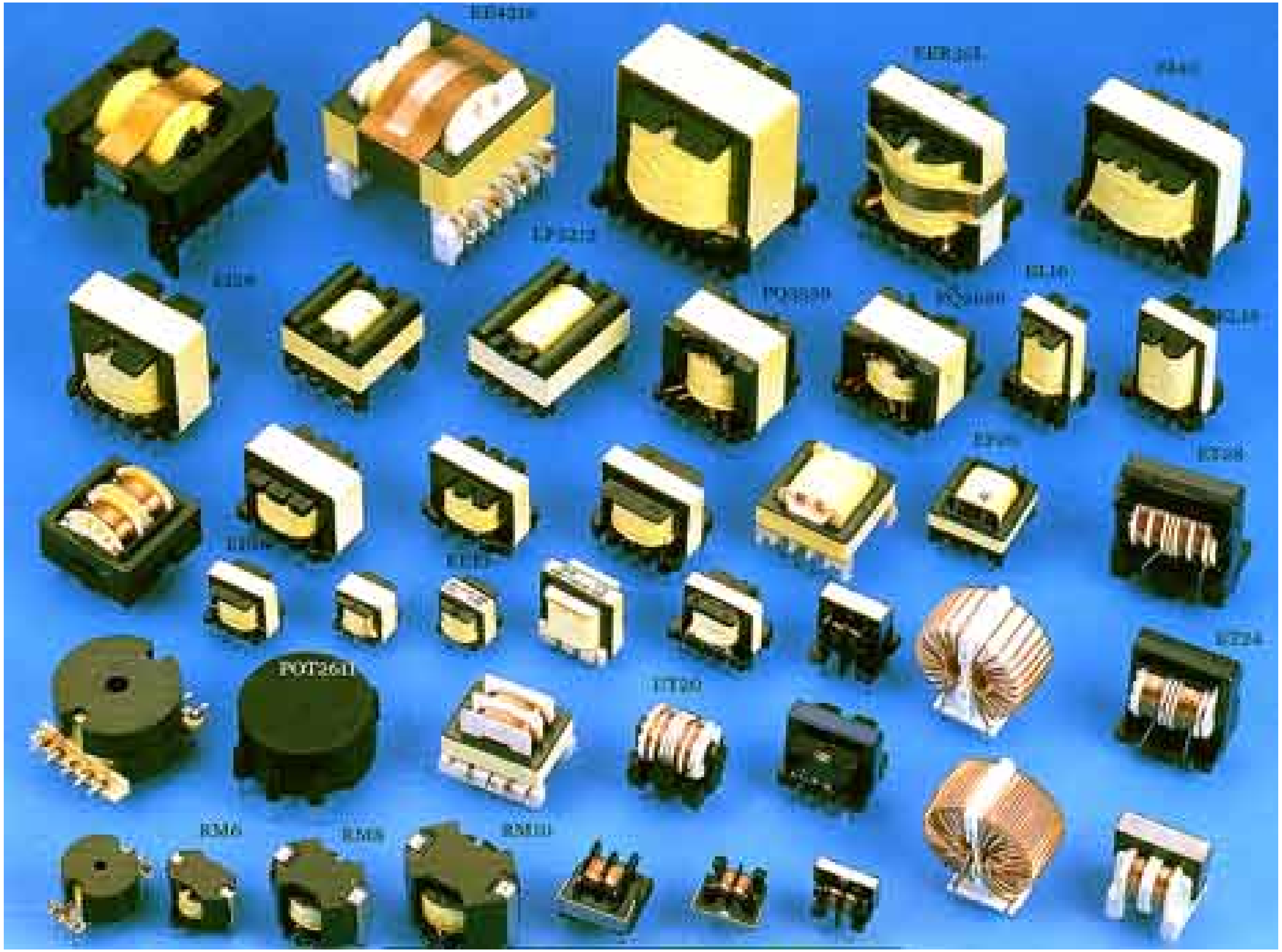
Các công thức

$V_1/V_2 = I_2/I_1 = n$

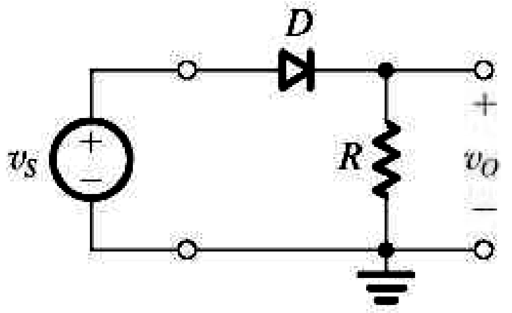
$Z_1 = n^2 Z_2$

n = tỉ số vòng dây

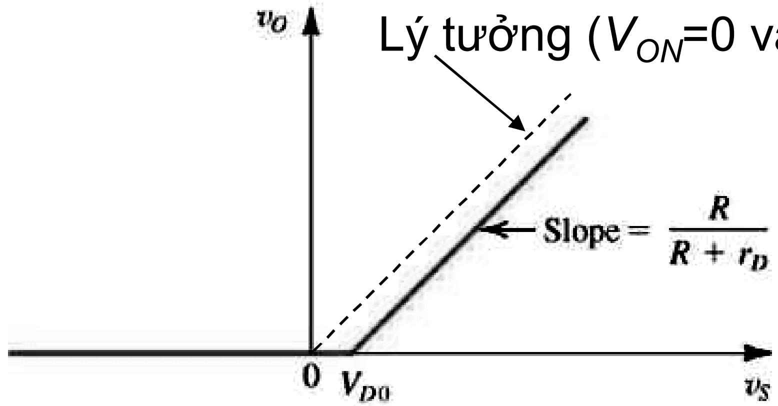
Một số hình dạng của Máy biến thế



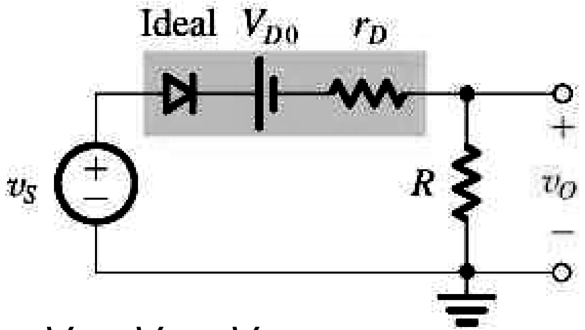
Half-Wave Rectifier (mạch chỉnh lưu bán kỳ)



(a) Mạch

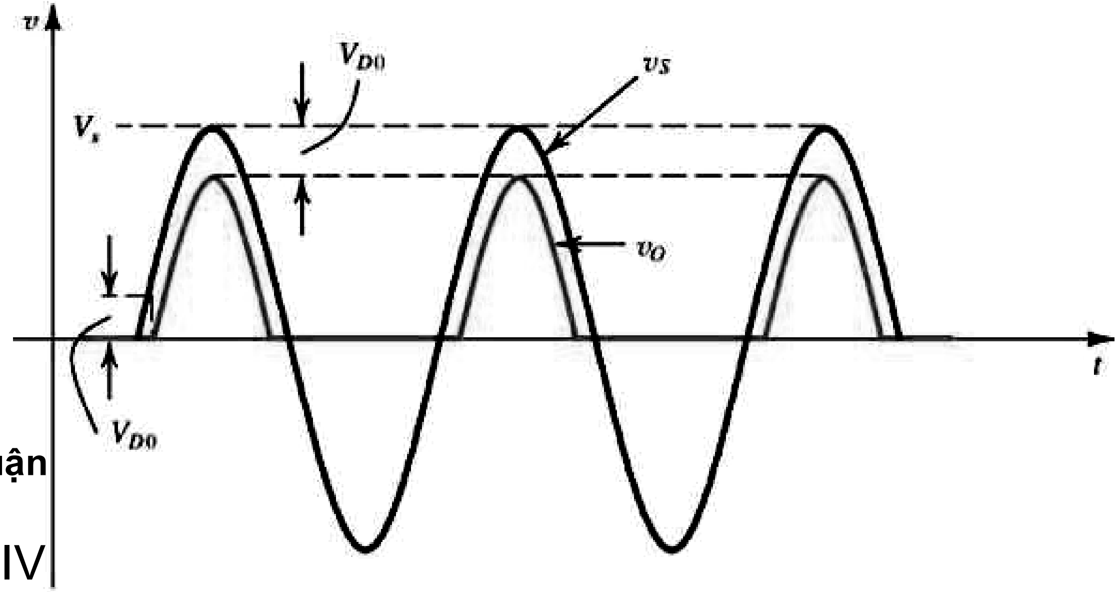


(c) Đặc tuyến truyền đạt



V_{D0}=V_{ON}=V_γ

(b)**Mô hình điện trở thuận**

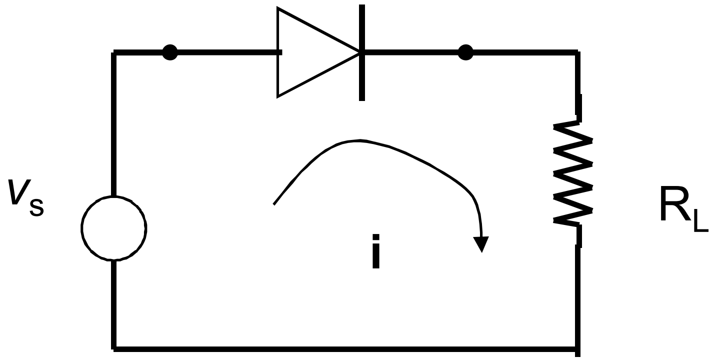


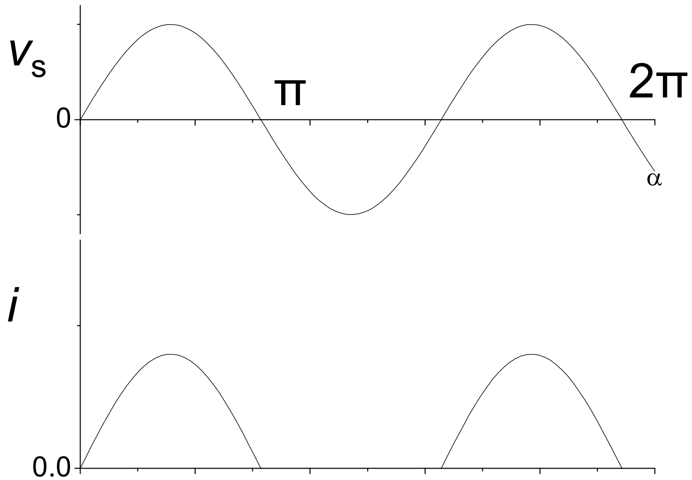
(d) Dạng sóng đầu ra

Điện áp ngược đỉnh của diode PIV
(Peak inverse voltage)

$\mathrm{PIV} = V_s$ = biên độ đỉnh của điện áp vào

Các công thức trong mạch chỉnh lưu bán kỳ





$$v_s = V_m \sin\alpha$$

$$\begin{cases} i = \dfrac{v_i - V_{D0}}{r_D + R_L}\sin\alpha & \text{với } v_s > V_{D0} \\ i = 0 & \text{với } v_s < V_{D0} \end{cases}$$

$$f_{out} = f_{in}$$

$$I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\alpha \, d\alpha = \frac{I_m}{\pi}$$

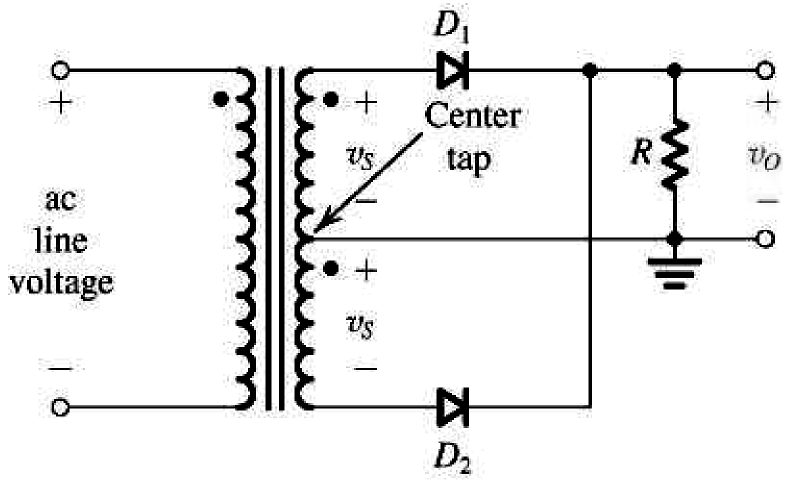
$$V_{DC} = \frac{I_m}{\pi} R_L$$

$V_{p(out)} = V_{p(in)} - 0.7V$ (diode Si)

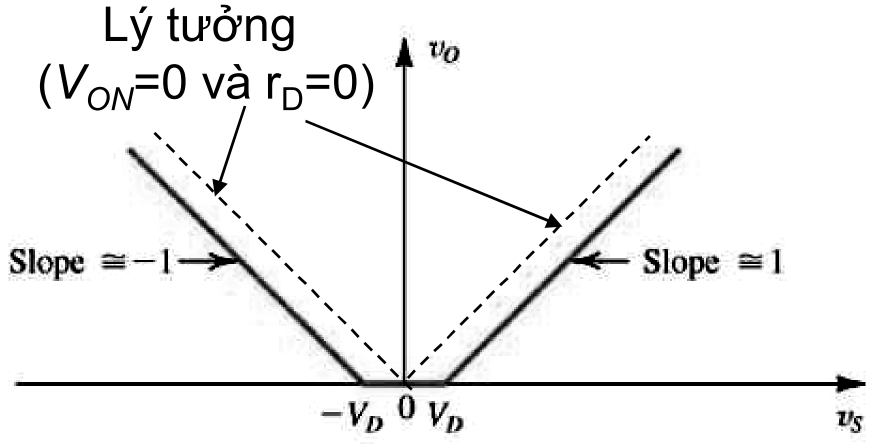
$V_{p(out)} = I_m R_L$ và $V_{p(in)} = V_s$

$V_{DC} = V_{p(out)}/\pi = 0.318\ V_{p(out)}$

Full-Wave Rectifier (mạch chỉnh lưu toàn sóng)



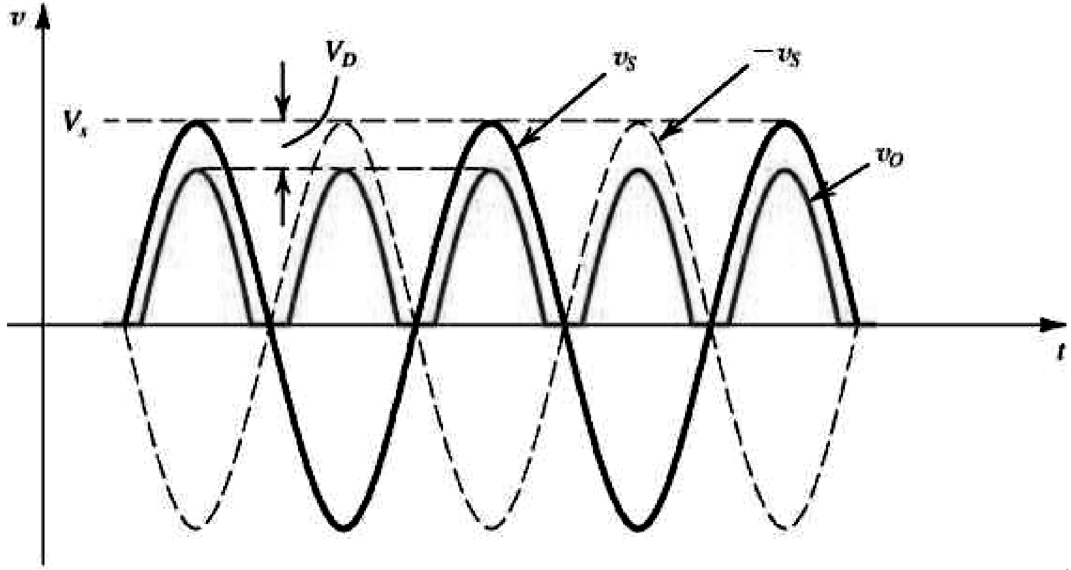
(a) Mạch



(b) Đặc tuyến truyền đạt

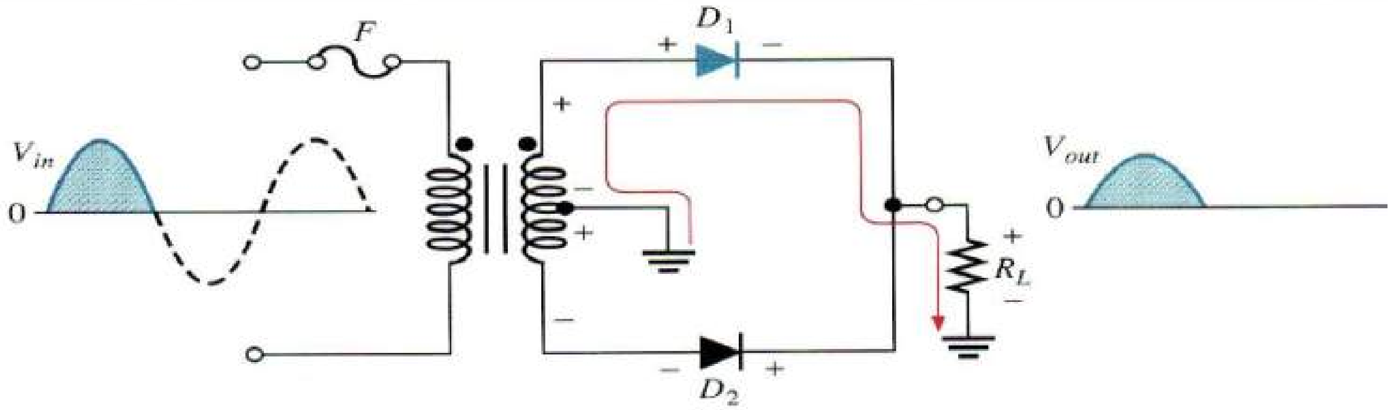
- *Yêu cầu*: Sử dụng biến thế có chấu giữa ở thứ cấp (nghĩa là phần giữa của cuộn dây thứ cấp)
- ***Ưu điểm:*** Cả 2 bán kỳ đều có dòng
- ***Khuyết điểm:*** là không sử dụng hết điện áp ở thứ cấp

$$\text{PIV} = 2V_s - V_D$$

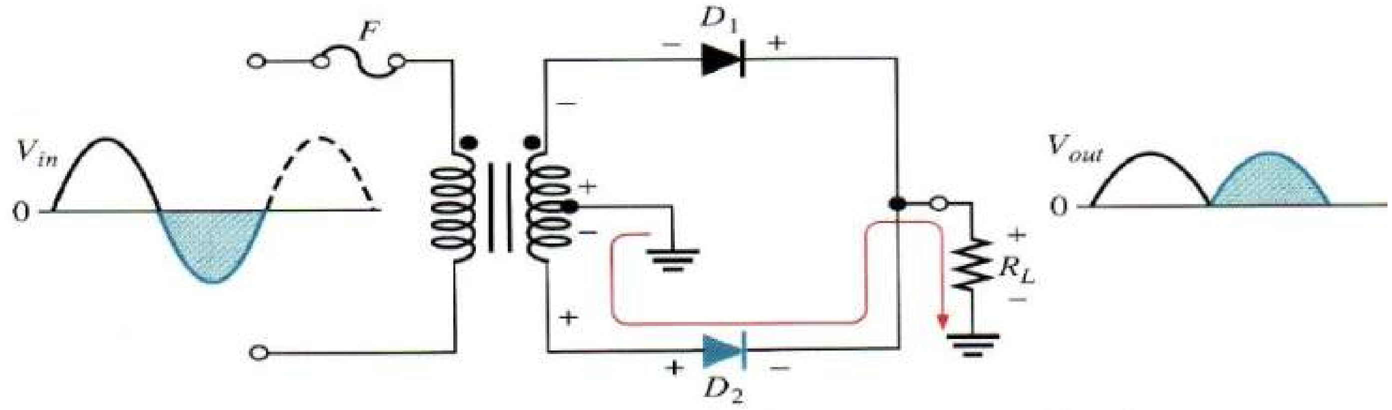


(c) Dạng sóng đầu ra

Full –wave rectification

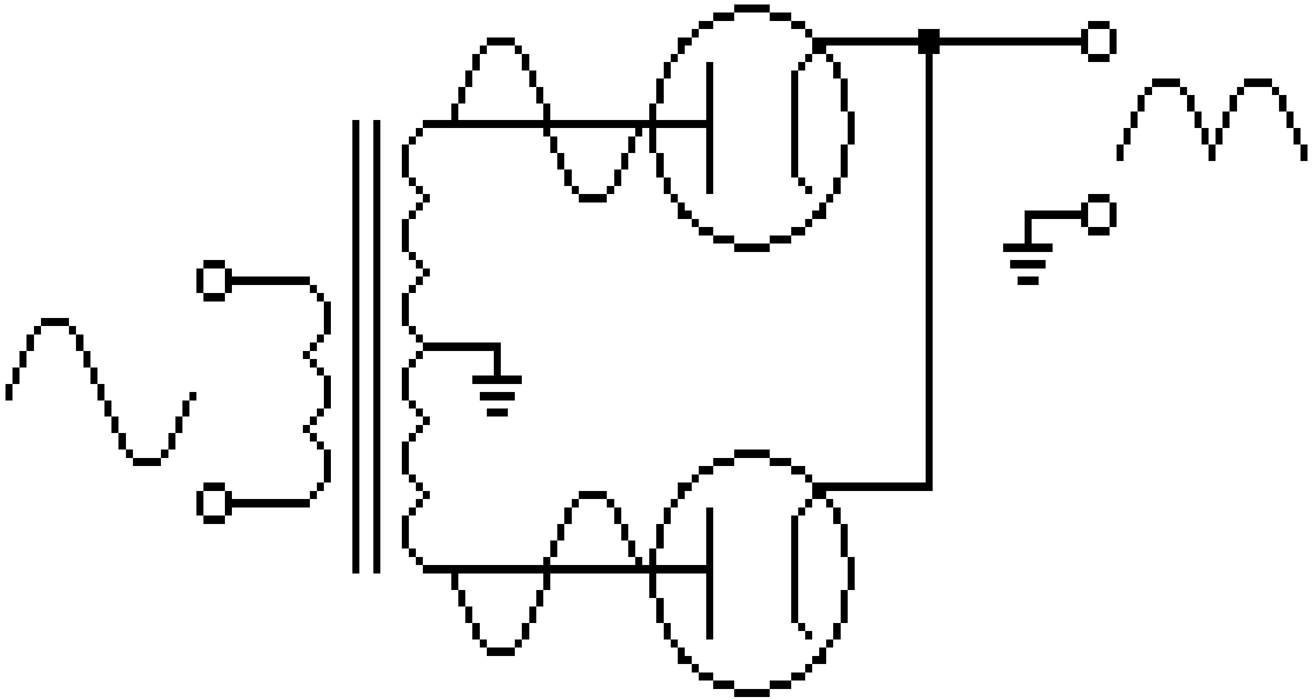


(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.



(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

Animation of center-tapped transformer rectifier



Các công thức trong mạch chỉnh lưu toàn sóng

- Giá trị DC hay trung bình V_{dc}:

$$V_{dc} = 2V_p/\pi \cong 0.636\ V_p$$

- Tần số ra:

$$f_{out} = 2f_{in}$$

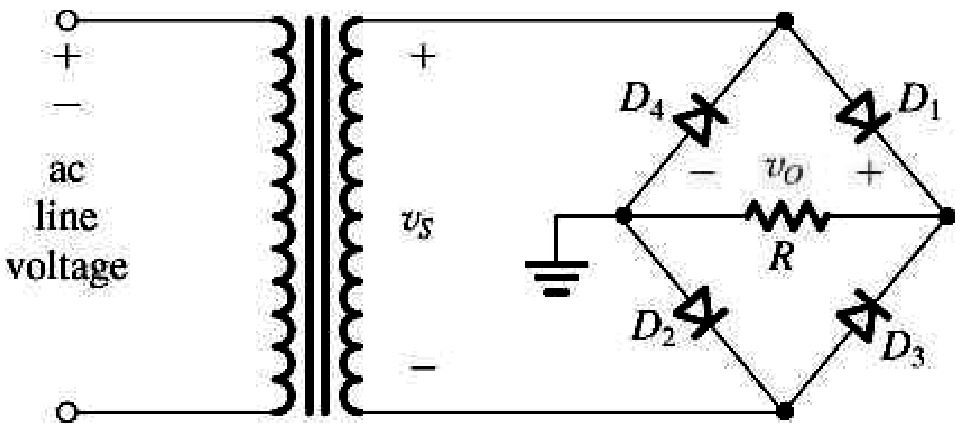
- Xấp xỉ bậc 2:

$$V_{p(out)} = V_{p(in)} – 0.7V \text{ (diode Si)}$$

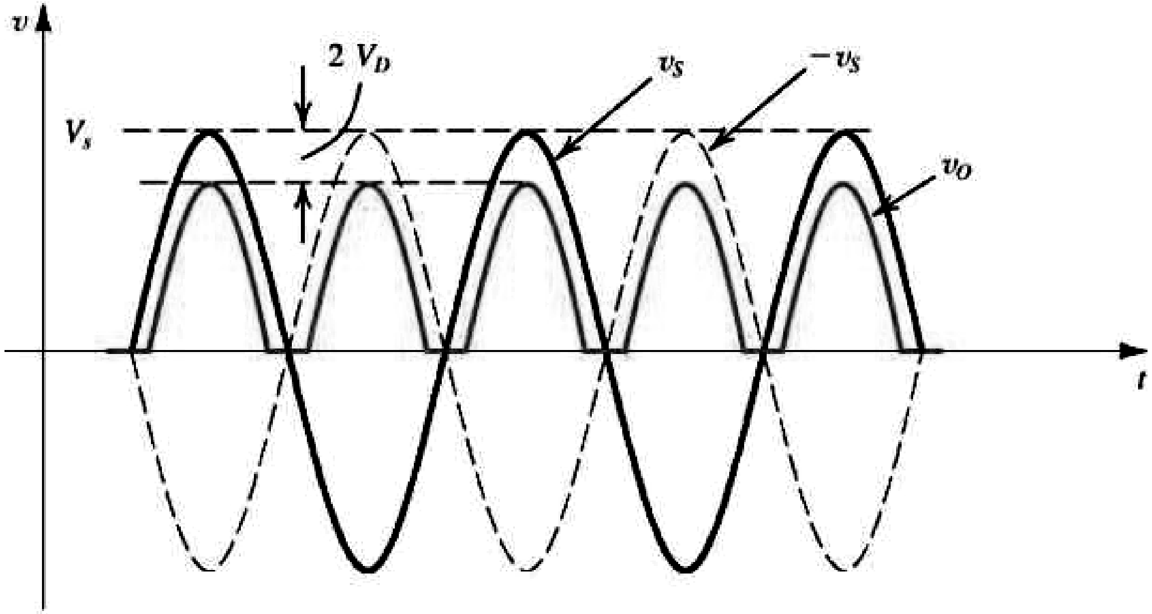
- Chú ý:

  $V_{p(in)} = 0.5\ V_2$ (V_2 là điện áp ở thứ cấp vì ngõ ra có chấu giữa (center tap))

Bridge Rectifier (mạch chỉnh lưu cầu)



(a)



(b)

$$\text{PIV} = V_s - V_D$$

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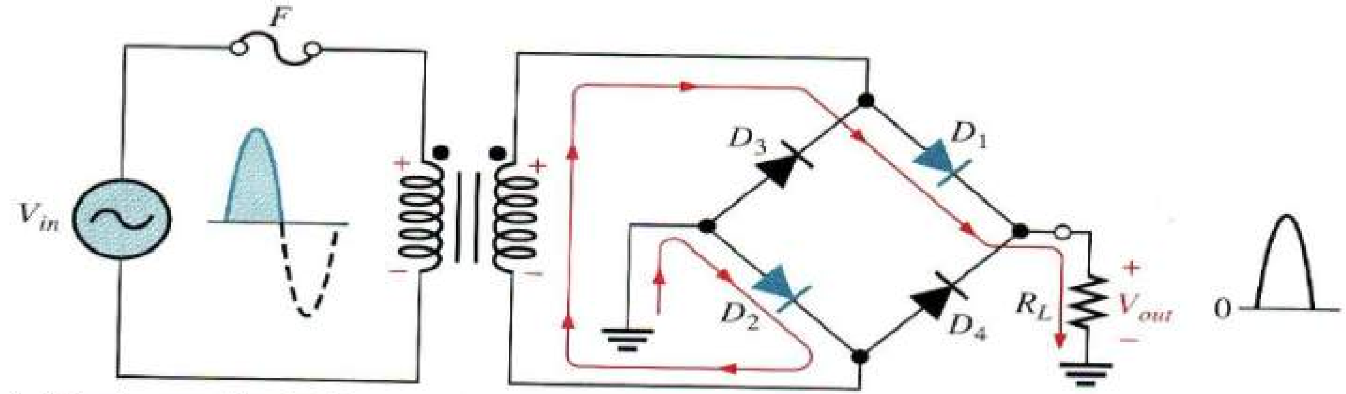
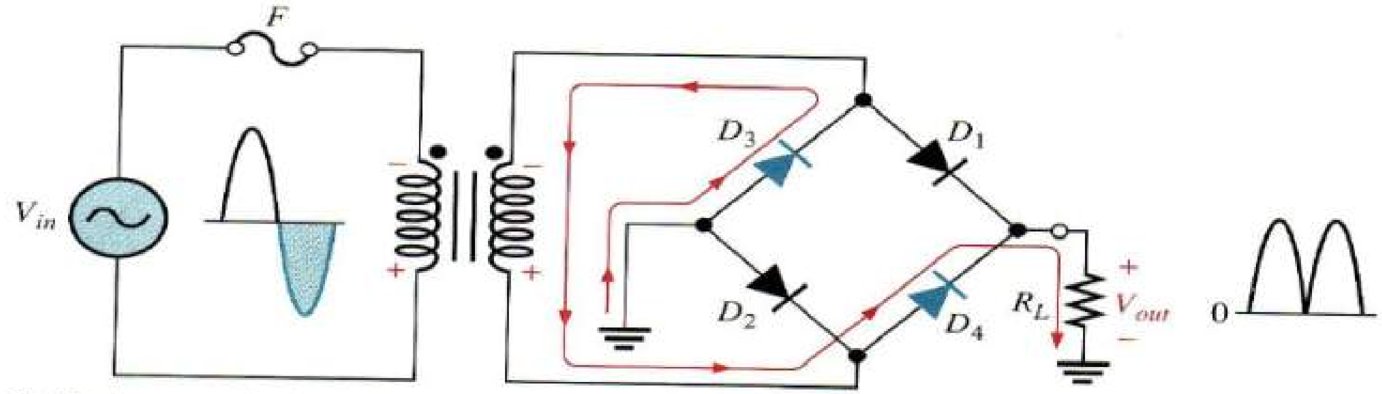
Bridge Full –wave rectification

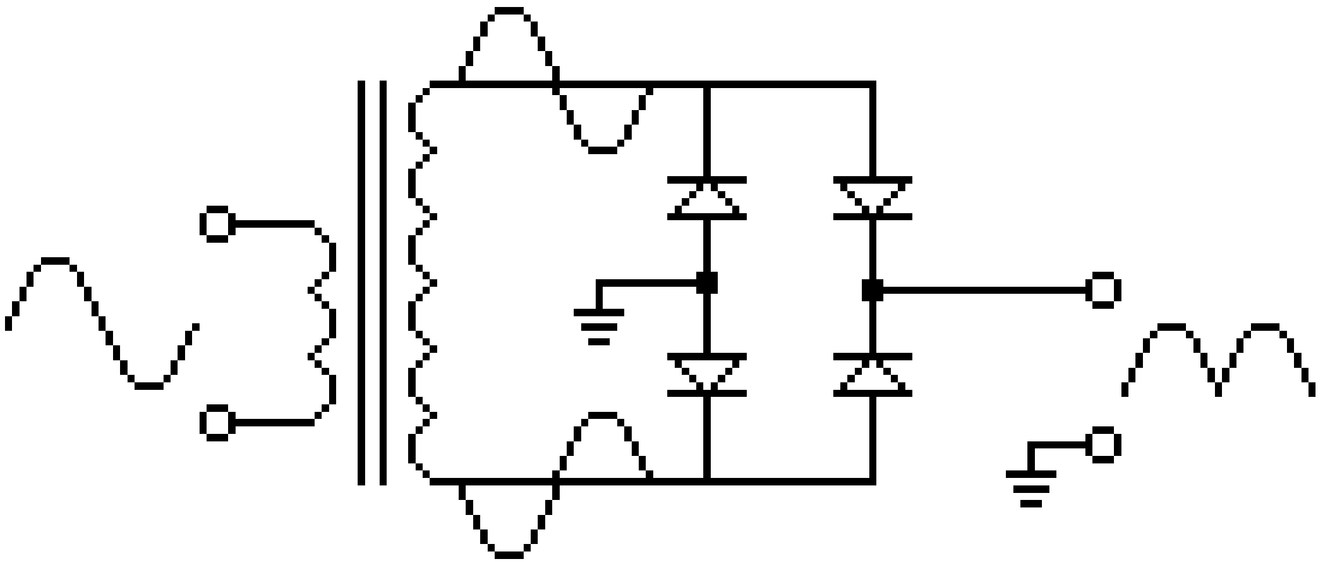


(a) During positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

Animation of full bridge rectifier



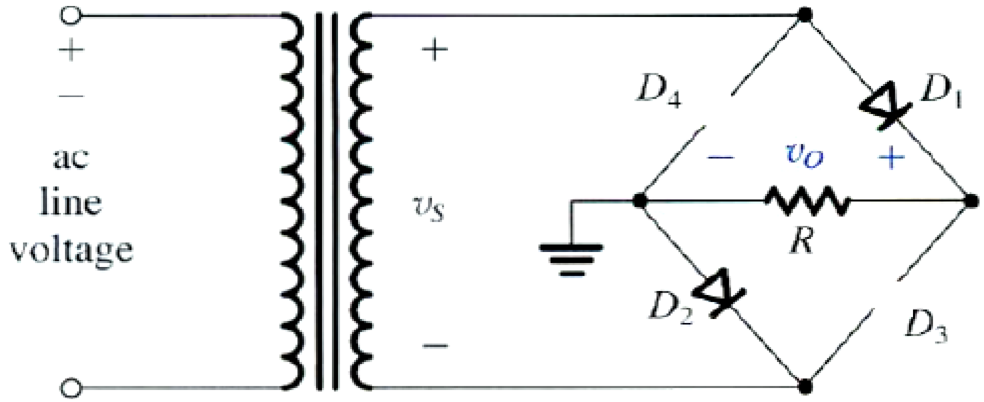
Chỉnh lưu cầu

- Chỉnh lưu cầu

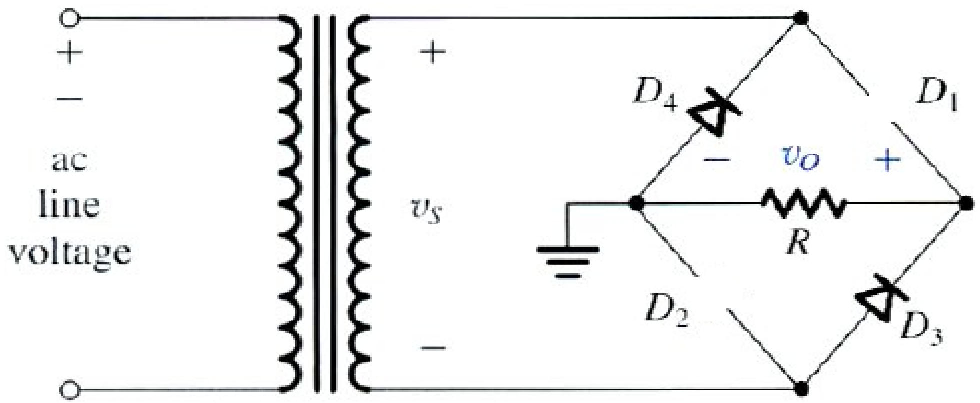
$$V_O = v_S - 2V_{D0}\ ;$$
$$\text{PIV} = V_O + V_{D0} = v_S - V_{D0}$$

- So với các mạch chỉnh lưu trước thì mạch này có ưu điểm:
  - Không cần biến thế có chấu giữa
  - PIV chỉ bằng phân nửa loại thứ 2
  - Số vòng dây ở cuộn thứ cấp cũng giảm phân nửa so với loại thứ 2

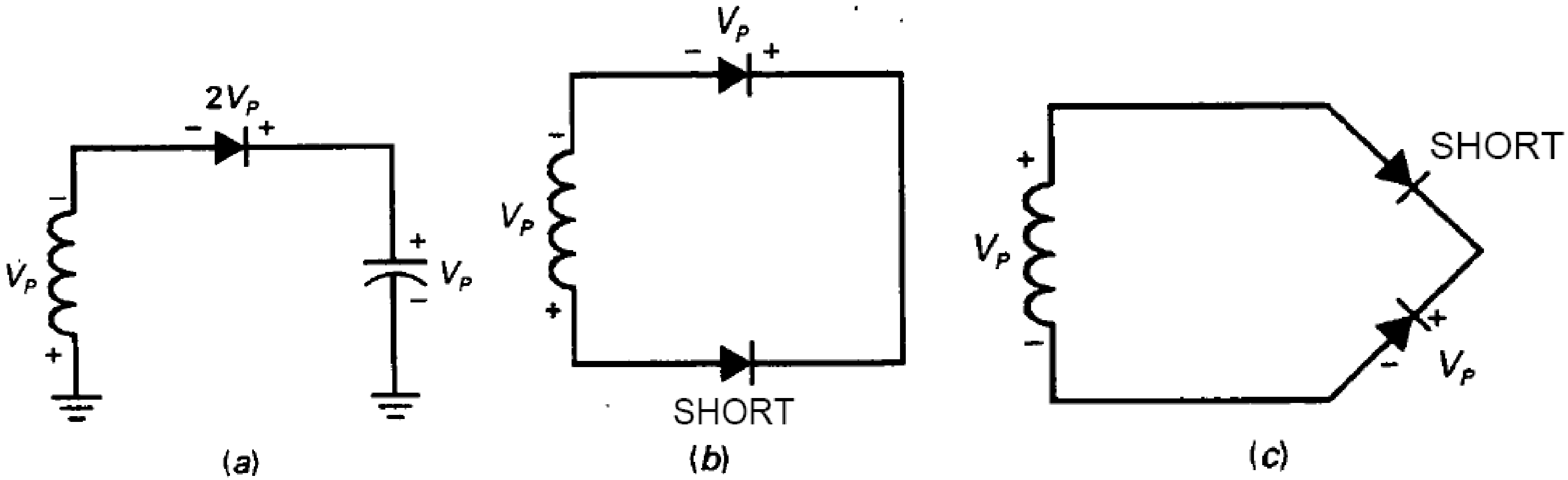
$V_S > 2V_{D0}$



$V_S < 2V_{D0}$



Điện áp ngược đỉnh PIV



(a) Mạch bán kỳ

PIV = $2V_P$

(b) Mạch toàn sóng

PIV = V_P

(c) Mạch cầu

PIV = V_P

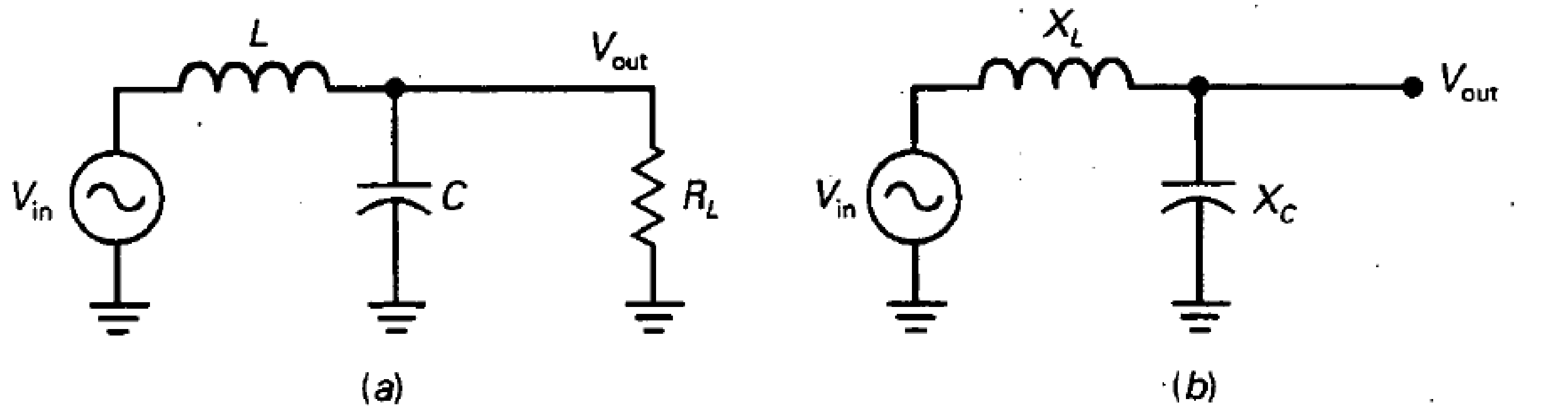
So sánh các mạch chỉnh lưu

Mạch chỉnh lưu	PIV	Điện áp ra đỉnh V_0	Điện áp ra DC V_{DC}	Hiệu suất	Tỉ số vòng dây
Bán kỳ	$2V_S$	$V_S - V_{D0}$	V_0/π	~40%	$N_1:N_2$
Toàn sóng	$V_S - V_{D0}$	$V_S - V_{D0}$	$2V_0/\pi$	~90%	$N_1:2N_2$
Cầu	$V_S - V_{D0}$	$V_S - 2V_{D0}$	$2V_0/\pi$	~80%	$N_1:N_2$

Chú thích:

- Điện áp tại thứ cấp $v_s = V_S \sin \omega t$
- V_S=điện áp đỉnh của điện áp tại thứ cấp
- V_0=điện áp đỉnh ở ngõ ra của mạch chỉnh lưu
- $V_{D0}=V_{ON}=V_\gamma$=điện áp dẫn của diode
- $N_1:N_2$=tỉ số vòng dây của biến thế

Mạch lọc [ngõ vào] dùng cuộn dây



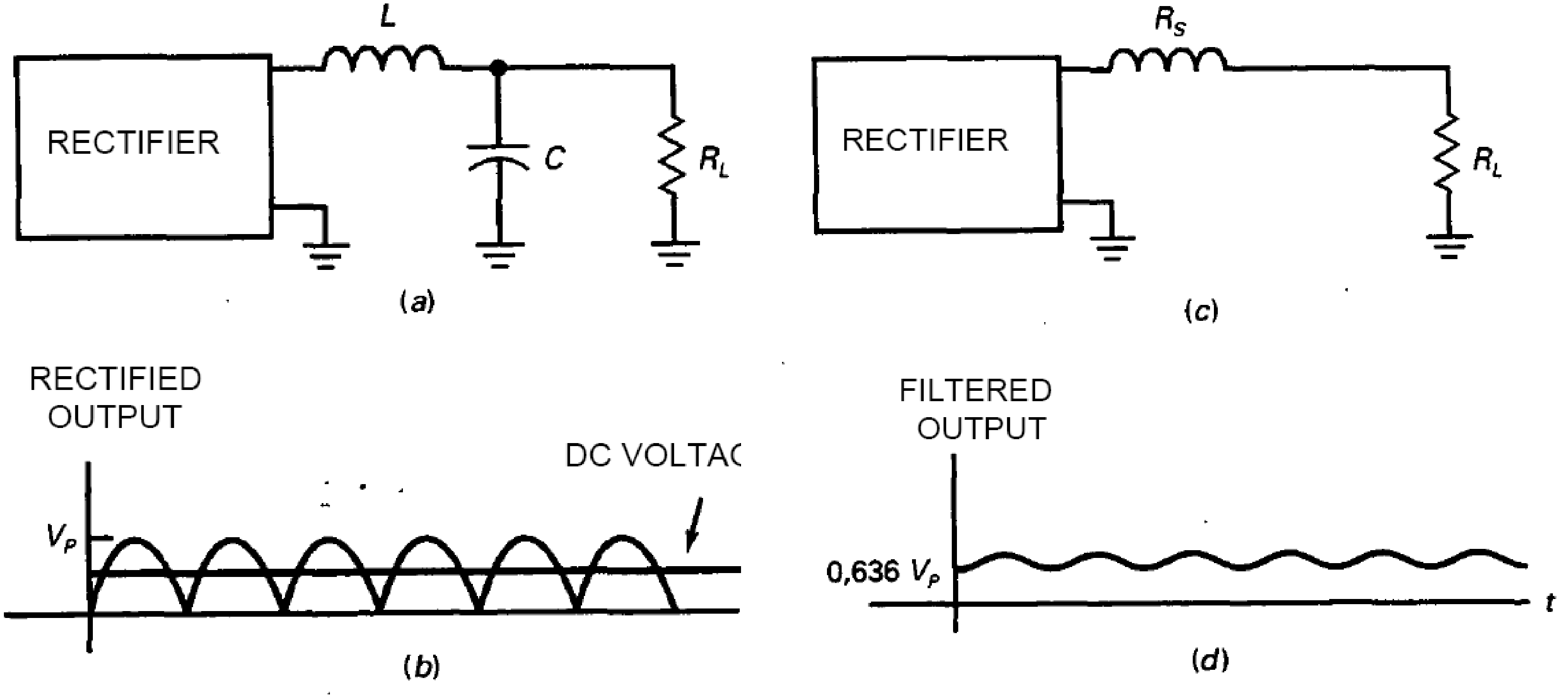
(a) Mạch lọc ngõ vào (dùng) cuộn dây;

(b) Mạch tương đương AC

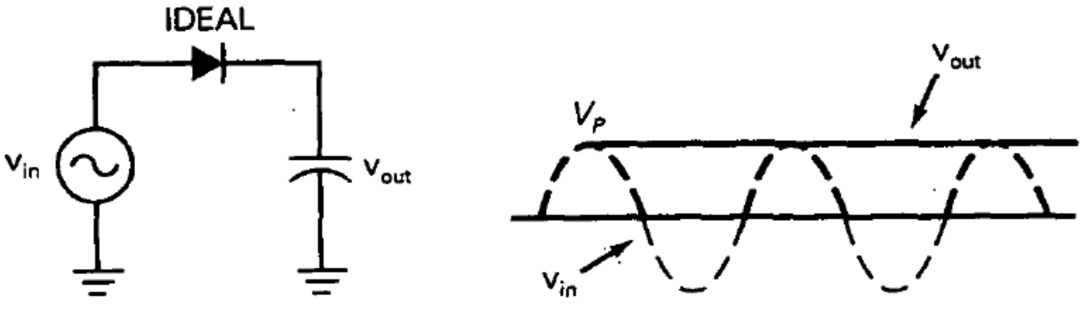
- <u>Ý tưởng cơ bản</u>: Nếu $X_L >> X_C$ thì

  $Vout \cong X_C V_{in}/X_L$

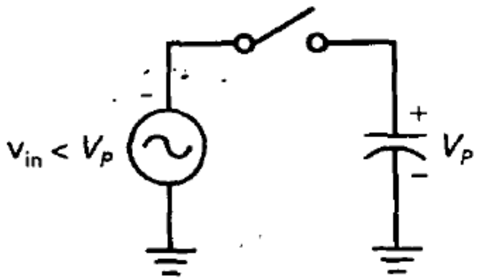
Lọc ngõ ra của mạch chỉnh lưu



Mạch lọc [ngõ vào] dùng tụ

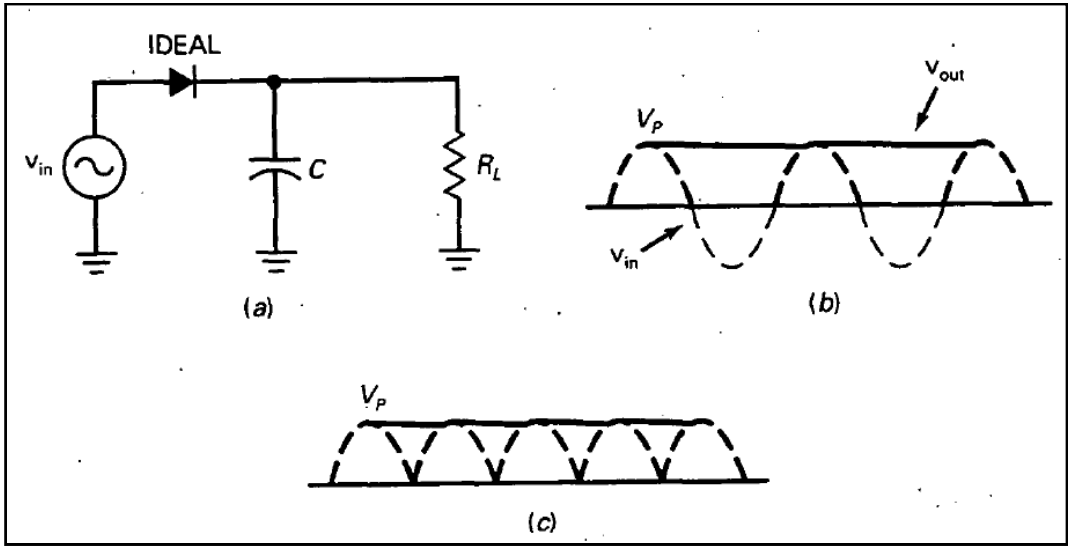


(a) (b)



(c)

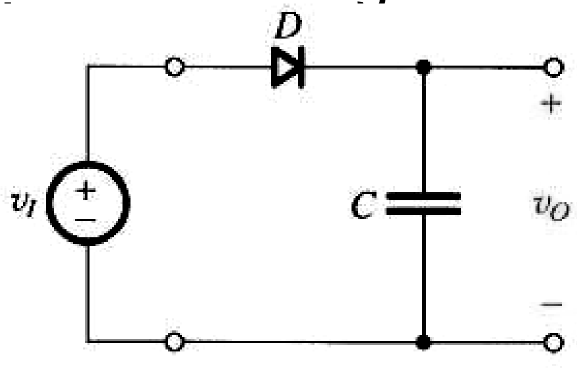
Ý tưởng cơ bản



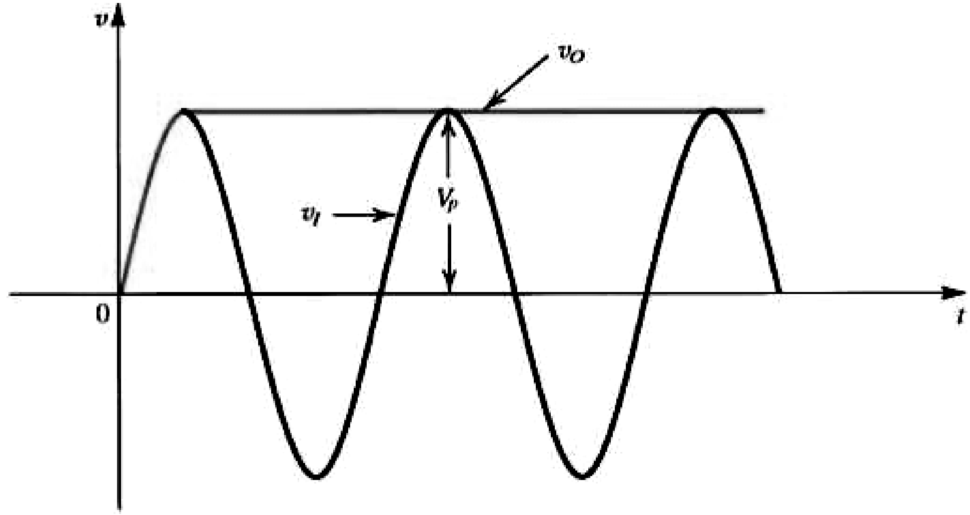
Hiệu ứng của điện trở tải

Mạch tách sóng đỉnh (Peak Detector)

- Mạch tách sóng đỉnh:

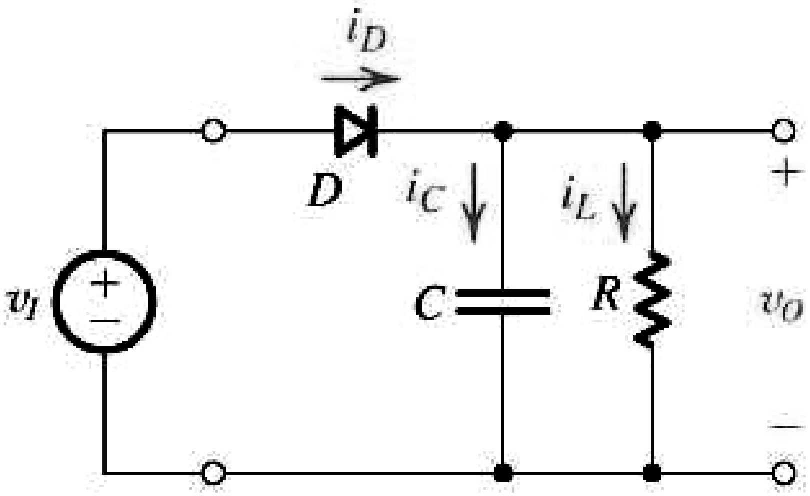


(a)



(b)

- Mạch tách sóng đỉnh thực tê:

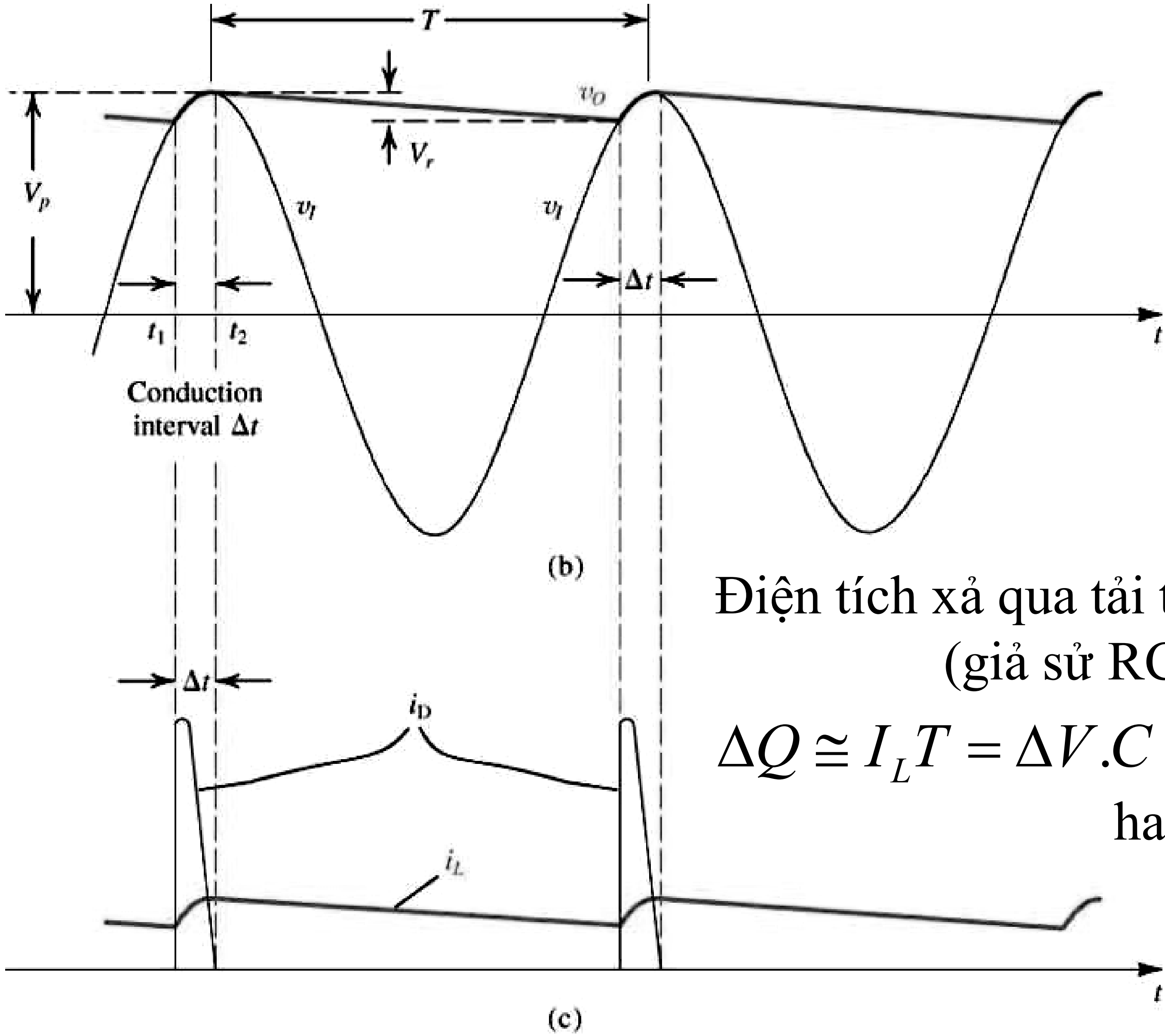


(a)

Định nghĩa các tham số

- V_r = điện áp gợn đỉnh-đỉnh
- I_L = dòng điện DC qua tải
- T = chu kỳ gợn
- C = điện dung của tụ lọc

Mạch tách sóng đỉnh (2)



Điện tích xả qua tải trong một chu kỳ:
(giả sử RC >> T)

$$\Delta Q \cong I_L T = \Delta V.C = V_r C \rightarrow C = \frac{I_L T}{V_r}$$

hay

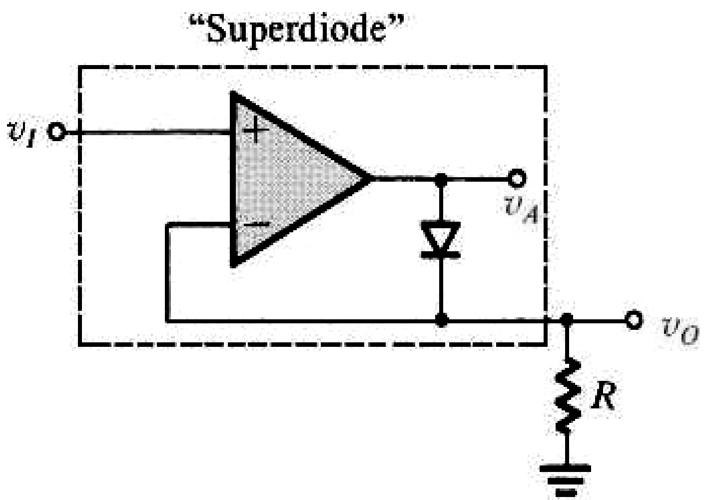
$$C = \frac{V_p}{f V_r R}$$

Mạch tách sóng đỉnh (3)

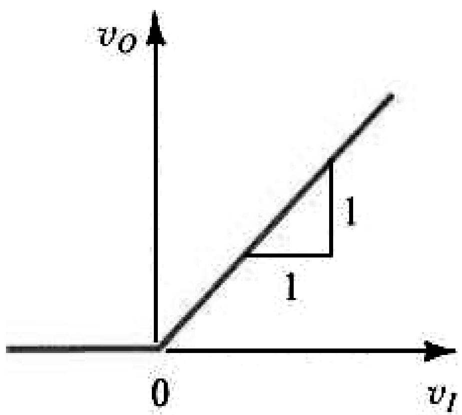
- Với mạch tách sóng đỉnh toàn sóng: (tần số gợn tăng gấp đôi thành *2f*)

$$C = \frac{V_p}{2fV_rR}$$

- ***Mạch chỉnh lưu bán kỳ chính xác – Siêu diode***

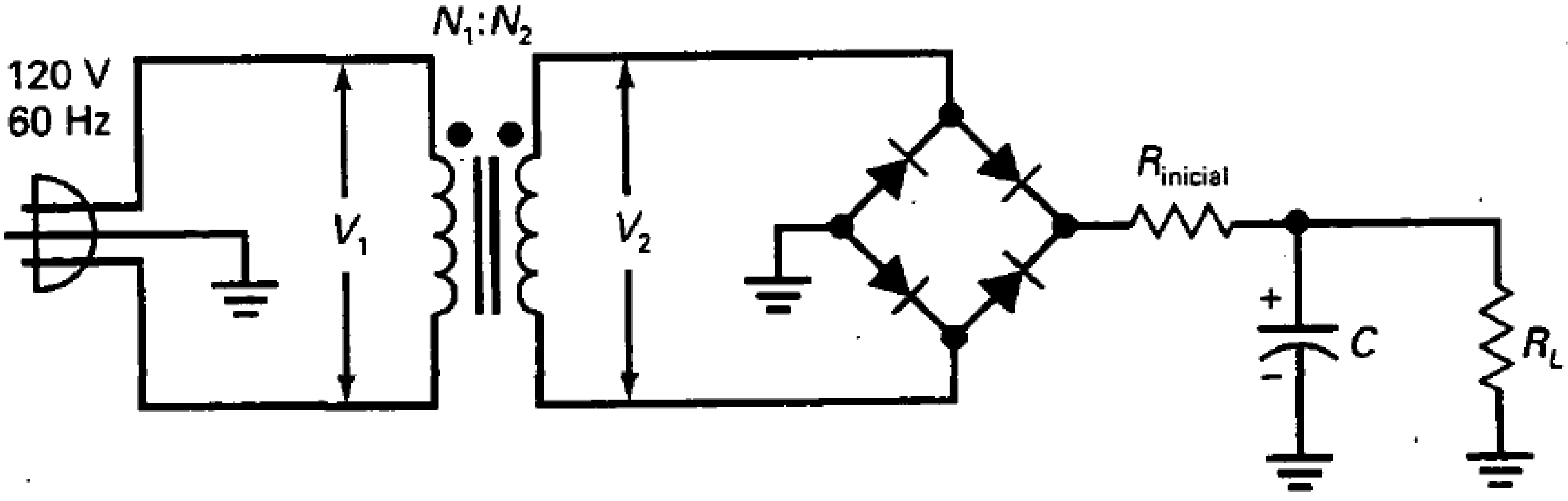


(a) Mạch



(b) Đặc tuyến truyền đạt

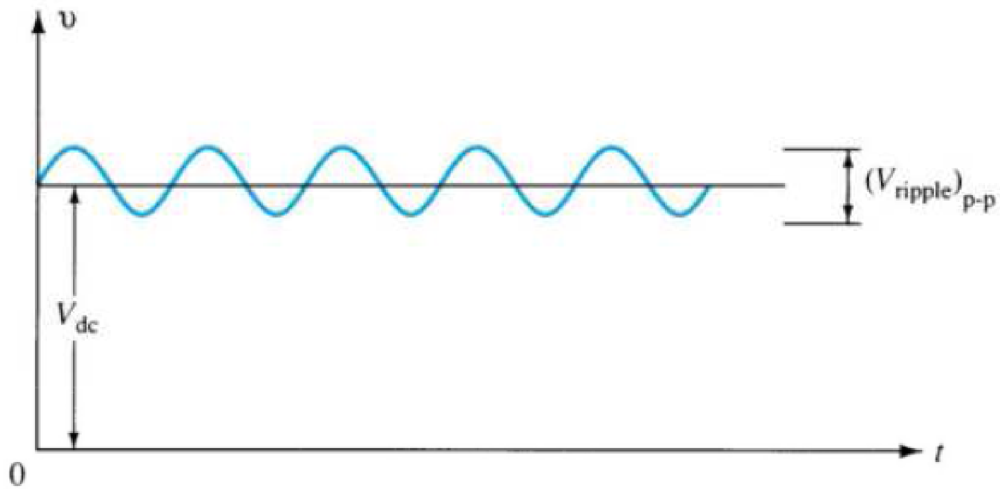
Surge resistor



Điện trở bảo vệ giới hạn dòng quá độ

Ripple Factor

After the filter circuit a small amount of AC is still remaining. The amount of ripple voltage can be rated in terms of **ripple factor** (r).



$$\%r = \frac{\text{ripple voltage (rms)}}{\text{dc voltage}} = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

Rectifier Ripple Factor
(Hệ số gợn của mạch chỉnh lưu)

Half-Wave

DC output:

$$V_{dc} = 0.318V_m$$

AC ripple output:

$$V_{r(rms)} = 0.385V_m$$

Ripple factor:

$$\%r = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

$$= \frac{0.385V_m}{0.318V_m} \times 100 = 121\%$$

Full-Wave

DC output:

$$V_{dc} = 0.636V_m$$

AC ripple output:

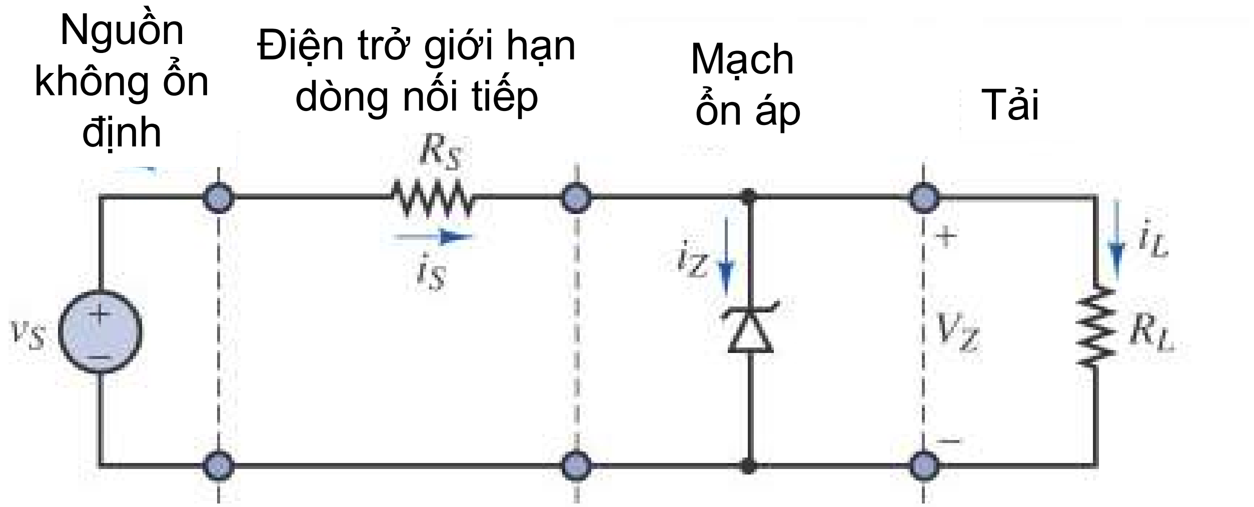
$$V_{r(rms)} = 0.308V_m$$

Ripple factor:

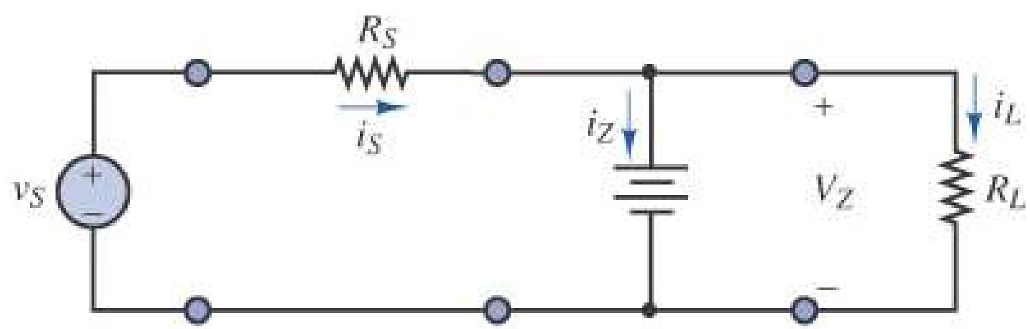
$$\%r = \frac{V_{r(rms)}}{V_{dc}} \times 100$$

$$= \frac{0.308V_m}{0.636V_m} \times 100 = 48\%$$

Mạch ổn áp dùng diode Zener



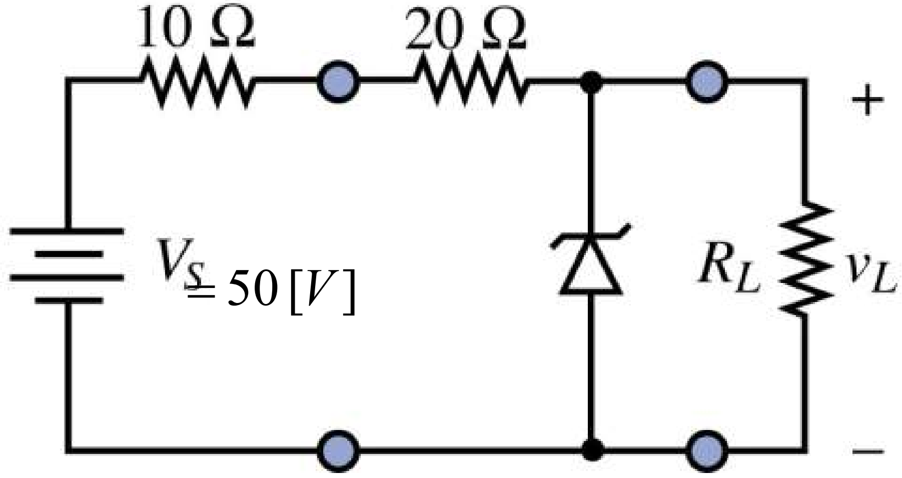
(a)



(b) Mạch tương đương

Tính tầm điện trở giới hạn dòng

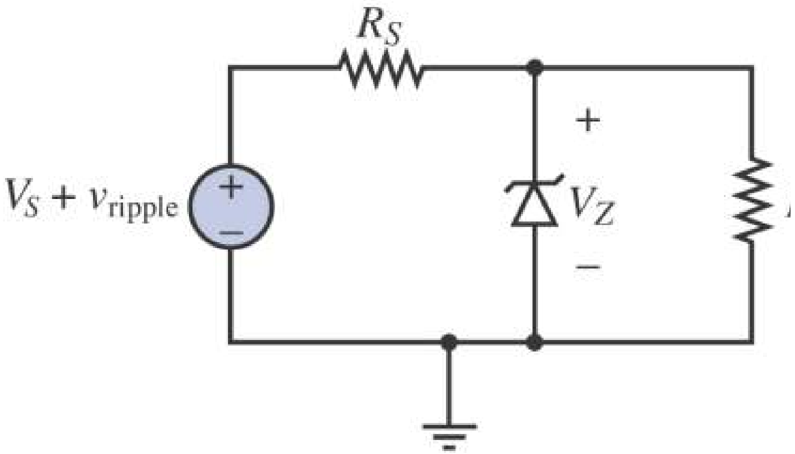
$$V_Z = 14\,[V],\ P_Z = 5\,[W]$$

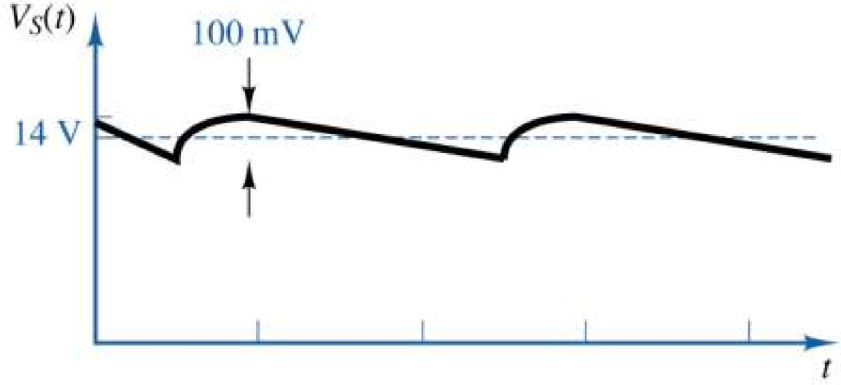


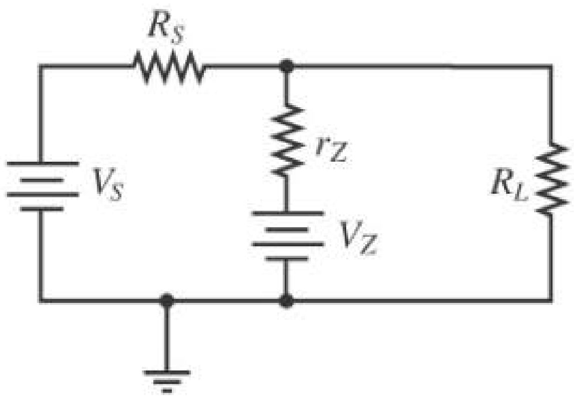
$$R_{\min} = \left.\frac{V_Z}{I_s - I_Z}\right|_{I_Z=0} = \frac{14}{(50-14)/30} = 11.7\,\Omega$$

$$R_{\max} = \left.\frac{V_Z}{I_s - P_Z / V_Z}\right|_{P_Z=5[W]} = \frac{14}{(50-14)/30 - 5/14} = 16.6\,\Omega$$

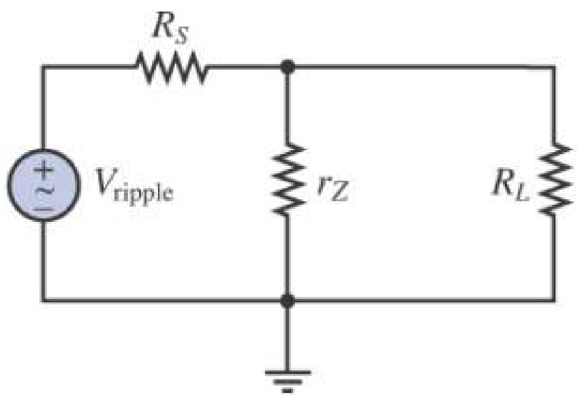
Hiệu ứng của điện trở Zener khác zero







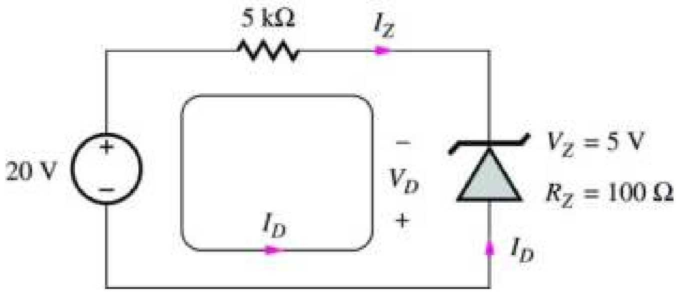
Mạch tương đương DC

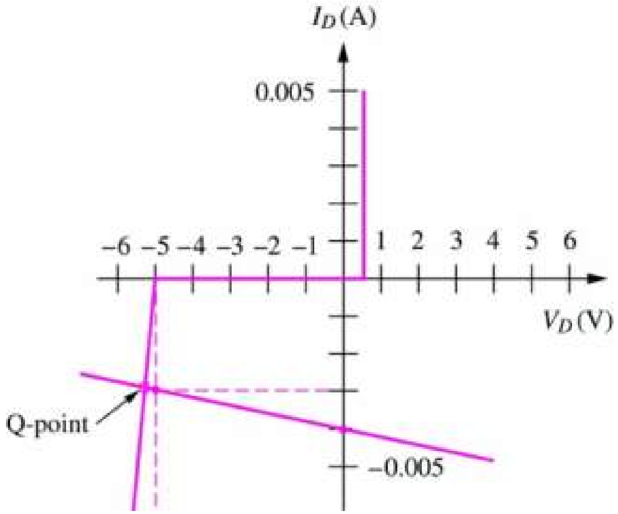


Mạch tương đương AC

NX: Điện áp gợn trên tải sẽ nhỏ vì điện trở Zener thường rất nhỏ

Analysis of Diodes in Reverse Breakdown Operation



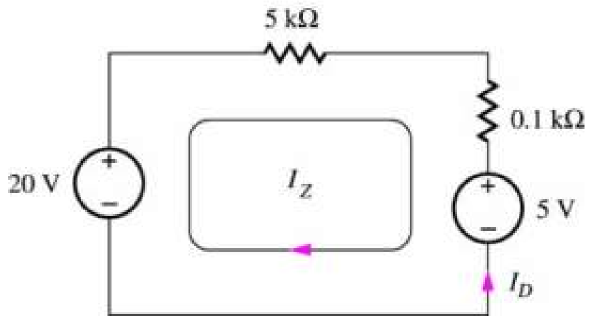


Using load-line analysis:

$$-20 = V_D + 5000 I_D$$

Choose 2 points (0V, -4 mA) and (-5 V, -3 mA) to draw the load line. It intersects the *i*-*v* characteristic at the Q-point: (-2.9 mA, -5.2 V).

Using the piecewise linear model:



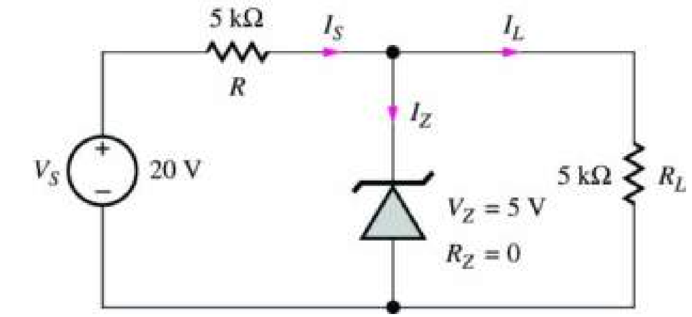
$$I_Z = -I_D > 0$$

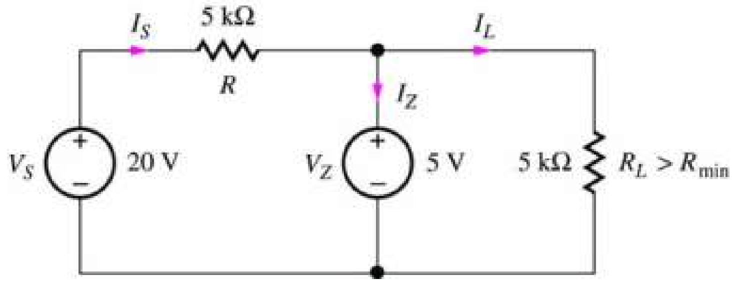
$$20 - 5100 I_Z - 5 = 0$$

$$I_Z = \frac{(20-5)\text{V}}{5100\Omega} = 2.94 \text{ mA}$$

Since $I_Z > 0$ ($I_D < 0$), the solution is consistent with Zener breakdown.

Voltage Regulator Using the Zener Diode





$$I_S = \frac{V_S - V_Z}{R} = \frac{(20-5)\text{V}}{5\text{k}\Omega} = 3 \text{ mA}$$

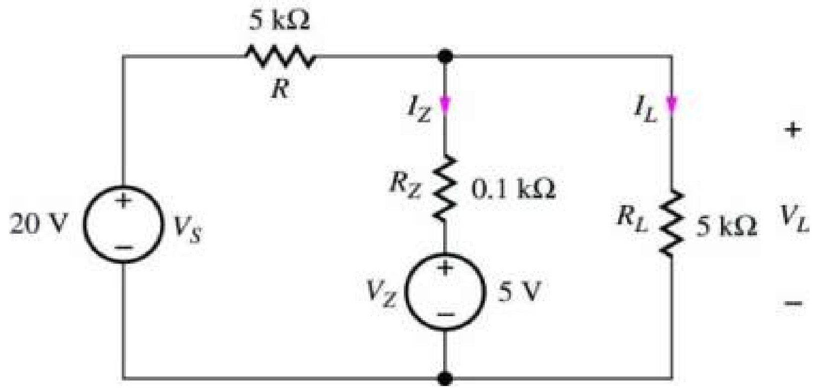
$$I_L = \frac{V_Z}{R_L} = \frac{5\text{V}}{5\text{k}\Omega} = 1\ mA \quad | \quad I_Z = I_S - I_L = 2\ mA$$

The Zener diode keeps the voltage across load resistor R_L constant. For Zener breakdown operation, $I_Z > 0$.

For proper regulation, Zener current must be positive. If the Zener current < 0, the Zener diode no longer controls the voltage across the load resistor and the voltage regulator is said to have "dropped out of regulation".

$$I_Z = \frac{V_S}{R} - V_Z\left(\frac{1}{R} + \frac{1}{R_L}\right) > 0 \quad | \quad R_L > \frac{R}{\left(\frac{V_S}{V_Z} - 1\right)} = R_{\min}$$

Voltage Regulator Using a Zener Diode: Example Including Zener Resistance



$$\frac{V_Z - 20\text{V}}{5000\Omega} + \frac{V_L - 5\text{V}}{100\Omega} + \frac{V_L}{5000\Omega} = 0$$

$$V_L = 5.19 \text{ V}$$

$$I_Z = \frac{V_L - 5\text{V}}{100\Omega} = \frac{5.19\text{V} - 5\text{V}}{100\Omega} = 1.9 \text{ mA} > 0$$

Problem: Find the output voltage and Zener diode current for a Zener diode regulator.

Given data: V_S = 20 V, R = 5 kΩ, R_Z = 0.1 kΩ, V_Z = 5 V

Analysis: The output voltage is a function of the current through the Zener diode.

Line and Load Regulation

Line regulation characterizes how sensitive the output voltage is to input voltage changes.

$$\text{Line Regulation} = \frac{dV_L}{dV_S} \text{ mV/V}$$

$$\text{For a fixed load current, Line Regulation } = \frac{R_Z}{R + R_Z}$$

Load regulation characterizes how sensitive the output voltage is to changes in load current withdrawn from regulator.

$$\text{Load Regulation} = \frac{dV_L}{dI_L} \ \Omega$$

$$\text{For changes in load current, Load Regulation} = -\left(R_Z \| R\right)$$

Load regulation is the Thévenin equivalent resistance looking back into the regulator from the load terminals.

Practical power supply circuits

Figure 6.20 shows a simple power supply circuit capable of delivering an output current of up to 250 mA.

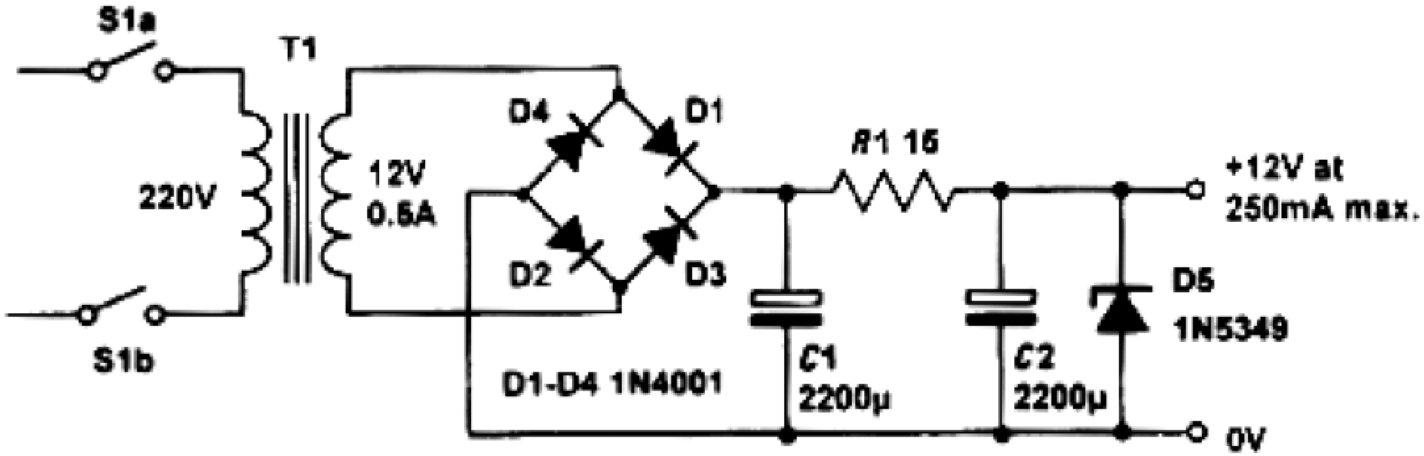


Figure 6.20
Simple d.c. power supply with shunt zener regulated output

The circuit uses a full-wave bridge rectifier arrangement (D_1 to D_4) and a simple C-R filter. The output voltage is regulated by the shuntconnected 12 V zener diode.

Figure 6.21 shows an improved power supply in which a transistor is used to provide current gain and minimize the power dissipated in the zener diode (T_{R1} is sometimes referred to as a ***seriespass transistor***).

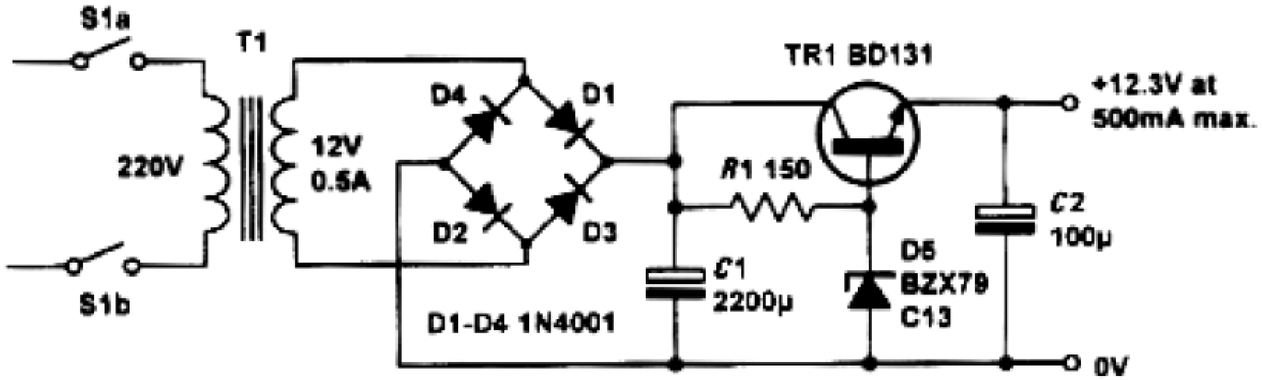


Figure 6.21
Improved regulated d.c. power supply with series-pass transistor

The zener diode. D5. is rated at 13 V and the output voltage will be approximately 0.7 V less than this (i.e. 13 V minus the baseemitter voltage drop associated with T_{R1}). Hence the output voltage is about 12.3 V. The circuit is capable of delivering an output current of up to 500 mA (note that T_{R1} should be fitted with a small heatsink to conduct away all', heat produced).

Figure 6.22) shows a variable power supply.

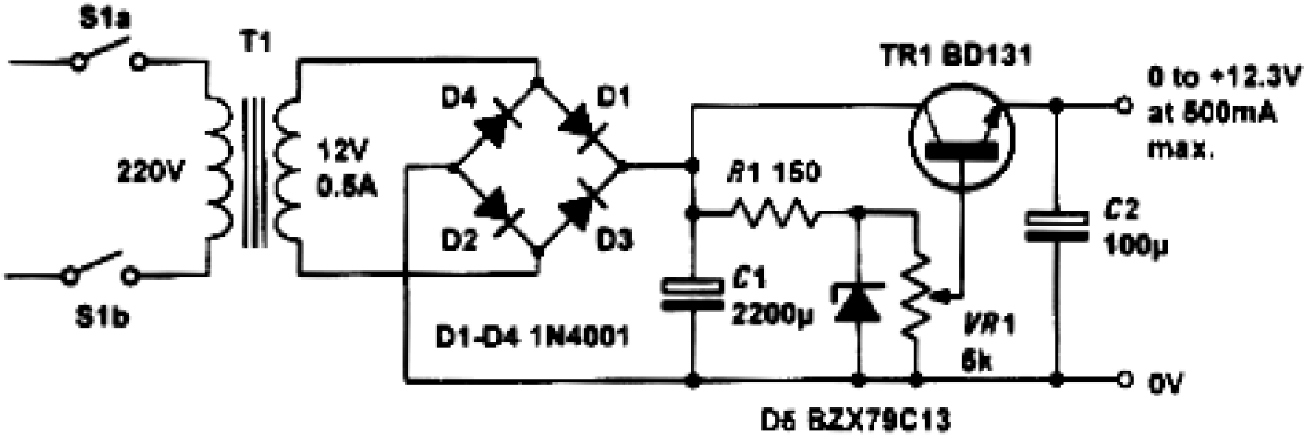


Figure 6.22
Variable d.c. power supply

The base voltage to the series-pass transistor is derived from a potentiometer connected across the zener diode. $D_{5.}$ Hence the base voltage is variable from 0V to 13 V. The transistor requires a substantial heatsink (note that T_{R1} 's dissipation increases a, the output voltage is reduced).

Finally. Fig. 6.23 shows a d.c. power supply - based on a fixed-voltage ***three-terminal integrated circuit voltage regulator***.

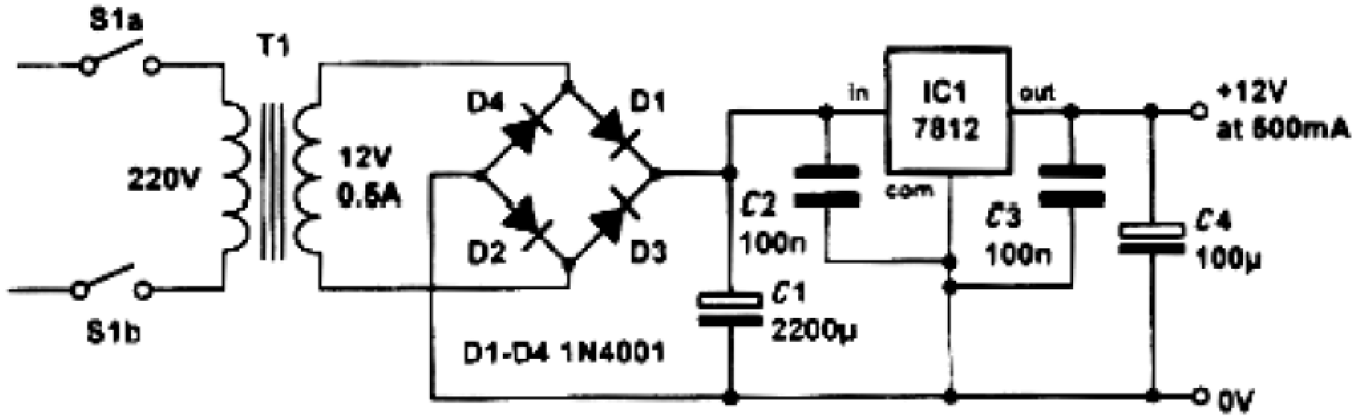


Figure 6.23
Power supply with three-terminal IC voltage regulator

These devices are available in standard voltage and current ratings (e.g. 5 V. 12 V, 15 V at I A, 2 A and > A) and they provide excellent performance in terms of output resistance, ripple rejection and voltage regulation.

In addition, such devices usually incorporate overcurrent protection and can withstand a direct short-circuit placed across their output terminals. This is an essential feature in many practical applications!

Mạch xén (clipper) và mạch hạn biên (limiter)

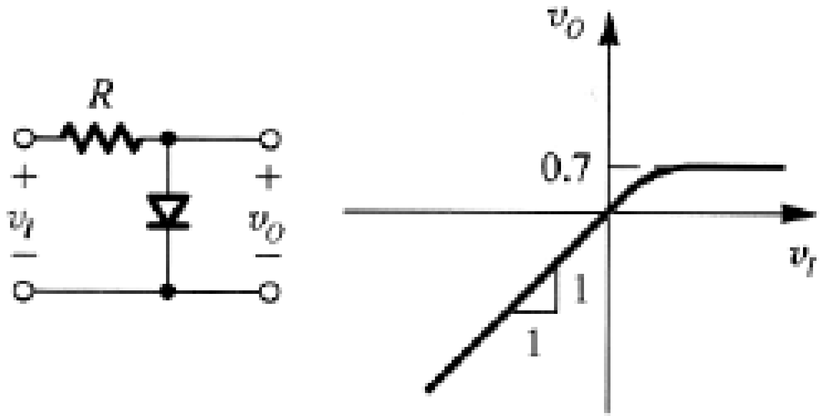
- Có 3 loại mạch xén:
  - Mạch xén trên (mạch xén dương) = Positive clipper
  - Mạch xén dưới (mạch xén âm) = Negative clipper
  - Mạch xén 2 mức độc lập (mạch xén kết hợp)=Combination clipper

Chú ý: Tổng quát các mạch xén có phân cực

- Mạch hạn biên hay kẹp diode

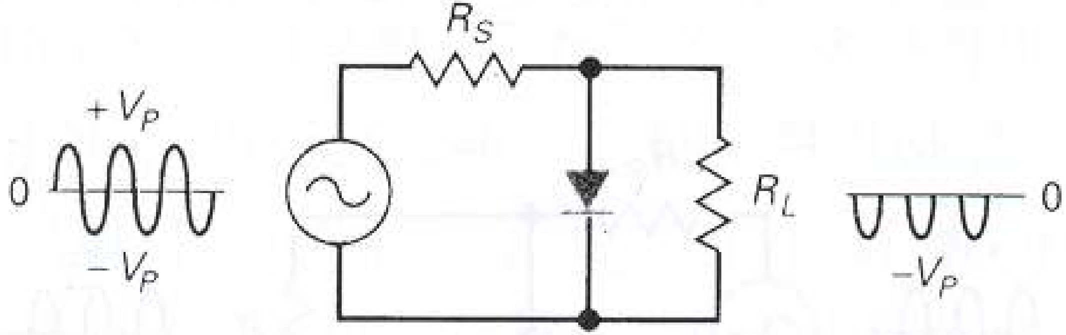
❑ Các Mạch xén và hạn biên (Clippers and Limiters)

Đặc tuyến truyền đạt

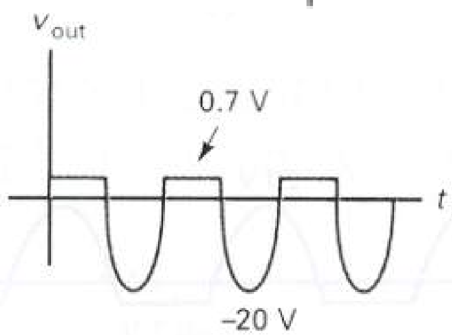


- Small Signal Diode

① The positive clipper



or

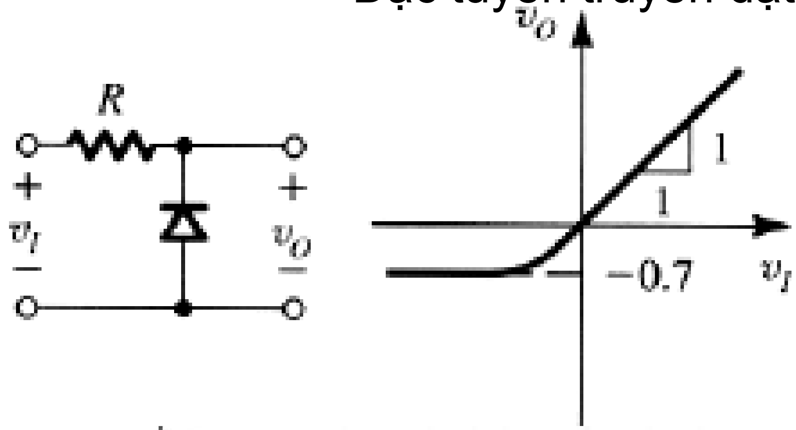


* 1N914 : I_F = 10mA for 1V

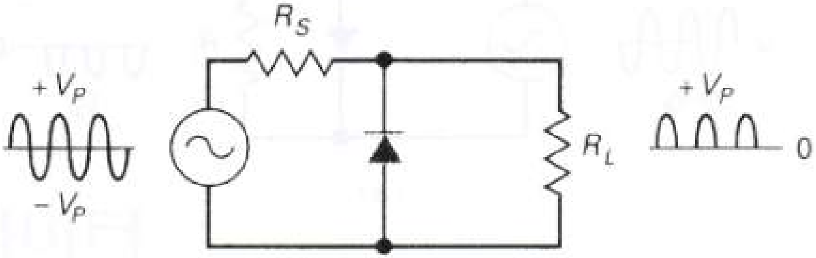
∴ $R_B = \dfrac{1-0.7V}{10mA}$ = 30 Ohm Ω

* Stiff Clipper : 100 $R_B < R_S < 0.01\ R_L$

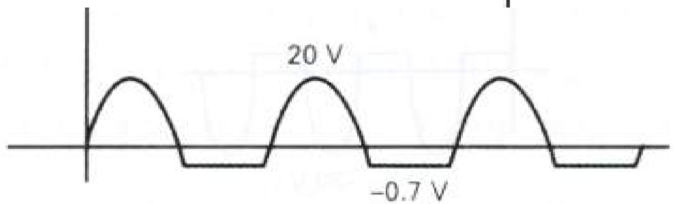
Đặc tuyến truyền đạt



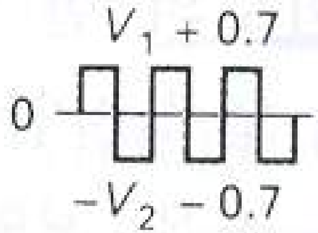
② The Negative clipper

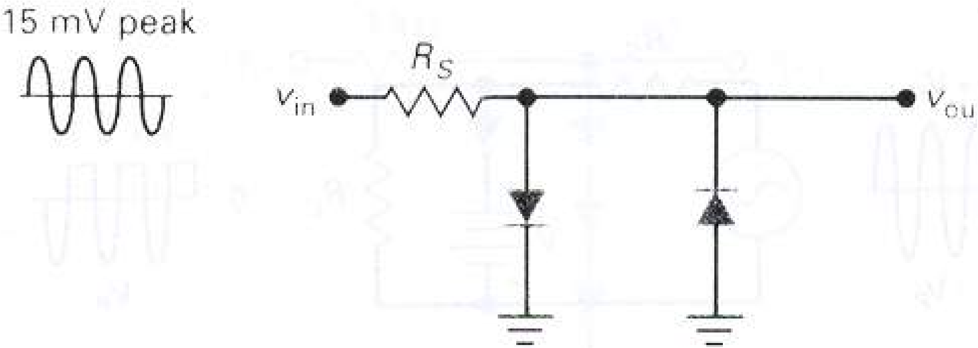


or

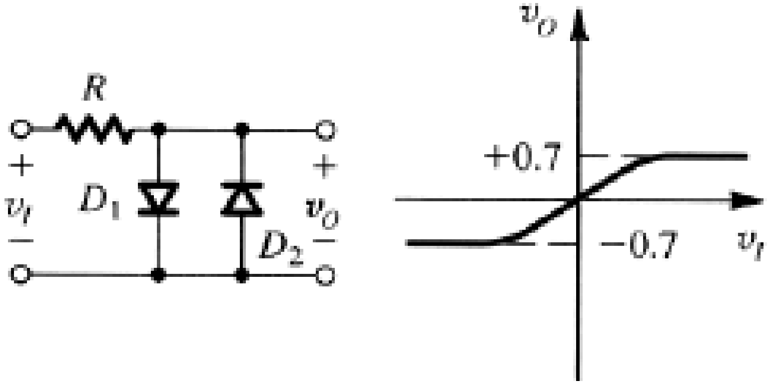


③ The Limiter or Diode clamp



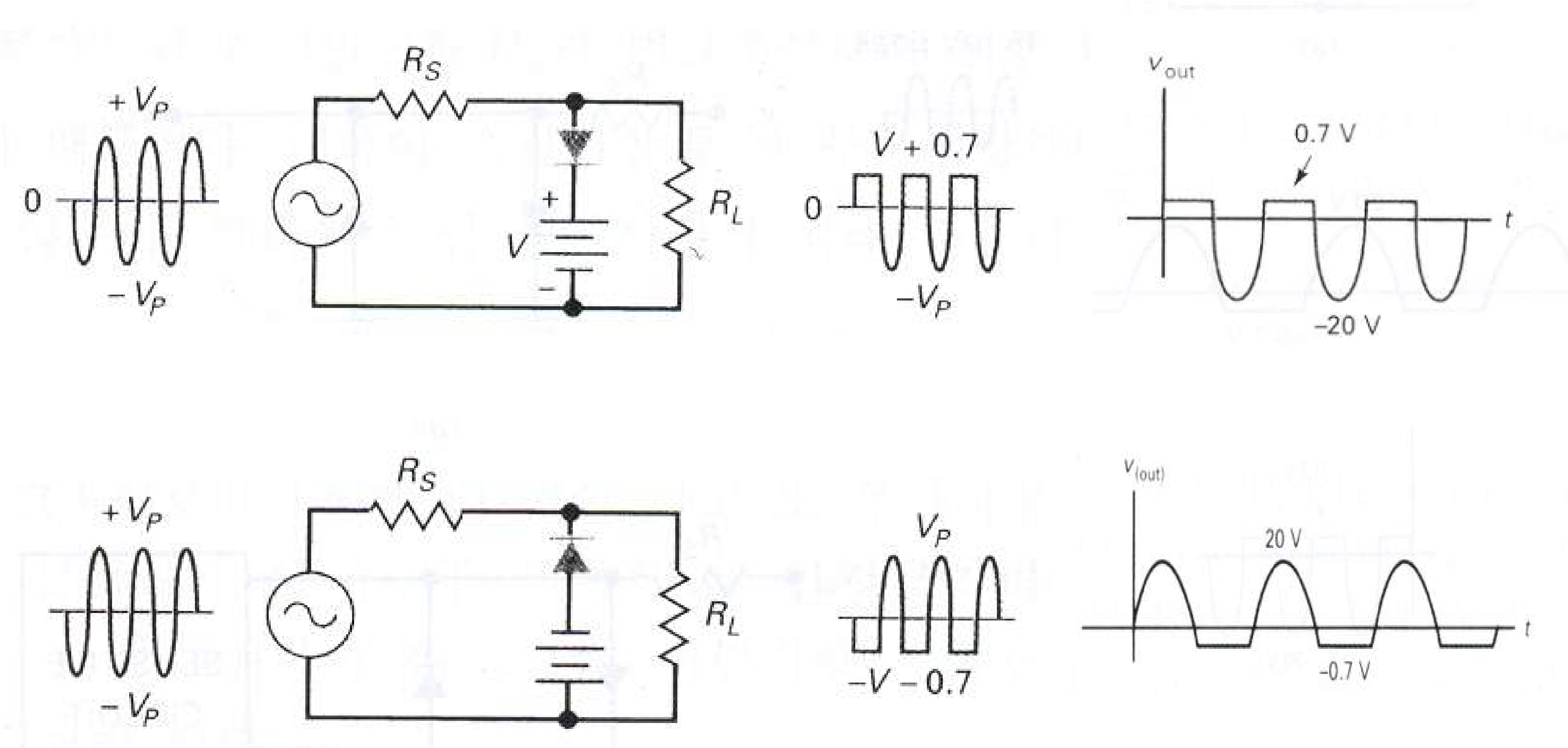


Đặc tuyến truyền đạt

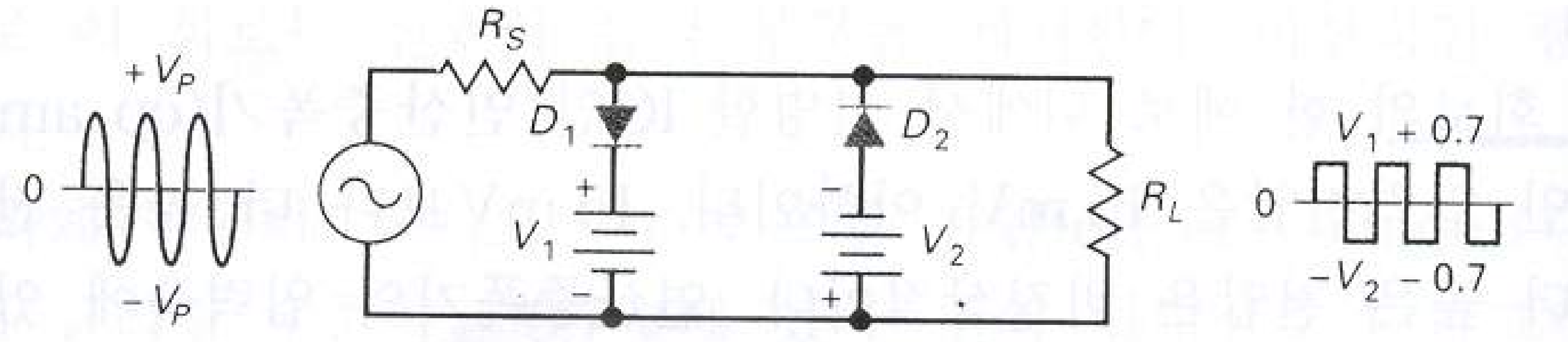


protect sensitive circuits

④ Biased Clippers

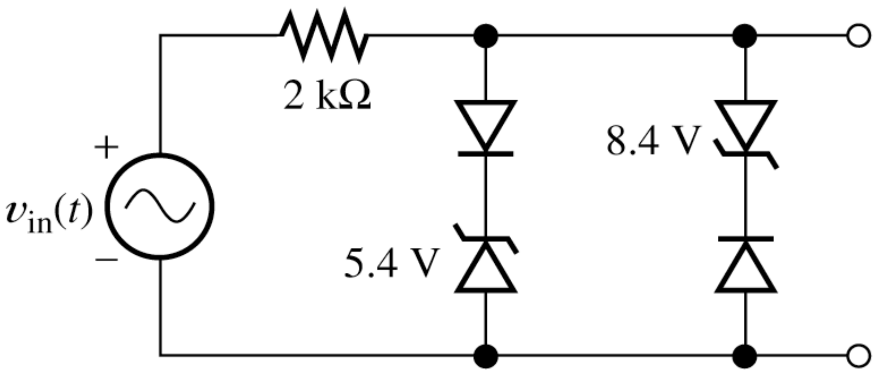


⑤ Combination Clipper (slicer)

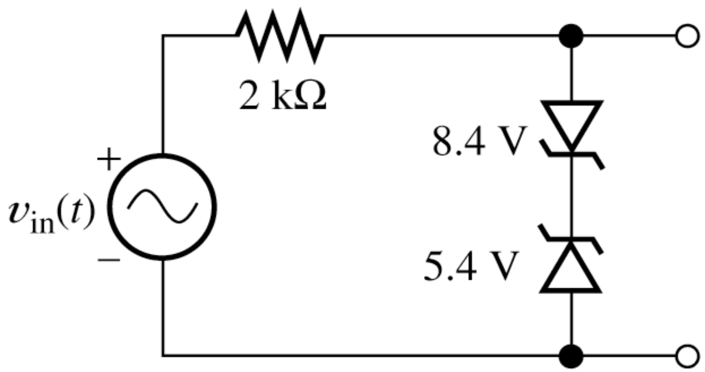


Clipper Circuits using Zener Diodes

Zener diode provides a reference voltage of V_Z

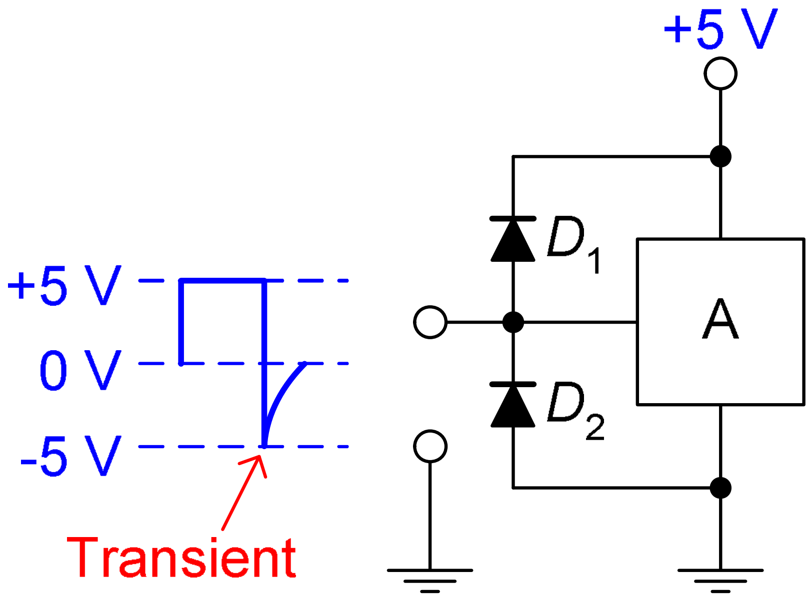


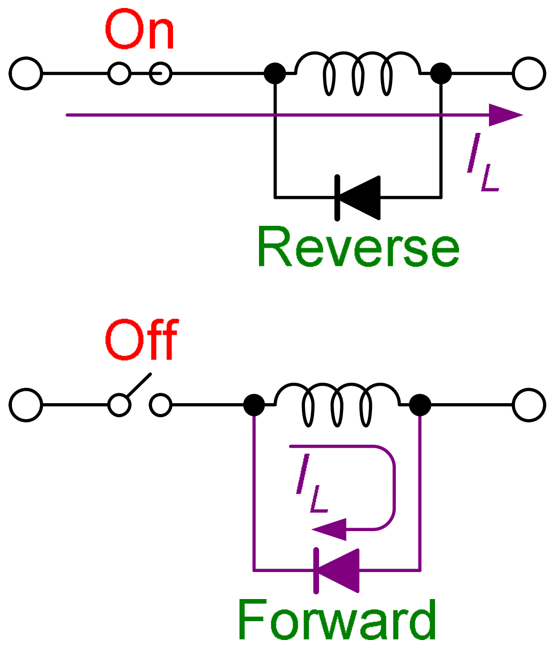
(a) Circuit of Figure 10.29 with batteries replaced by Zener diodes and allowance made for a 0.6-V forward diode drop



(b) Simpler circuit

Clipper applications (1)

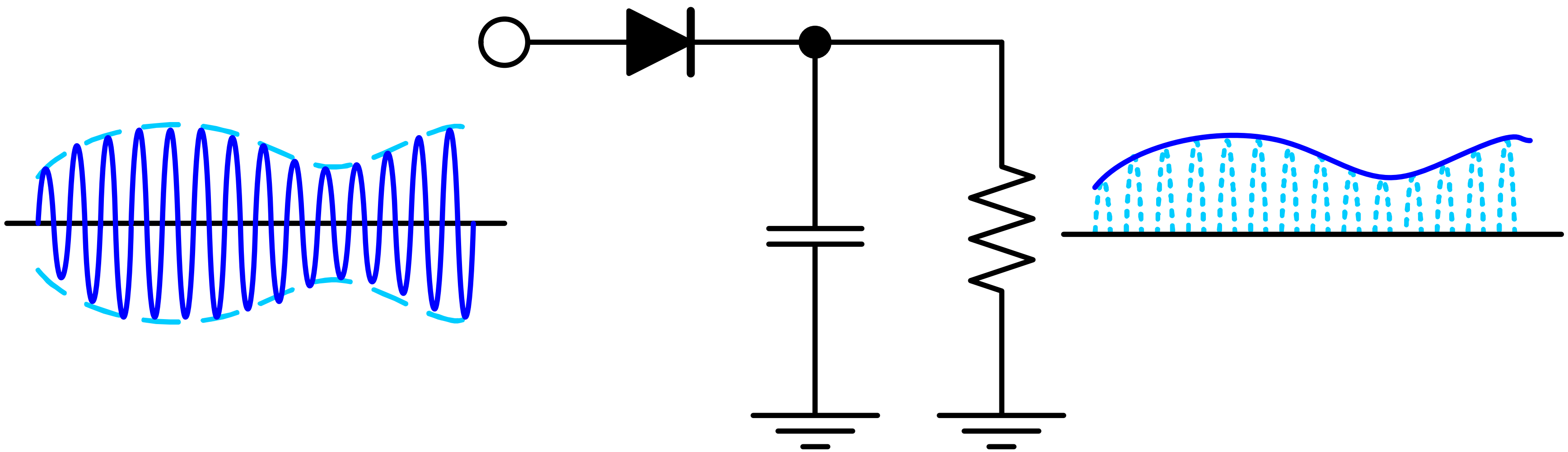




Free-wheeling diode

Transient-protection circuits

Clipper applications (2)



AM detector

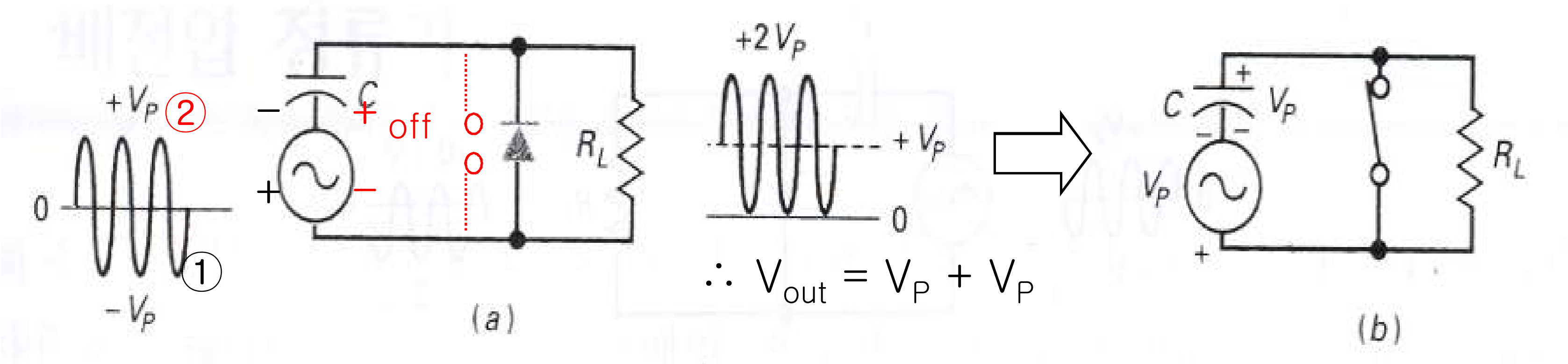
Mạch kẹp (Clamper)

- Có 2 loại mạch kẹp:
  - Mạch kẹp dương (Positive clamper)
  - Mạch kẹp âm (Negative clamper)

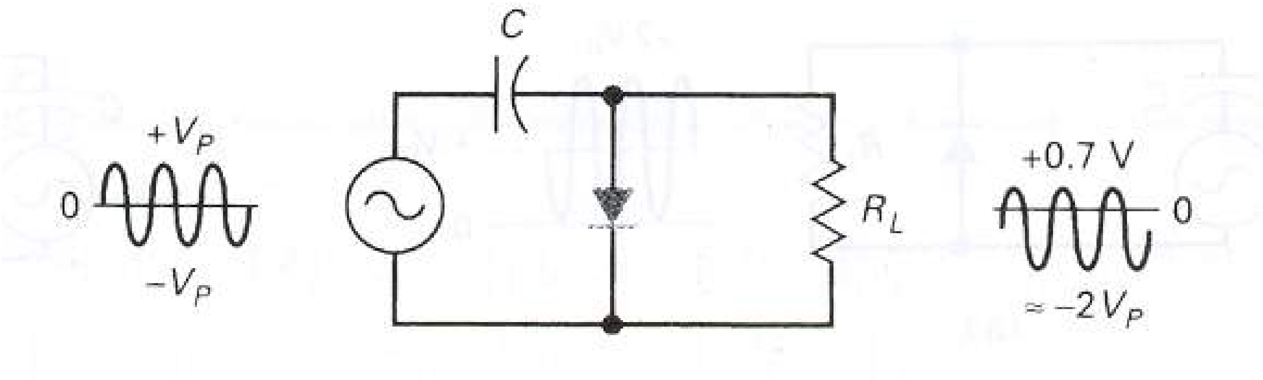
- Mạch tách sóng đỉnh-đỉnh: thường dùng cho diode tín hiệu nhỏ ở tần số cao

❑ Clampers

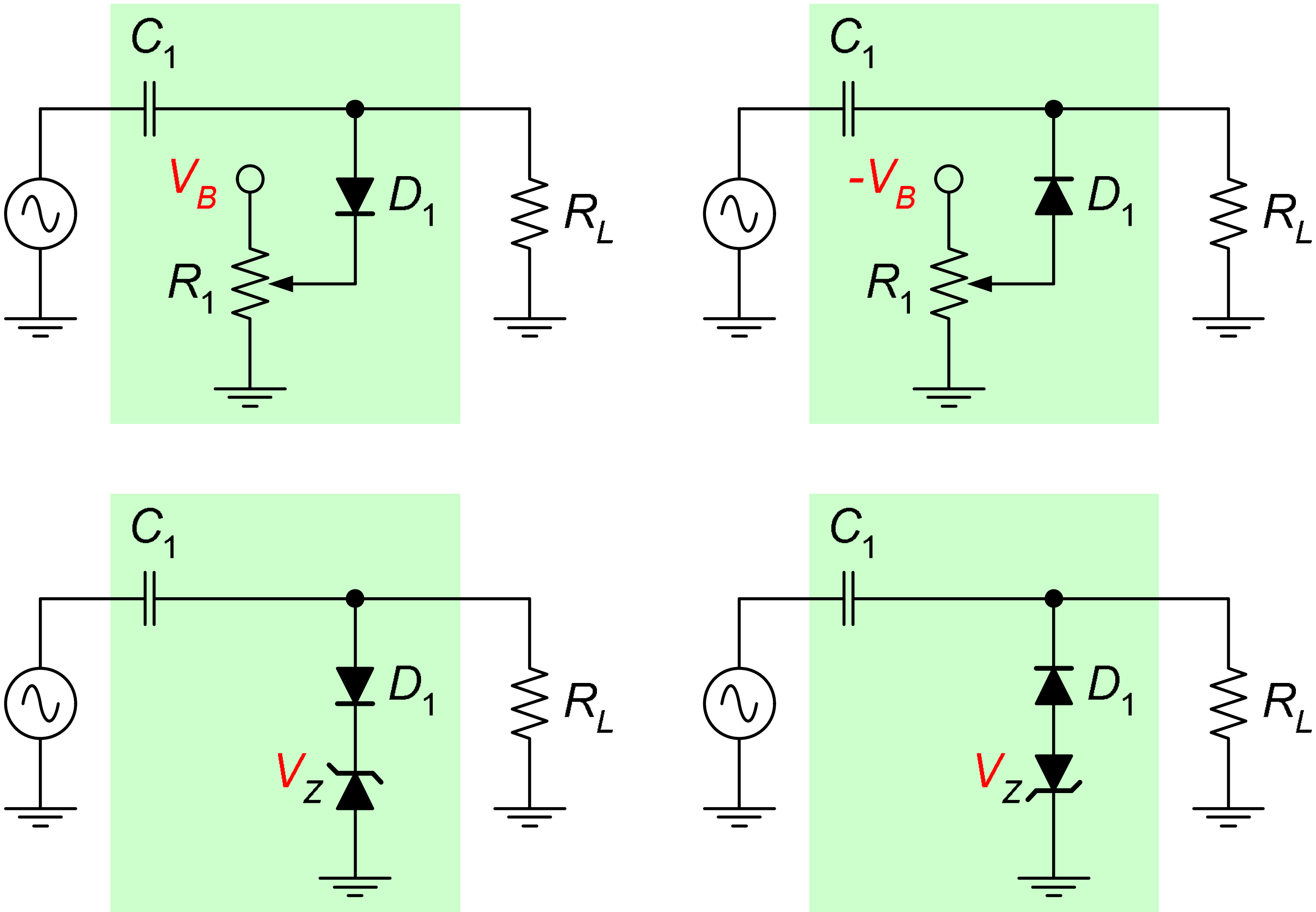
① Positive clamper



② Negative clamper



Biased clampers

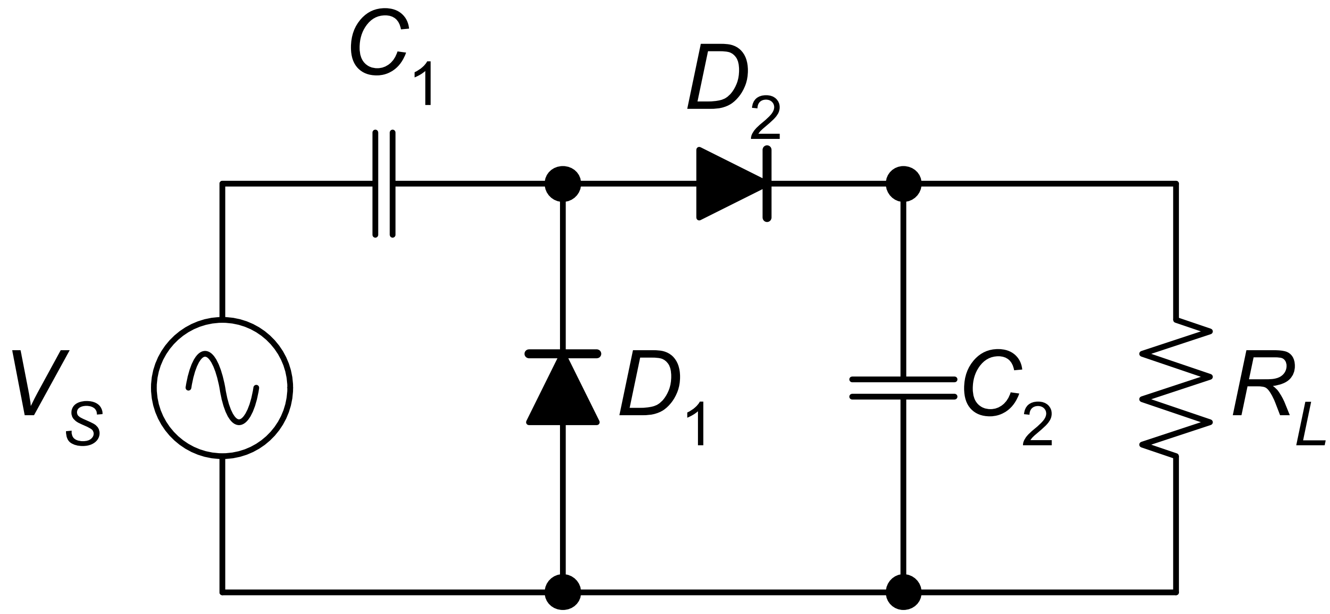


Biased clampers.

Mạch nhân điện áp

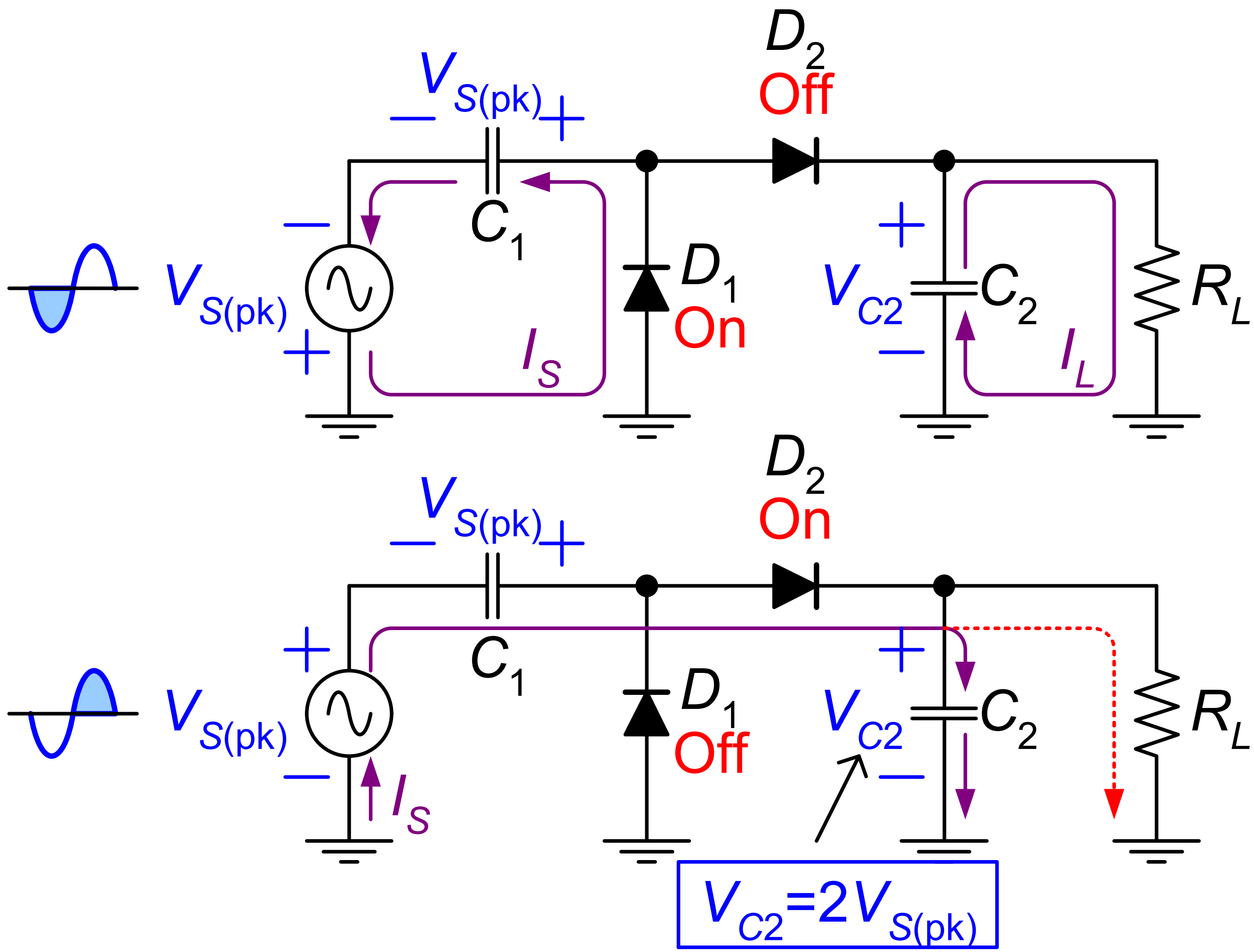
- Thí dụ một số mạch nhân áp:
  – Nhân đôi điện áp (voltage doubler)
  – Nhân 3 điện áp (voltage tripler)
  – Nhân 4 điện áp (voltage quadrupler)
  – Nhân đôi điện áp toàn sóng (full-wave voltage doubler)

Voltage multipliers (1)



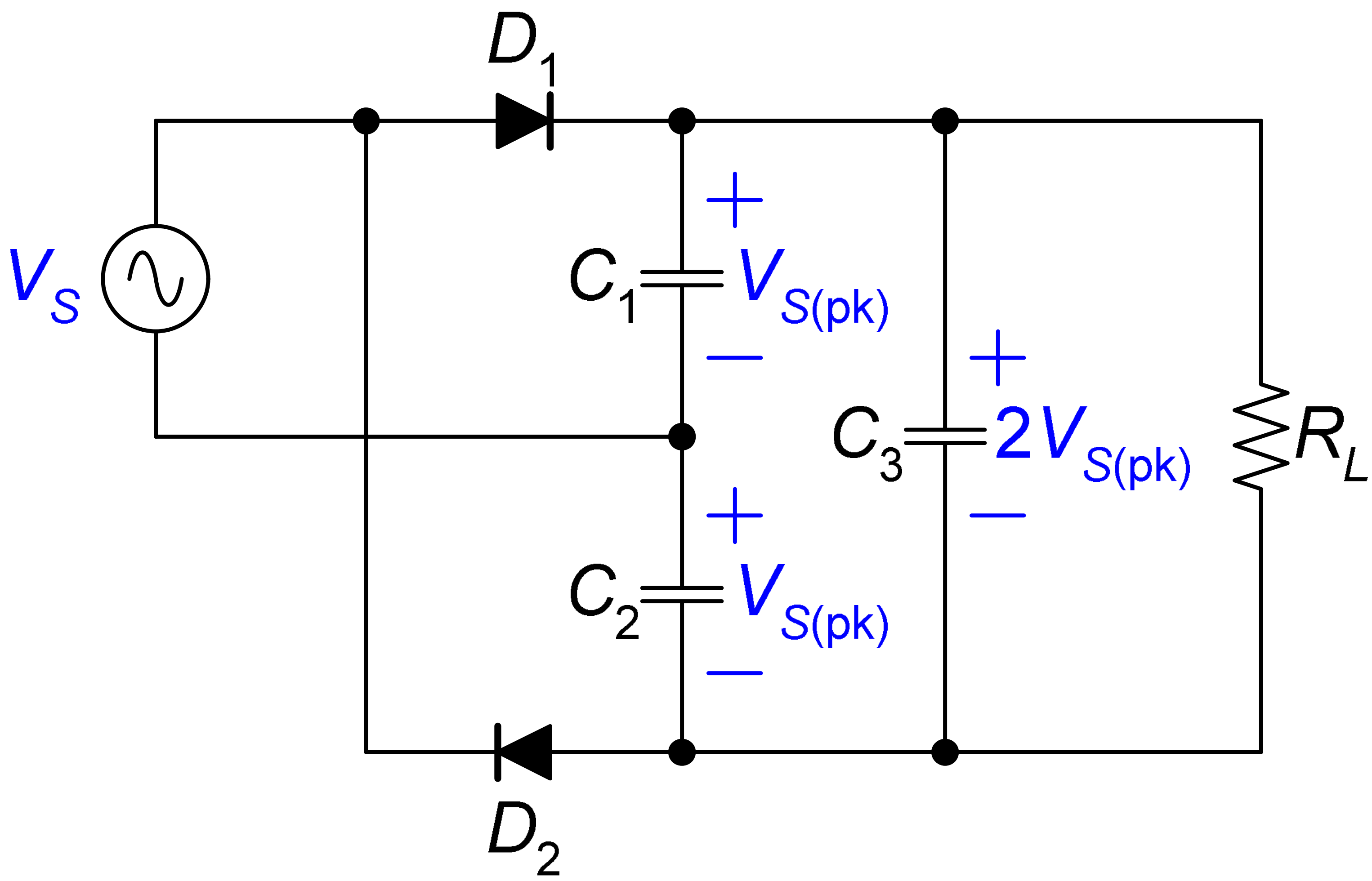
Half-wave voltage doublers.

Voltage multipliers (2)

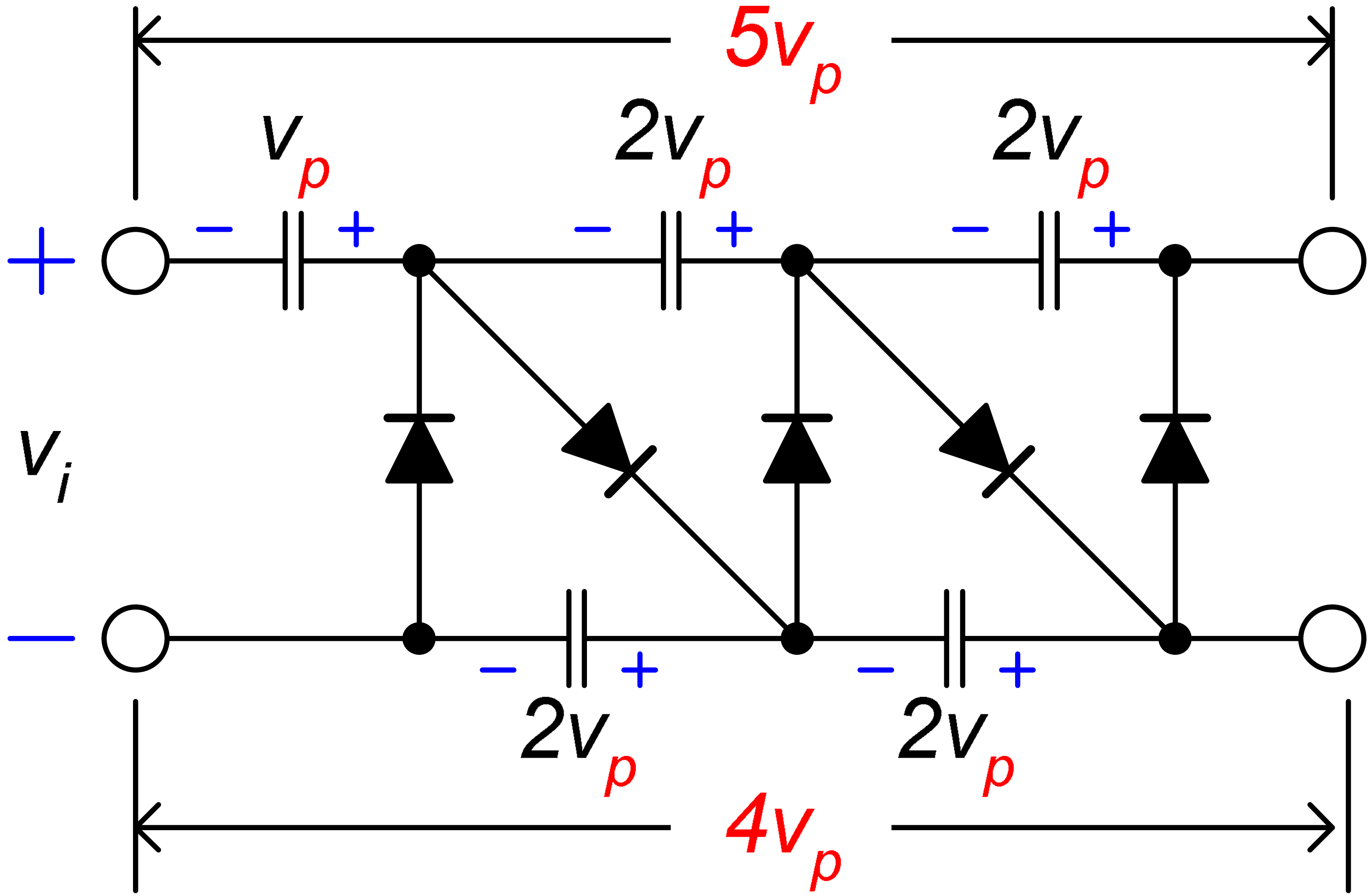


Operation of half-wave voltage doublers.

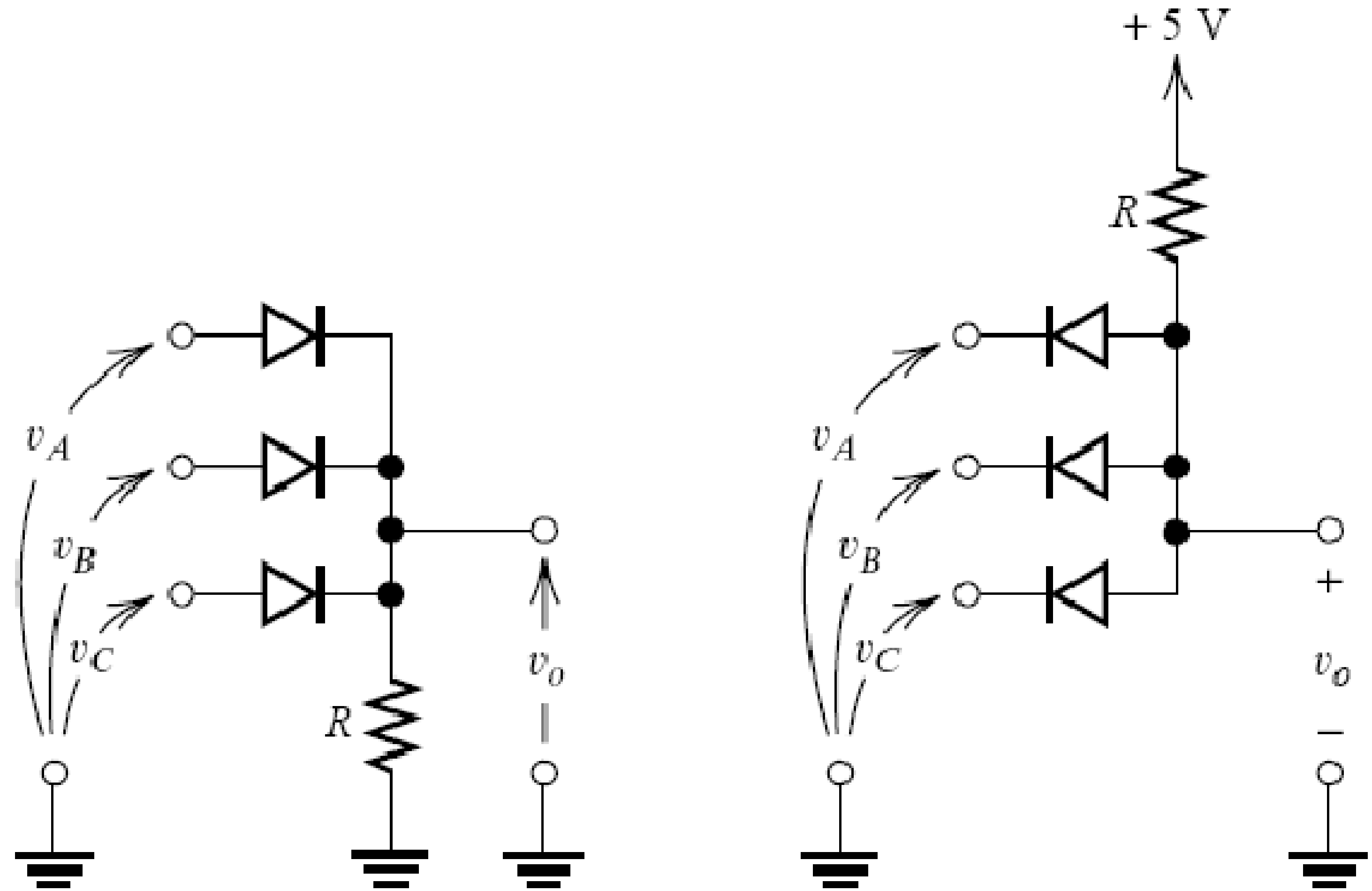
Full-wave voltage doubler



Cockcroft-Walton Circuit



Cổng logic dùng diode



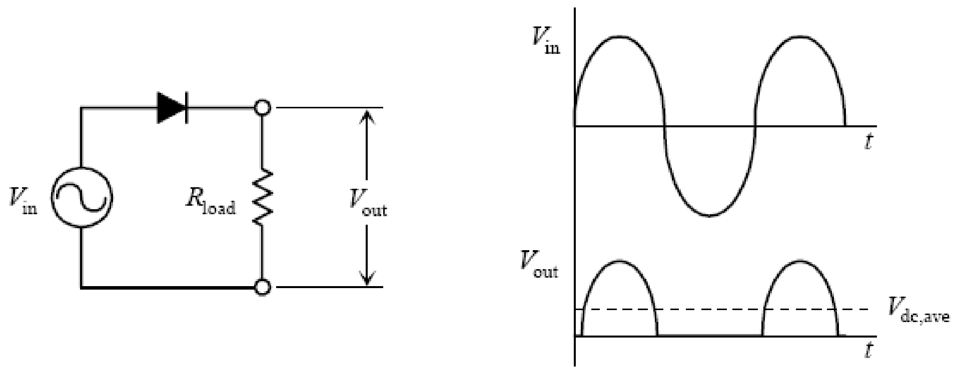
a) Cổng OR

b) Cổng AND

Với mức logic 0 = 0V, và logic 1 = 5V (hoặc 5V – V_{ON}[diode])

Một số ứng dụng cơ bản của diode

Half-Wave Rectifier



In this circuit, the diode acts to convert an ac input voltage into a pulsed dc output voltage. Whenever the voltage attempts to swing negative at the anode, the diode acts to block current flow, thus causing the output voltage (voltage across the resistor) to go to zero. This circuit is called a *half-wave rectifier,* since only half the input waveform is supplied to the output. Note that there will be a 0.6 V drop across the diode, so the output peak voltage will be 0.6V less than the peak voltage of V_{in}. The output frequency is the same as the input frequency, and the average dc voltage at the output is 0.318 times zero-to-peak output voltage. A transformer is typically used to step down or step up the voltage before it reaches the rectifier section.

Full-Wave Bridge Rectifier

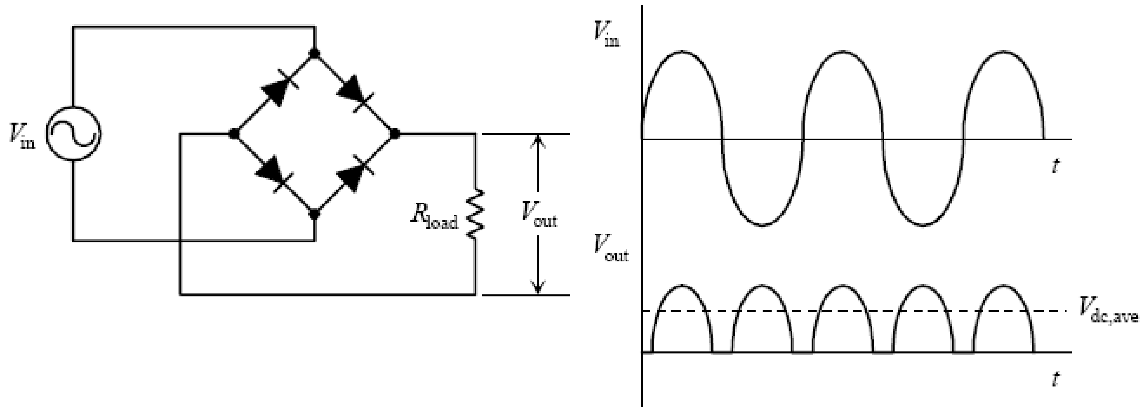
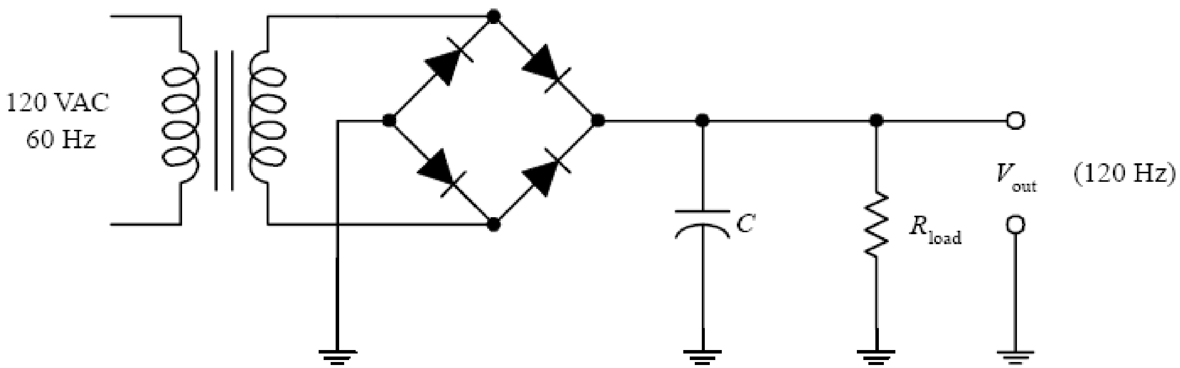
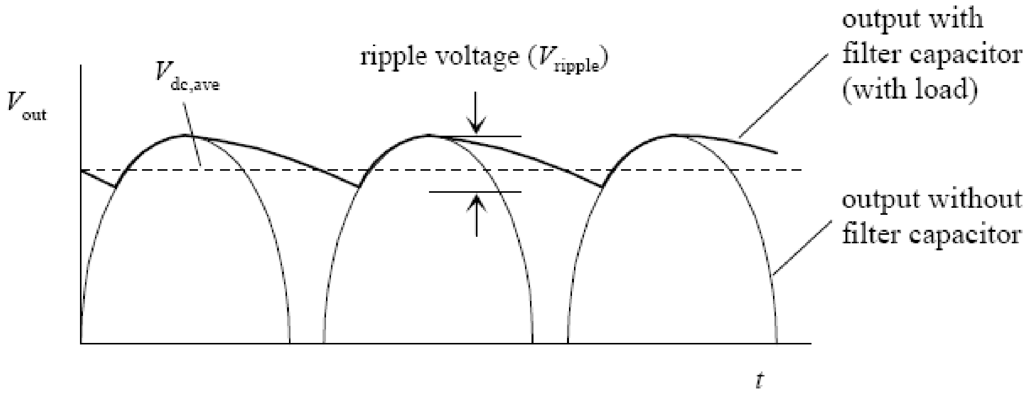


FIGURE 4.14

This circuit is called a *full-wave rectifier,* or *bridge rectifier.* Unlike the half-wave rectifier, a full-wave rectifier does not merely block negative swings in voltage but also converts them into positive swings at the output. To understand how the device works, just follow the current flow through the diode one-way gates. Note that there will be a 1.2-V drop from zero-to-peak input voltage to zero-to-peak output voltage (there are two 0.6-V drops across a pair of diodes during a half cycle). The output frequency is twice the input frequency, and the average dc voltage at the output is 0.636 times the zero-to-peak output voltage.

Basic AC-to-DC Power Supply





By using a transformer and a full-wave bridge rectifier, a simple ac-to-dc power supply can be constructed. The transformer acts to step down the voltage, and the bridge rectifier acts to convert the ac input into a pulsed dc output. A filter capacitor is then used to delay the discharge time and hence "smooth" out the pulses. The capacitor must be large enough to store a sufficient amount of energy to provide a steady supply of current to the load. If the capacitor is not large enough or is not being charged fast enough, the voltage will drop as the load demands more current. A general rule for choosing C is to use the following relation:

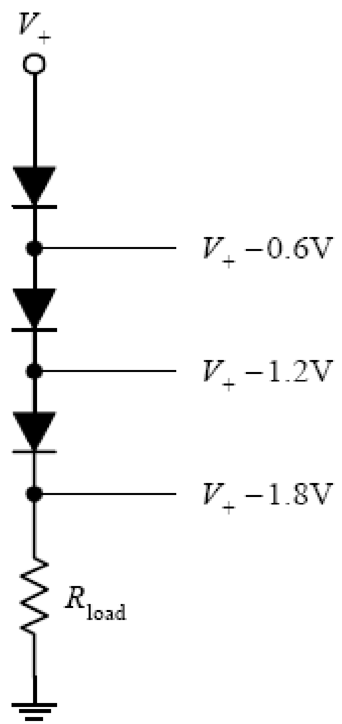
$$R_{load}C >> 1/f$$

where f is the rectified signal's frequency (120 Hz). The ripple voltage (deviation from dc) is approximated by

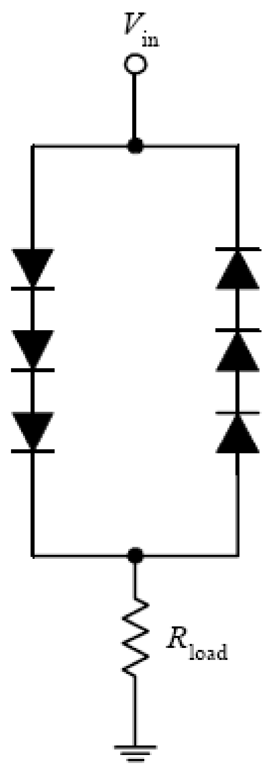
$$V_{ripple} = \frac{I_{load}}{fC}$$

Voltage Dropper

DC application

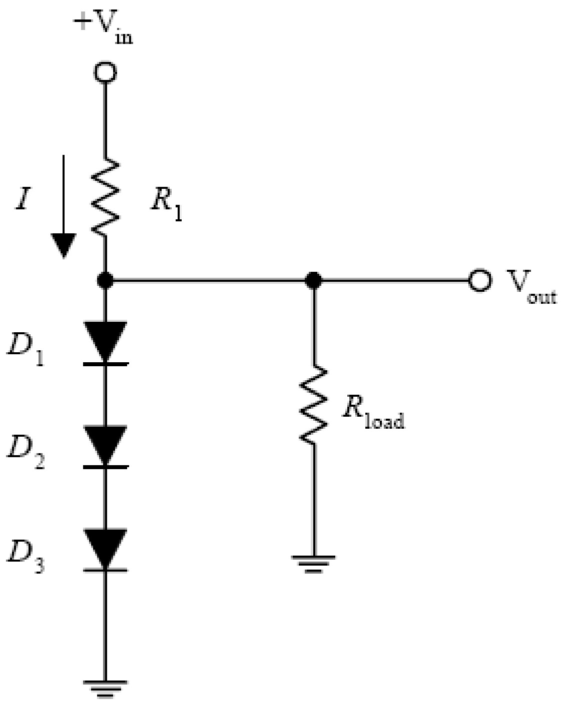


AC application



When current passes through a diode, the voltage is lowered by 0.6 V (silicon diodes). By placing a number of diodes in series, the total voltage drop is the sum of the individual voltage drops of each diode. In ac applications, two sets of diodes are placed in opposite directions.

Voltage Regulator

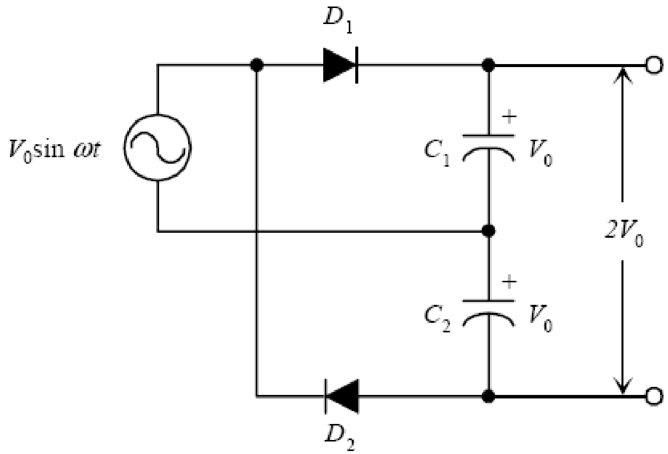


This circuit will supply a steady output voltage equal to the sum of the forward-biasing voltages of the diodes. For example, if D_1, D_2, and D_3 are silicon diodes, the voltage drop across each one will be 0.6 V; the voltage drop across all three is then 1.8 V. This means that the voltage applied to the load (V_{out}) will remain at 1.8 V. R_1 is designed to prevent the diodes from "frying" if the resistance of the load gets very large or the load is removed. The value of R_1 should be approximately equal to

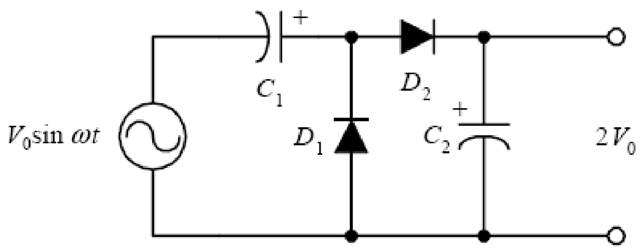
$$R_1 = \frac{(V_{in} - V_{out})}{I}$$

Voltage-Multiplier Circuits

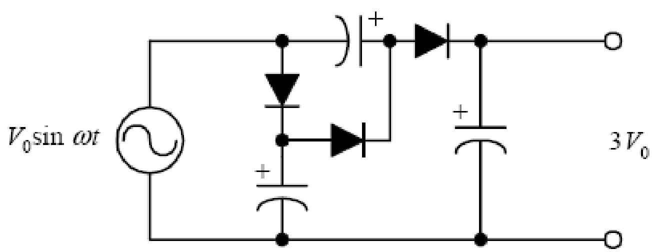
Conventional doubler



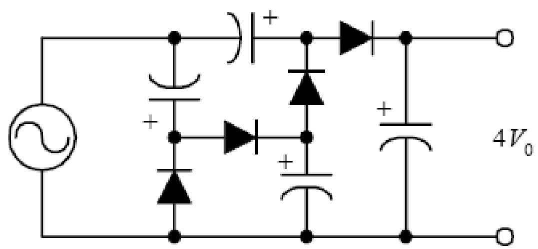
Charge pump doubler



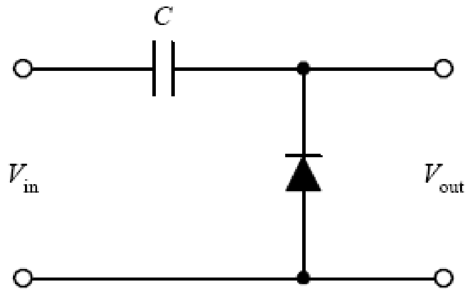
Voltage tripler

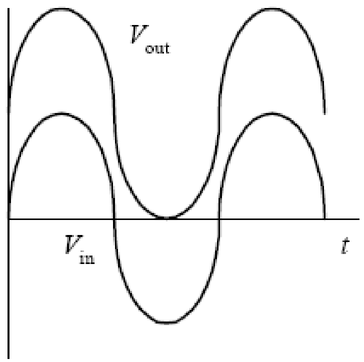


Voltage quadrupler



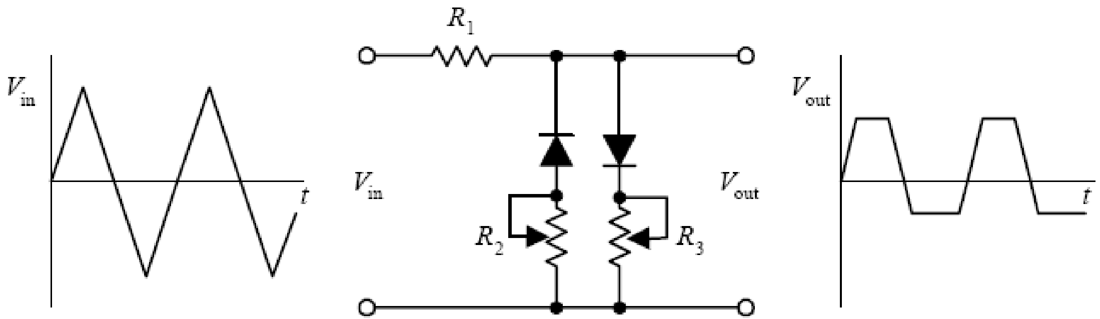
Diode Clamp





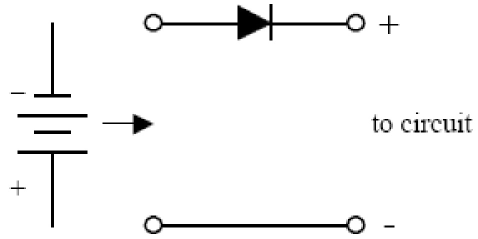
The diode clamp circuit shown here takes a periodic ac signal that oscillates between positive and negative values and displaces it so that it is either always positive or always negative. The capacitor charges up to a dc voltage equal to the zero-to-peak value of V_{in}. The capacitor is made large enough so that it looks like a short circuit for the ac components of V_{in}. If, for example, V_{in} is a sine wave, V_{out} will equal the sum of V_{in} and the dc voltage on the capacitor. By placing the diode in the opposite position (pointing down), V_{out} will be displaced downward so that it is always negative.

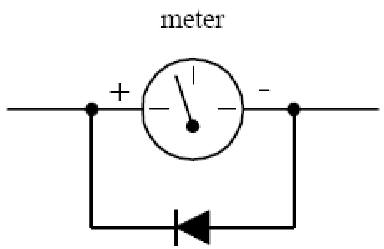
Waveform Clipper



This circuit is often used to protect circuit components from damage due to overvoltage and is used for generating special waveforms. R_2 controls the lower-level clipping at the output, while R_3 controls the upper-level clipping. R_1 is used as a safety resistor to prevent a large current from flowing through a diode if a variable resistor happens to be set to zero resistance.

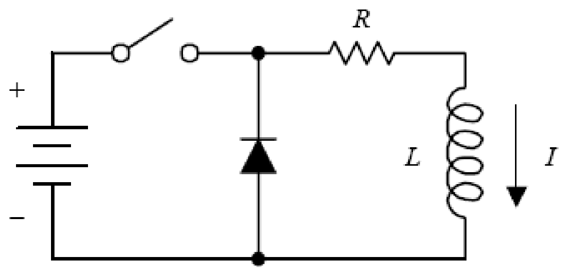
Reverse-Polarity Protector

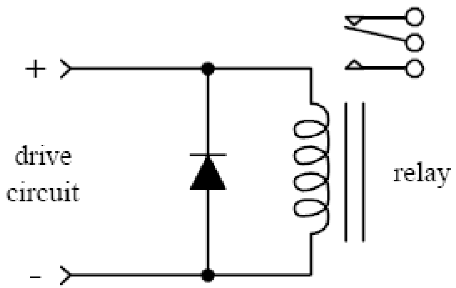




A single diode can be used to protect a circuit that could be damaged if the polarity of the power source were reversed. In the leftmost network, the diode acts to block the current flow to a circuit if the battery is accidentally placed the wrong way around. In the rightmost circuit, the diode prevents a large current from entering the negative terminal of a meter.

Transient Protector





Placing a diode in the reverse-biased direction across an inductive load eliminates voltage spikes by going into conduction before a large voltage can form across the load. The diode must be rated to handle the current, equivalent to the maximum current that would have been flowing through the load before the current supply was interrupted. The lower network shows how a diode can be used to protect a circuit from voltage spikes that are produced when a dc-actuated relay suddenly switches states.

Battery-Powered Backup

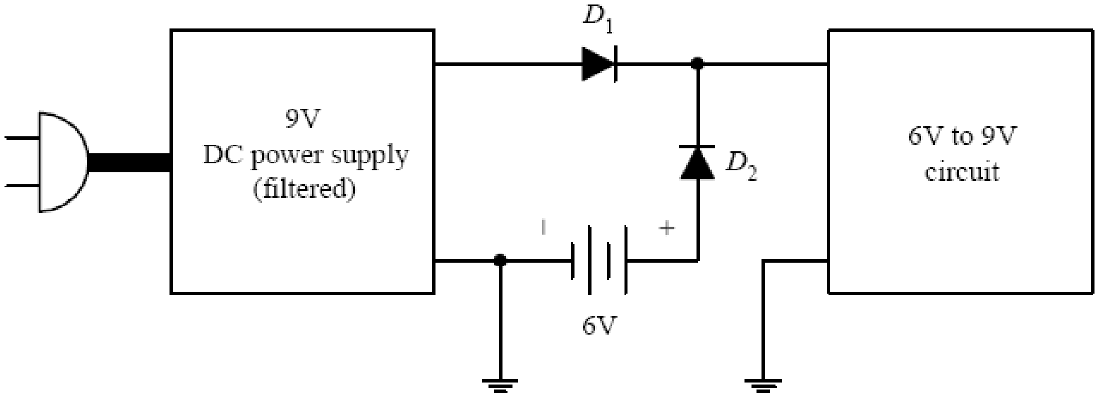
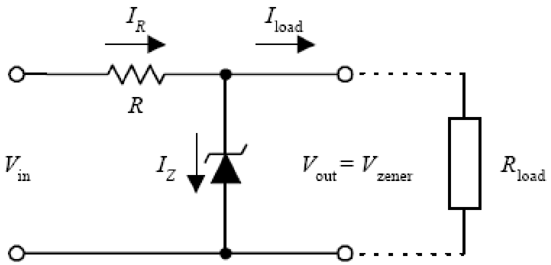
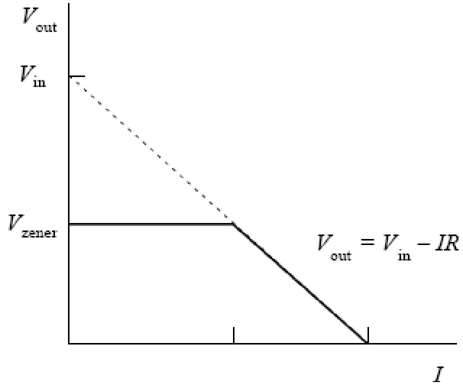


FIGURE 4.14 (*Continued*)

This circuit shows how a battery along with two diodes can be used to provide backup power to a circuit that is normally powered by an ac-driven dc power supply (with filtered output). Here you have a circuit that is designed to run off a voltage from 6 to 9 V. The voltage supplied by the power supply is at 9 V, while the battery voltage is 6 V. As long as power is supplied by the main power supply, the voltage that the circuit receives will be 8.4 V (there is a 0.6-V drop across D_1). At the same time, D_2's anode will be more negative in voltage than its cathode by 2.6 V (8.4 V minus 6.0 V), which means D_2 will block current flow from the battery, hence preventing battery drain. Now, if a lightning bolt strikes, causing the power supply to fail, D_2's anode will become more positive in voltage than its cathode, and it will allow current to flow from the battery to the load. At the same time, D_1 acts to block current from flowing from the battery into the power supply.

Voltage Regulator



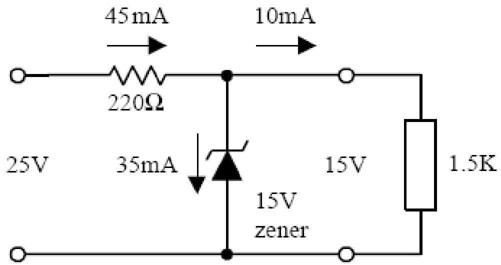


$$I_{load} = \frac{V_{in}}{R_{load}} \approx \frac{V_{zener}}{R_{load}}$$

$$I_R = \frac{V_{in} - V_{out}}{R} \approx \frac{V_{in} - V_{zener}}{R}$$

$$I_{zener} = I_R - I_{load}$$

Example 1

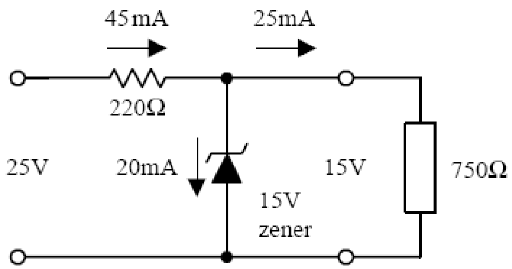


$$I_{load} = \frac{15V}{15K} = 10mA$$

$$I_R = \frac{25V - 15V}{220\Omega} = 45mA$$

$$I_{zener} = 45mA - 10mA = 35mA$$

Example 2



$$I_{load} = \frac{15V}{750\Omega} = 20mA$$

$$I_R = \frac{25V - 15V}{220\Omega} = 45mA$$

$$I_{zener} = 45mA - 20mA = 25mA$$

Here, a zener diode is used to regulate the voltage supplied to a load. When V_{in} attempts to push V_{out} above the zener diode's breakdown voltage (V_{zener}), the zener diode draws as much current through itself in the reverse-biased direction as is necessary to keep V_{out} at V_{zener}, even if the input voltage V_{in} varies considerably. The resistor in the circuit is used to limit current through the zener diode in case the load is removed, protecting it from excessive current flow. The value of the resistor can be found by using

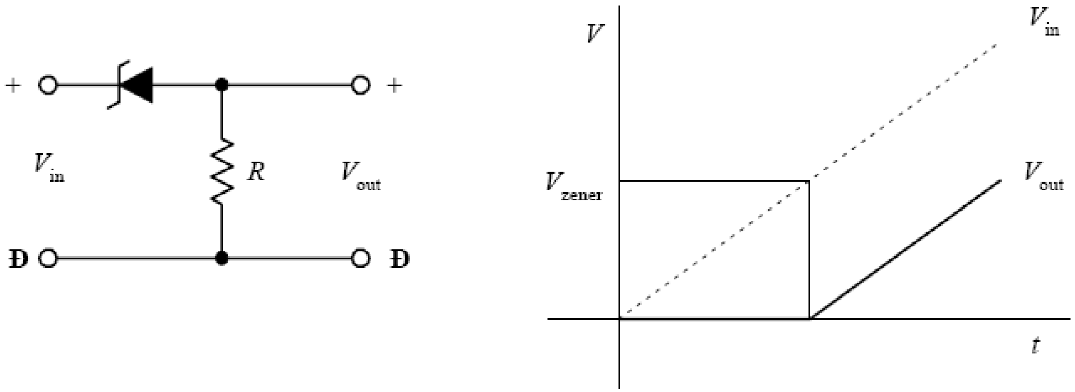
$$R = \frac{V_{in} - V_{zener}}{I_{max,zener}}$$

where $I_{max,zener}$ is the maximum current rating of the zener diode. The power rating of the resistor should be

$$P_R = IV_R = I_{max,zener}(V_{in} - V_{zener})$$

I_{load}, I_R, and I_{zener} are given by the formulas accompanying the figure.

Voltage Shifter



This circuit shifts the input voltage (V_{in}) down by an amount equal to the breakdown voltage of the zener diode.

Waveform Clipper

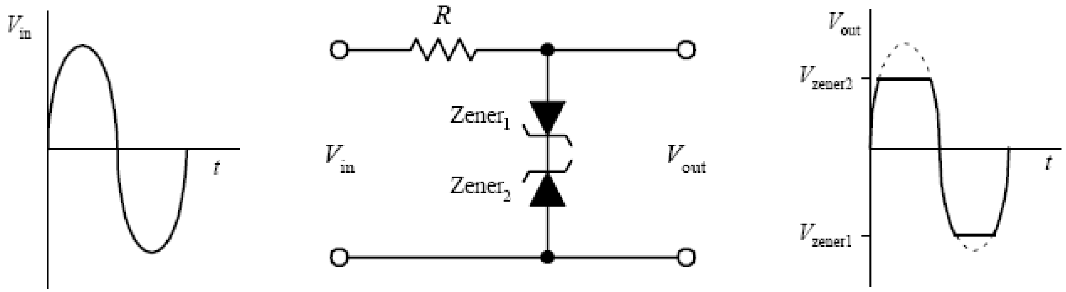
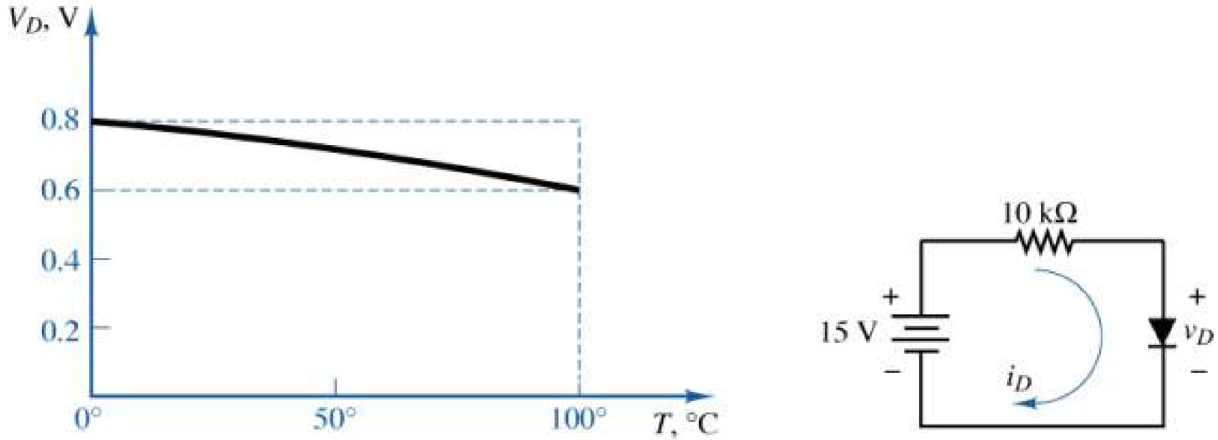


FIGURE 4.18

Two opposing zener diodes placed in series act to clip both halves of an input signal. Here, a sine wave is converted to a near square wave. Besides acting as a signal reshaper, this arrangement also can be placed across a power supply's output terminals to prevent voltage spikes from reaching a circuit that is attached to the power supply. The breakdown voltages of both diodes must be chosen according to the particular application.

Diode thermometer

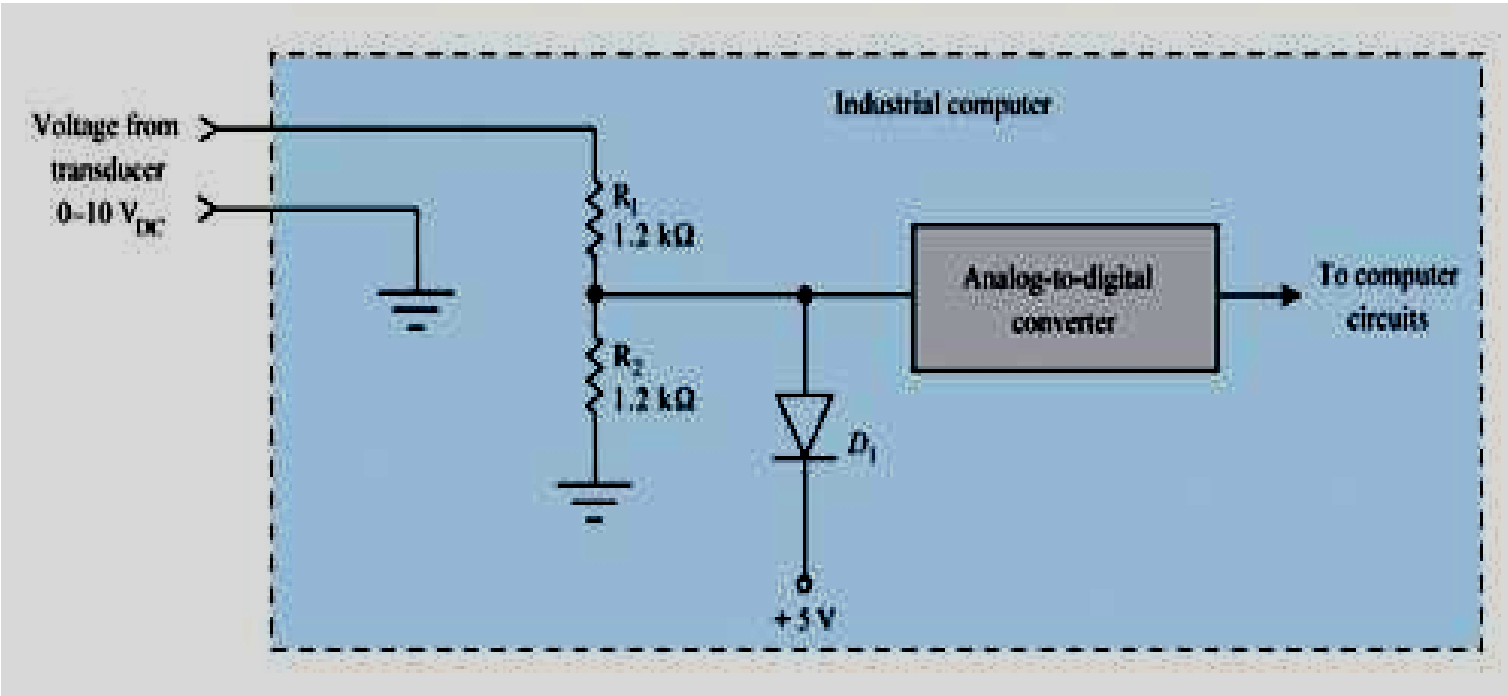


(a) (b)

$$I_D = I_0(T)(e^{qV_D/kT} - 1)$$

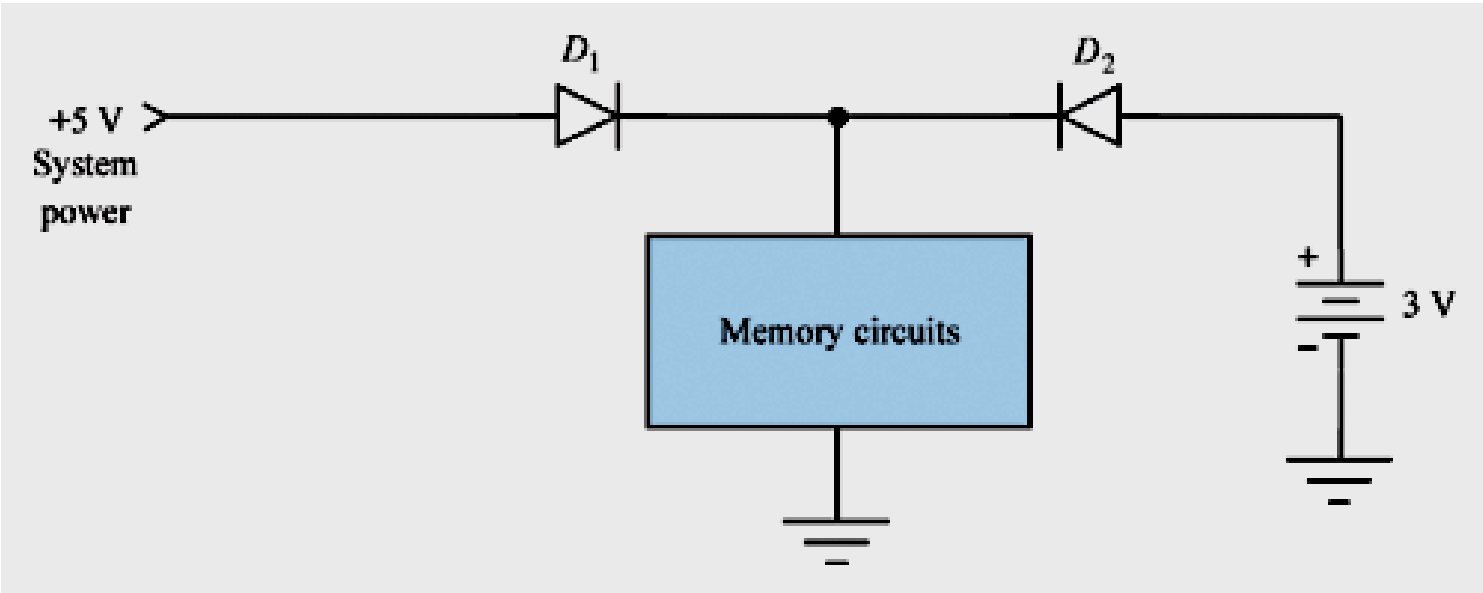
Miscellaneous Diode Applications

- There are many practical applications for diodes beyond power supplies.
- Some of these applications include:
  - Clipper circuits that serve to protect circuits from damage as a result of over-voltage conditions.
  - Clippers are common in computer circuits.



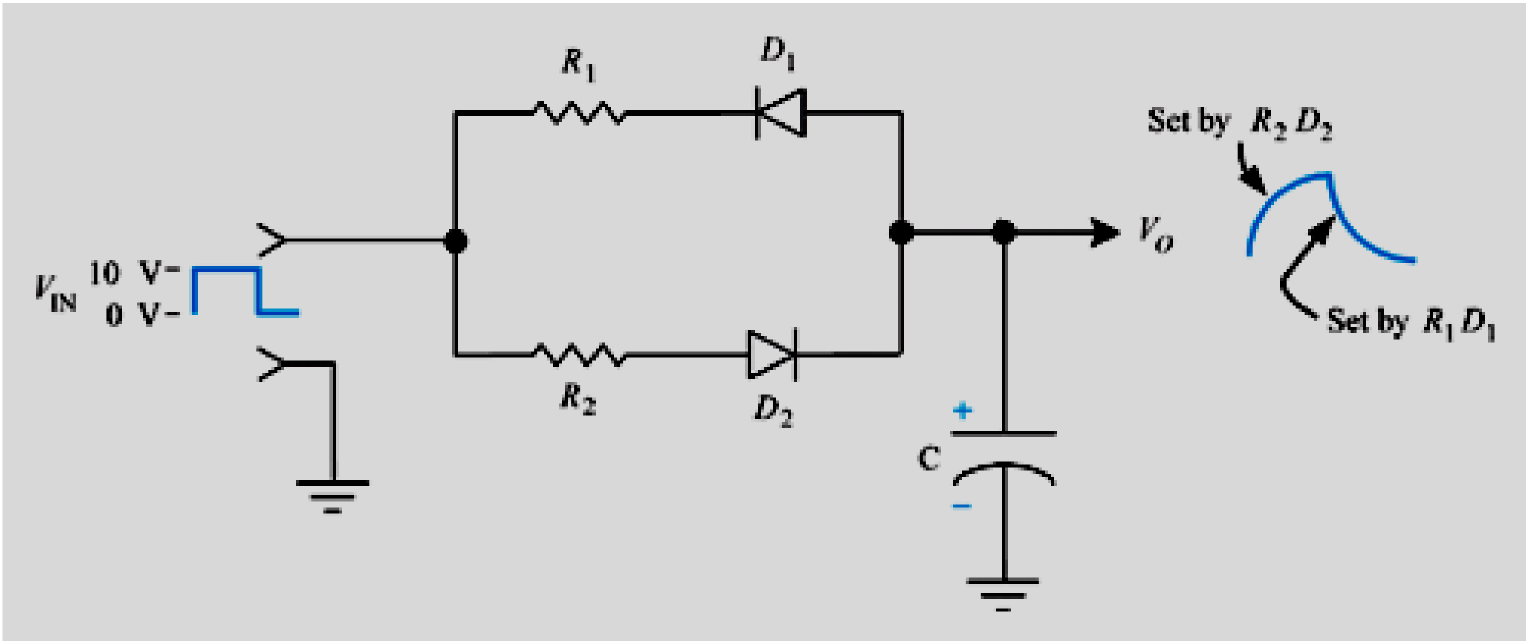
Miscellaneous Diode Applications

- Isolation diodes are used to isolate various sections of circuits from another.
- An example of this is the battery backup for computer memory.



Miscellaneous Diode Applications

- Diodes can be used to create an RC circuit that has different time constants for charge and discharge.
- This principle is called ***asymmetrical time constants***.



Miscellaneous Diode Applications

- Diodes can also be used as AM (amplitude modulation) detector circuits in radio receivers.