ECE 113- Basic Electronics

Lecture week 12: Diodes

Dr. Ram Krishna Ghosh, Assistant Professor

Office: B601, Research and Development Block

Email: rkghosh@iiitd.ac.in

INDRAPRASTHA INSTITUTE *of*
INFORMATION TECHNOLOGY
DELHI

Resources

- Sedra, Adel S., and Kenneth Carless Smith. Microelectronic circuits. Vol. 1. New York: Oxford University Press.

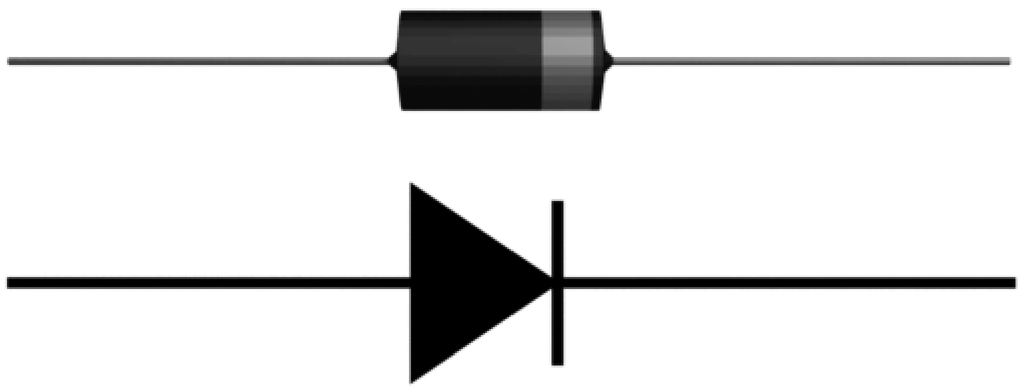
Diode

- A fundamental non-linear circuit element
- Conducts current in one direction
- Historically this device was vacuum tube based
- Now semiconductor diodes are used
- Used in
  - Rectifier circuits
  - Voltage regulator
  - Limiter
  - Logic gate

Semiconductor diode

- Two terminals: Anode and cathode (historical reference, has not changed)
- Two operation modes:
  - Forward bias: +ve voltage (relative to the reference direction)
  - Reverse bias: -ve voltage (relative to the reference direction)
- Current flows from anode to cathode when forward bias is applied
- No current flows when reverse bias is applied

Diode symbol

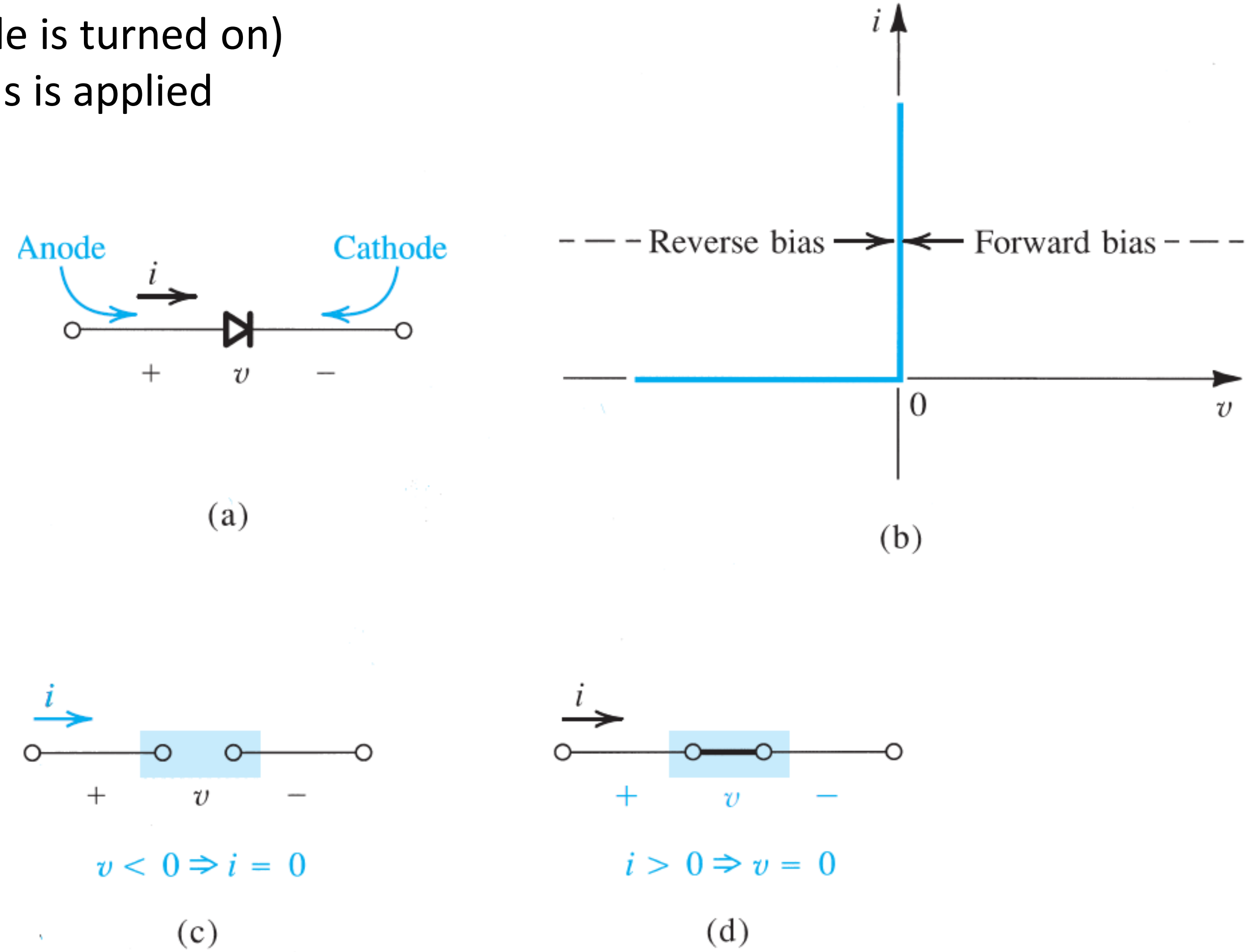


Anode

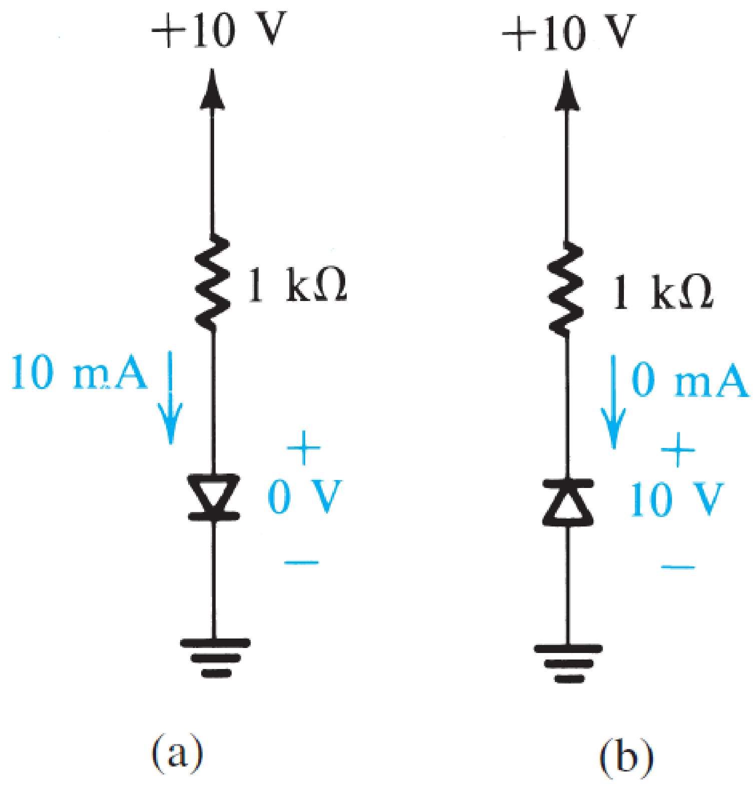
Cathode

Ideal diode characteristics

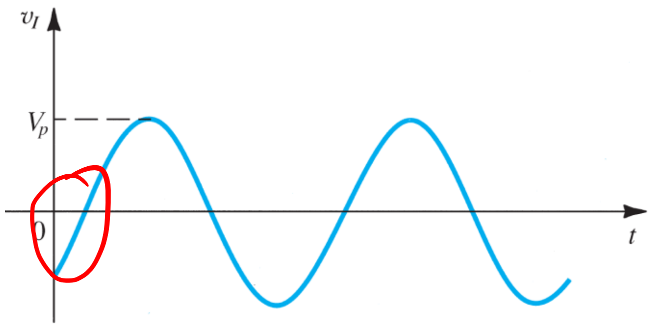
- Ideal diode acts as short circuit when forward bias is applied (this is also described as diode is turned on)
- Acts as open circuit when reverse bias is applied (diode is turned off/ cut off)

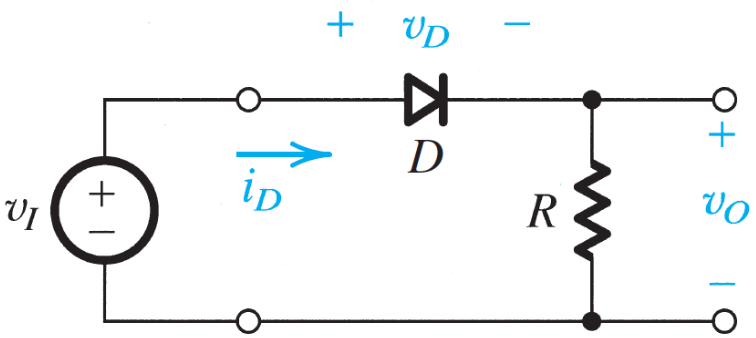


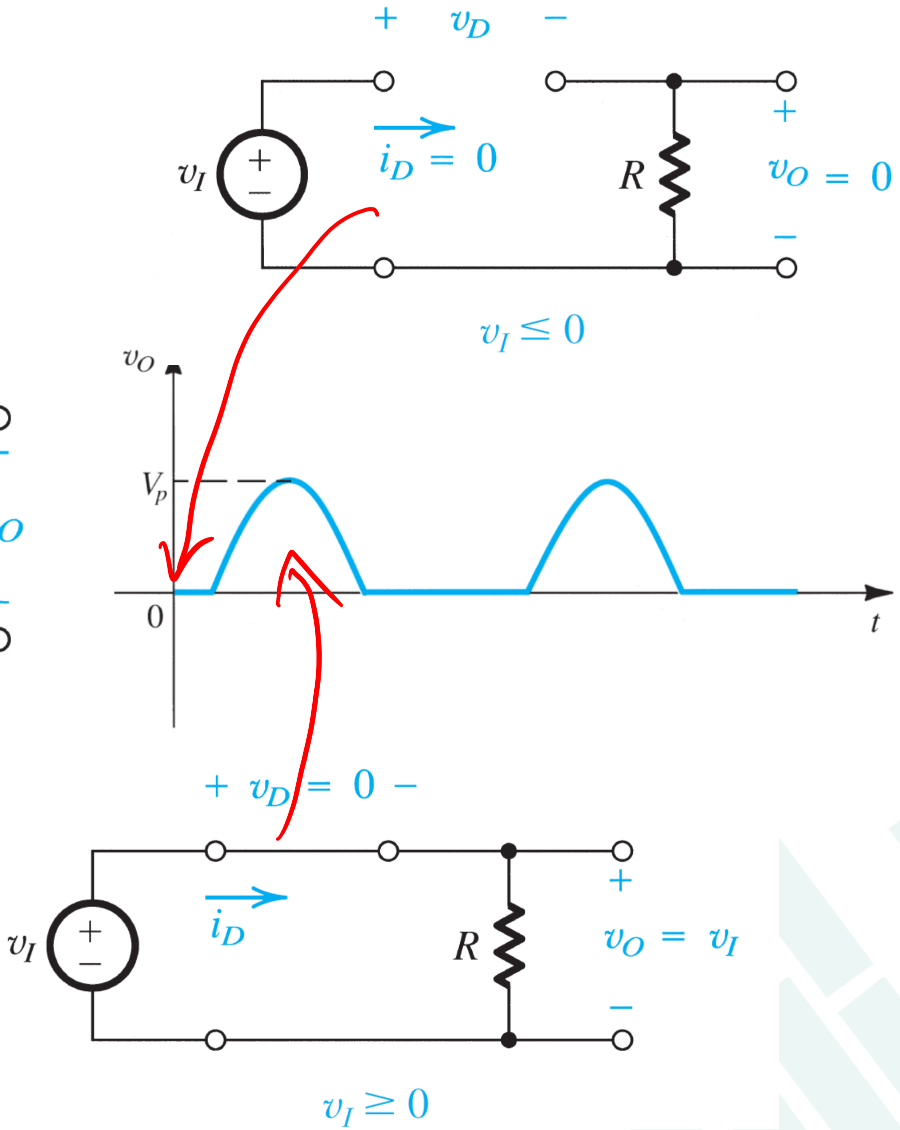
Two modes of operations



Simple Application

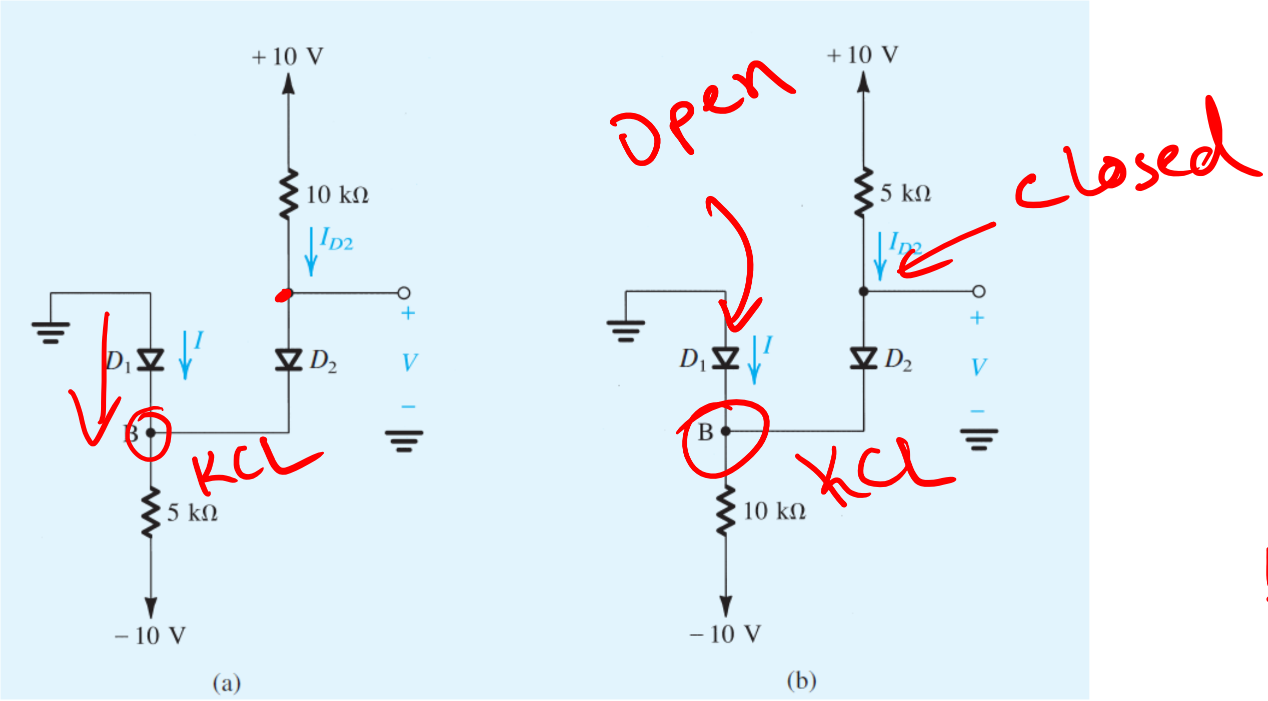






Example problem

Assuming the diodes to be ideal, find the values of *I* and *V* in the circuits



a) If D_1 and D_2 are short circuit →

$V = 0$

$$I_{D_2} = \frac{10-0}{10k\Omega} = 1mA$$

$$I + 1mA = \frac{0-(-10)}{5k\Omega}$$

$$I = 1mA$$

b) $$I_{D_2} = \frac{10-0}{5k\Omega} = 2mA$$

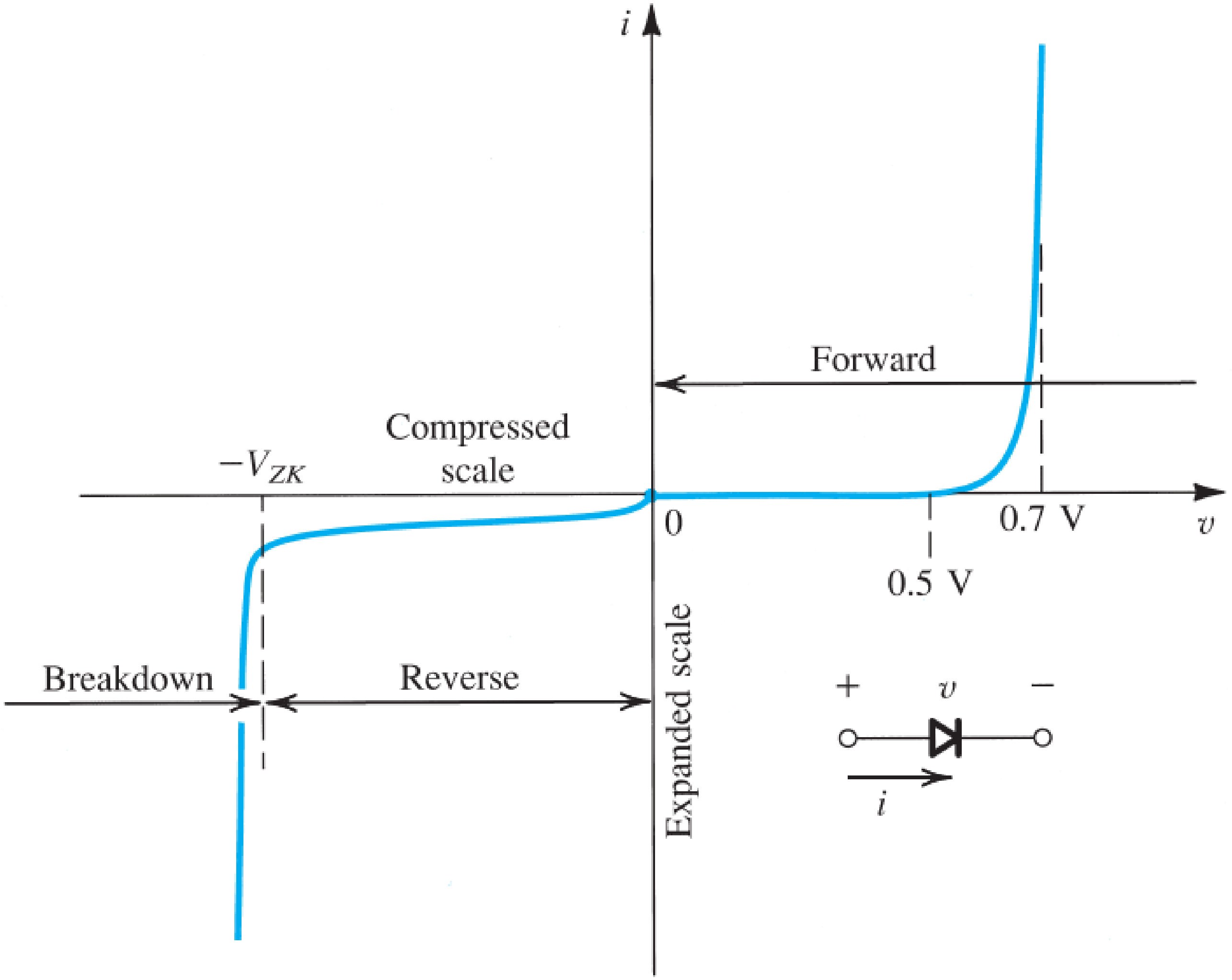
$$I + 2mA = \frac{10}{10k\Omega} \qquad I = -1mA$$

$$I_{D_2} = \frac{10-(-10)}{(10+5)k\Omega} = 1.33\,mA$$

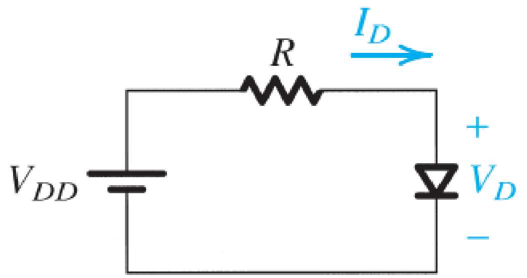
$V = 3.3V$

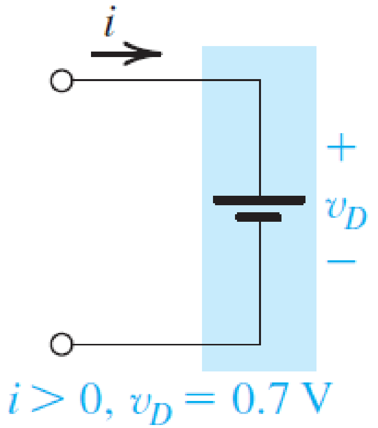
Practical consideration

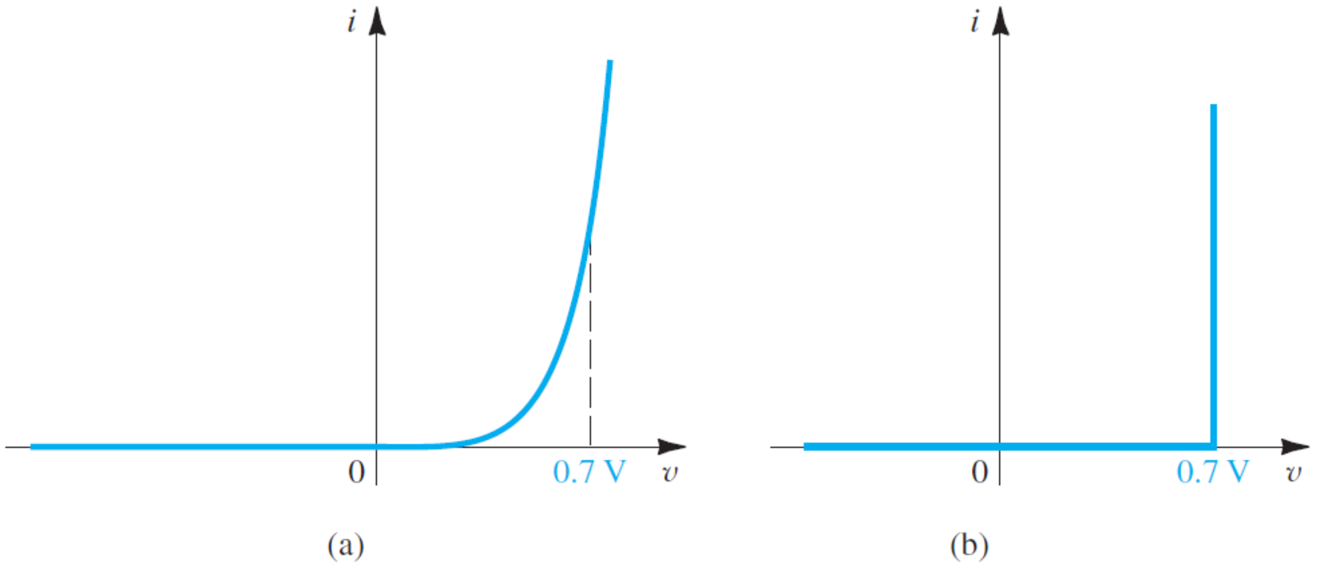
The i-v characteristics of a real diode is like this



Rapid analysis





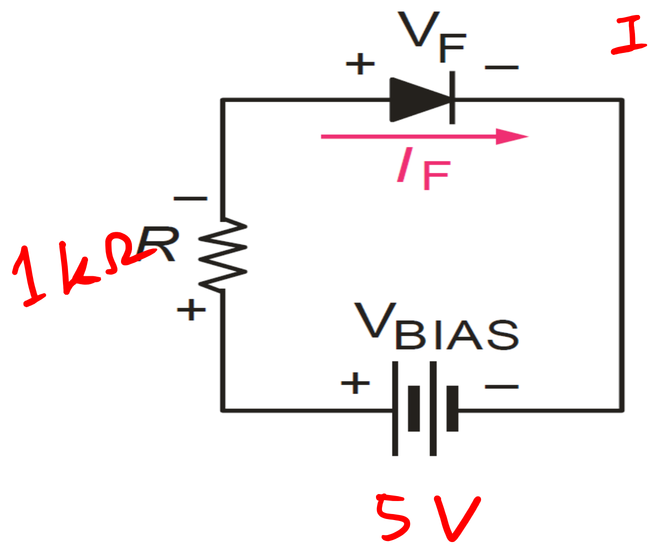


The knee voltage value for silicon & germanium includes the following.

Silicon (Si) diode is 0.7 V

Germanium (Ge) diode is 0.3 V

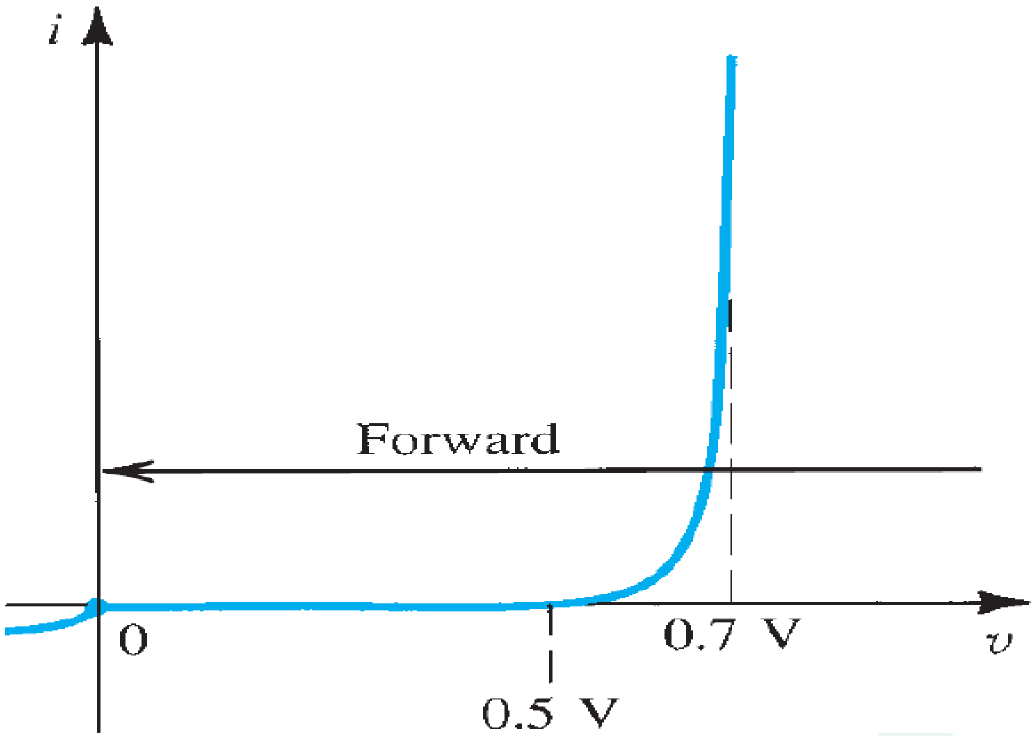
Forward Bias



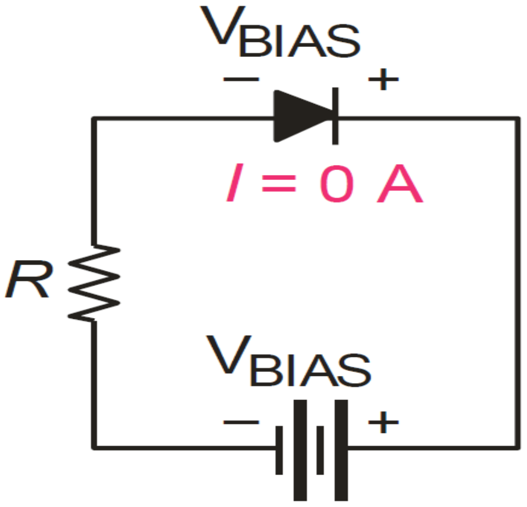
$I = ?$

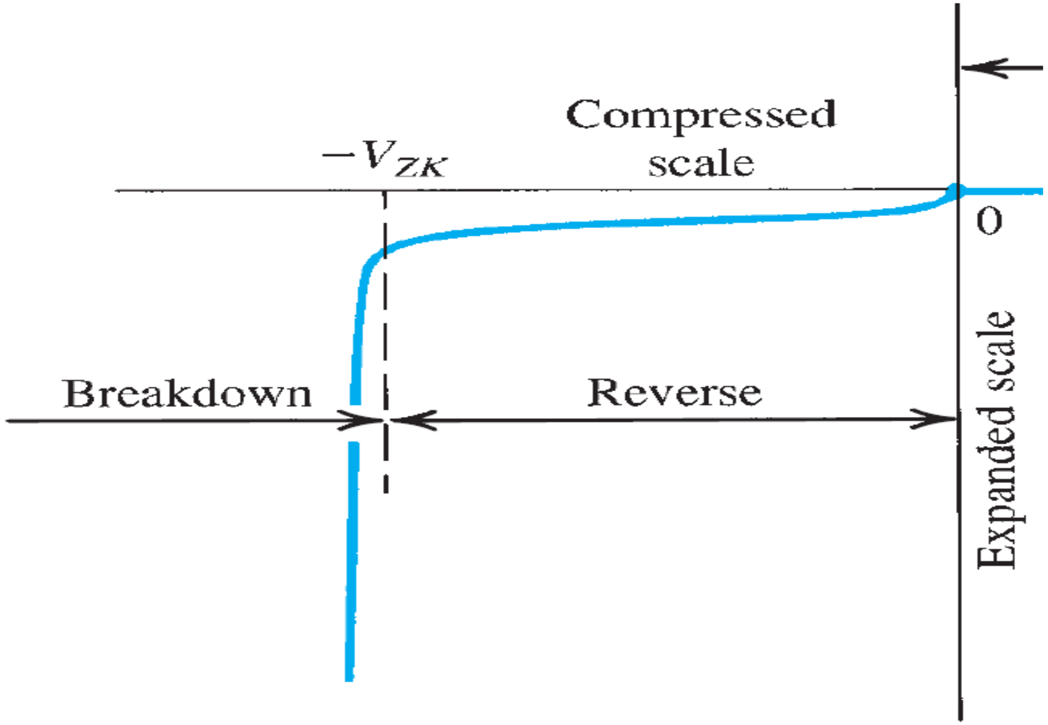
$$-5 + I \times 1\,k\Omega + 0.7 = 0$$

$$I = 4.3\ mA$$

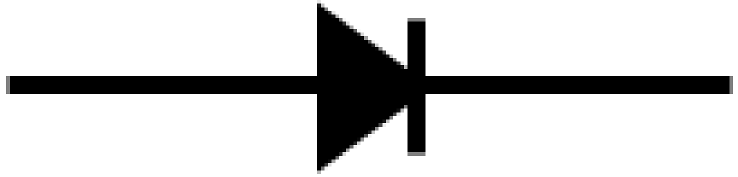


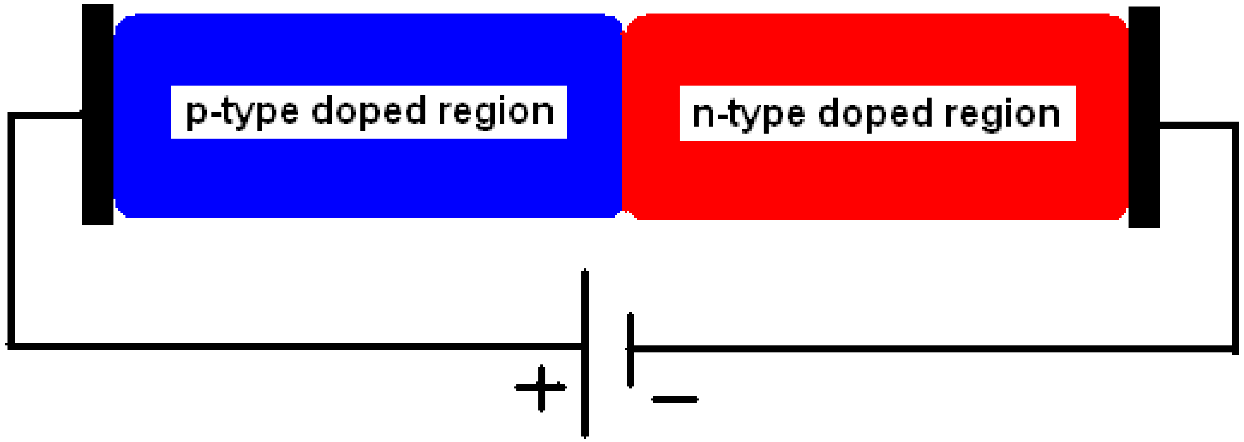
Reverse Bias



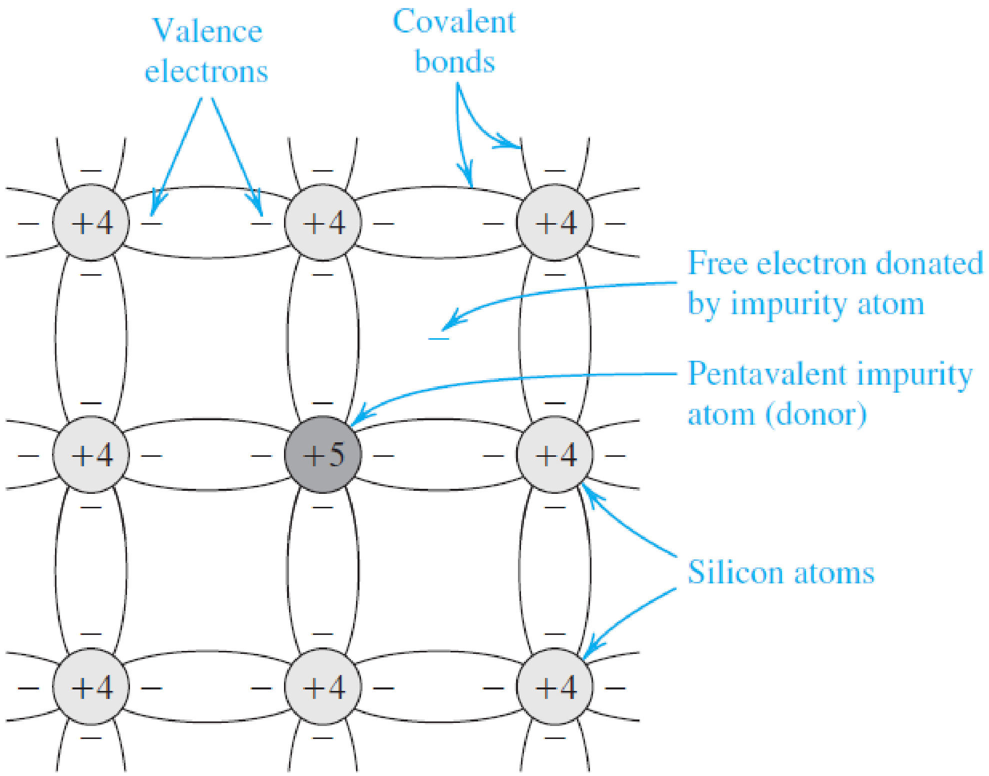


Discussion on p-n junction

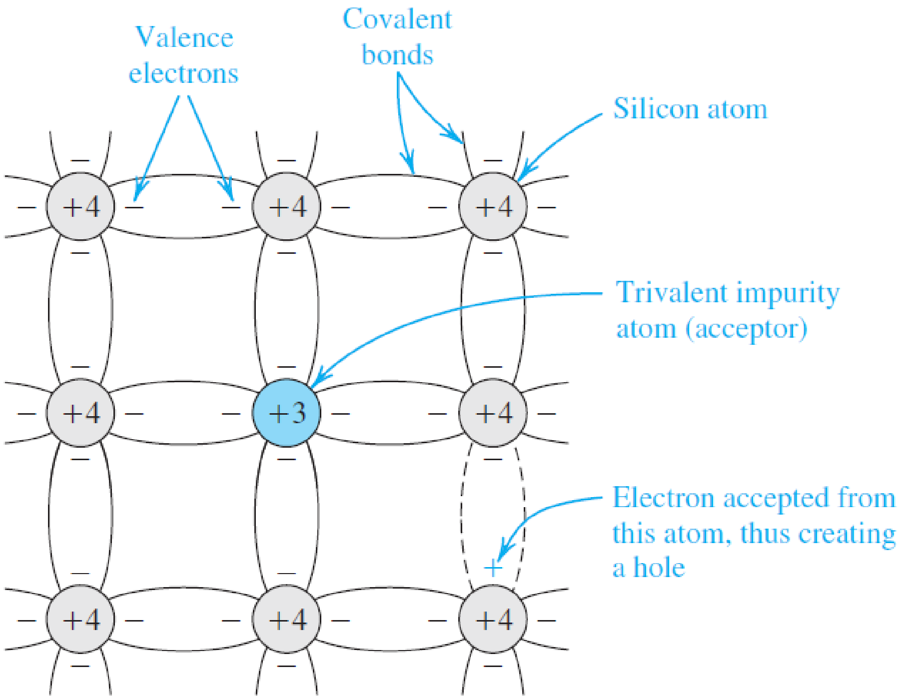




Discussion on p-n junction



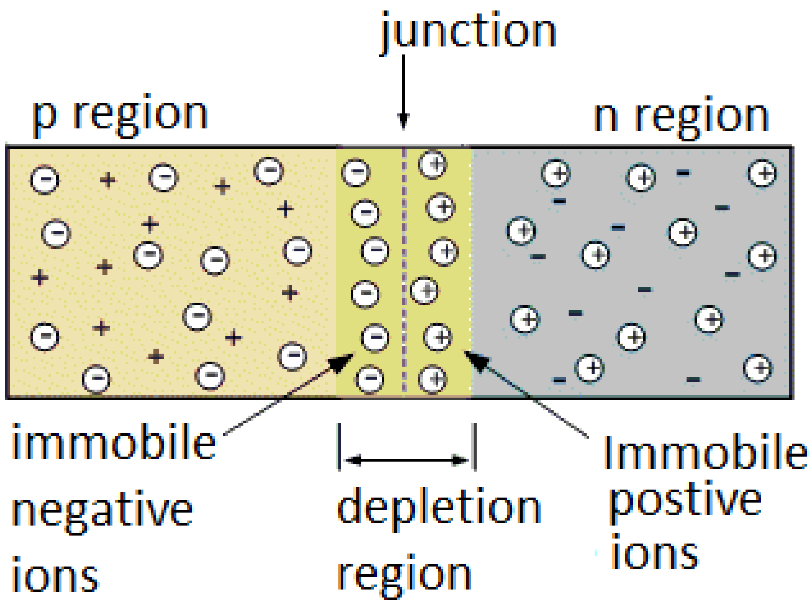
n- type

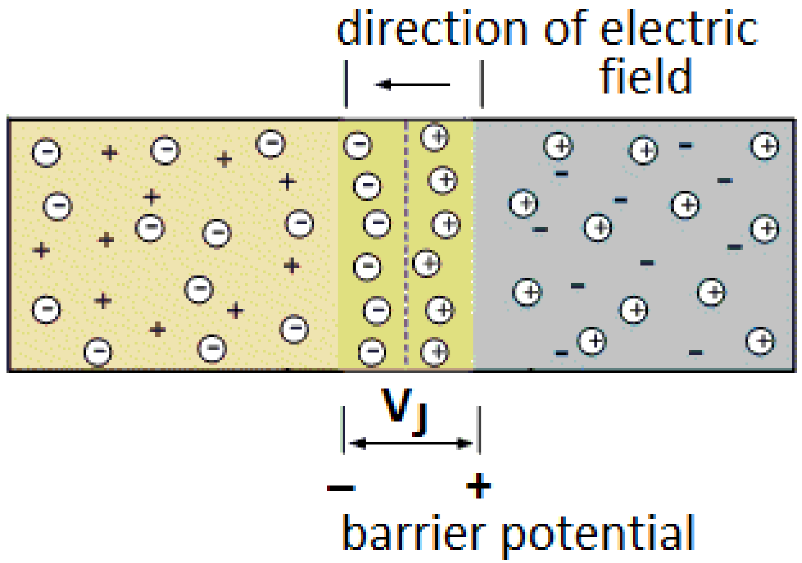


p- type

Open Circuited P - N Junction

Discussion on p-n junction





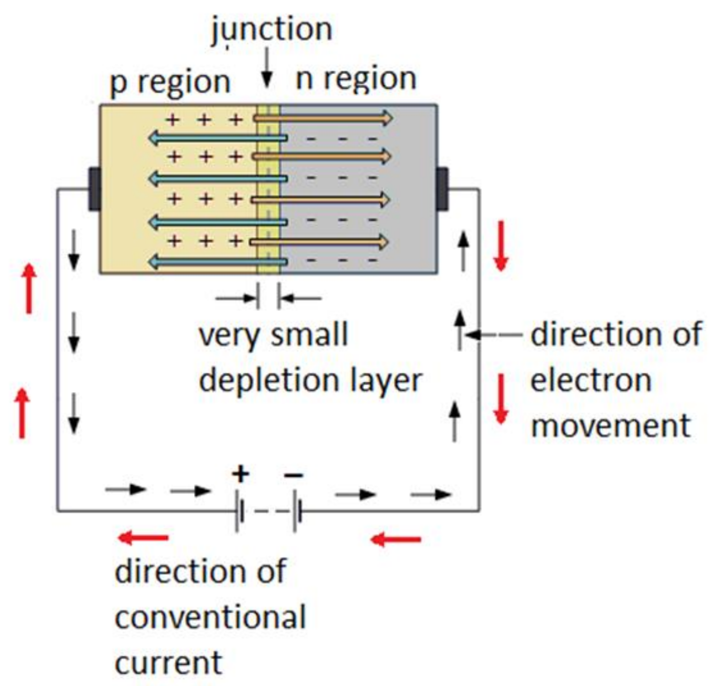
In an unbiased p-n junction, the majority holes on the **p** side start diffusing into the **n** side while the majority free electrons on the **n** side start diffusing into the **p** side. Due to this process, there are **positive immobile ions, just near the junction** in **n** region and **negative immobile ions, just near the junction** in **p**-region.

As more holes diffuse on the **n** side, a large immobile positive charge accumulates near the junction on **n** side. This positive charge repels the positively charged holes and the further **diffusion of holes stops**. Similarly large negative charge accumulates near the junction on the **p** side. This negative charge repels the negatively charged electrons and the further **diffusion of electrons stops**.

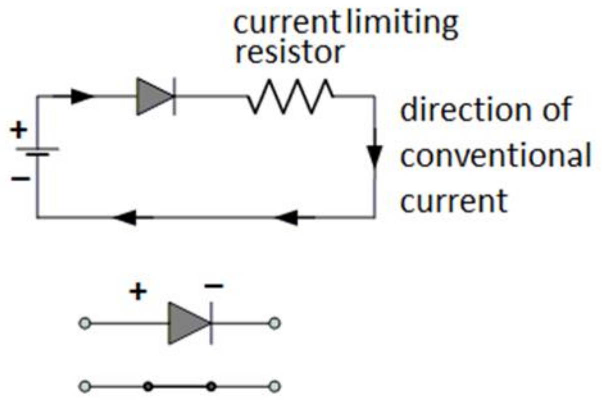
Thus there exists a wall near the junction with a negative immobile charge on the p side and positive immobile charge on the n side. There are no charge carriers in this region. **The region is depleted off the charge carriers hence called depletion region or depletion layer**.

In equilibrium condition, the depletion region gets widened up to a point where no further electrons or holes can cross the junction. Thus **it acts as a barrier**. For the silicon diodes, it is 0.7 V and for the germanium diodes, it is 0.3 V. The barrier potential depends on type of semiconductor, Donor impurity and Acceptor impurity, and Temperature.

Forward Baising of Diode



Symbolic Representation



In forward baising diode behaves like a **closed switch**

Forward Biasing of Diode

- When an external d.c. voltage is connected in such a way that the p-region is connected to positive and the n region to negative of the d.c. voltage then the biasing is called **forward biasing**.
- In this state, the negative of battery pushes the free electrons against the barrier from n to p-region while positive of battery pushes holes against barrier from p to n-region. Due to this, the width of the depletion region reduces and consequently, the barrier potential also reduces.
- As the applied voltage is increased, at a particular value, the depletion region becomes very narrow and majority charge carriers can easily cross the junction. **This large number of majority charge carriers constitute a current called forward current**. So the current can easily pass through the diode and we can say the diode behaves like a closed switch in the forward biasing state.
- The current in the p-region is due to the movement of holes so it is a hole current. The current in the n region is due to the movement of electrons so it is an electron current. The holes in p-region and electrons in n-region are majority charge carriers. Hence the forward current is due to majority charge carriers.

Reverse Biasing of Diode

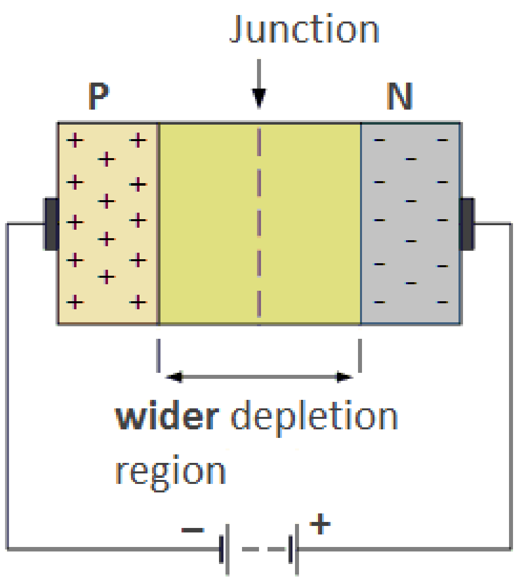
- When an external d.c. voltage is connected in such a way that p-region is connected to negative and n region to the positive terminal of the d.c. voltage then the biasing is called **reverse biasing.**

- In the reverse biasing of a diode, the negative of battery attracts the holes in p-region and positive of battery attracts the electrons in n region away from the junction. This widens the depletion region and increases the barrier potential. No majority charge carrier can cross the junction. Hence the resistance of the reversed biased diode is very high and the diode remains non-operative in this state. The diode behaves like an open switch in the reverse biasing state.

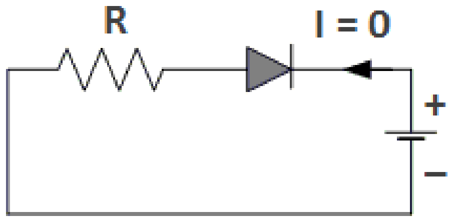
- However, due to increased barrier potential, the free minority electrons on the p side are dragged towards positive while minority holes on the n side are dragged towards the negative of the battery. **This constitutes a current called reverse current**. It flows due to minority charge carriers and hence its magnitude is very very small.

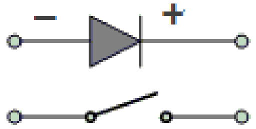
- For constant temperature, the **reverse current is almost constant** though applied reverse voltage is increased up to a certain limit. Hence it is called reverse saturation current. It is in the order of a few micro-amperes for Ge and a few nano-amperes for Si diodes.

Reverse Baising of Diode



Symbolic Representation



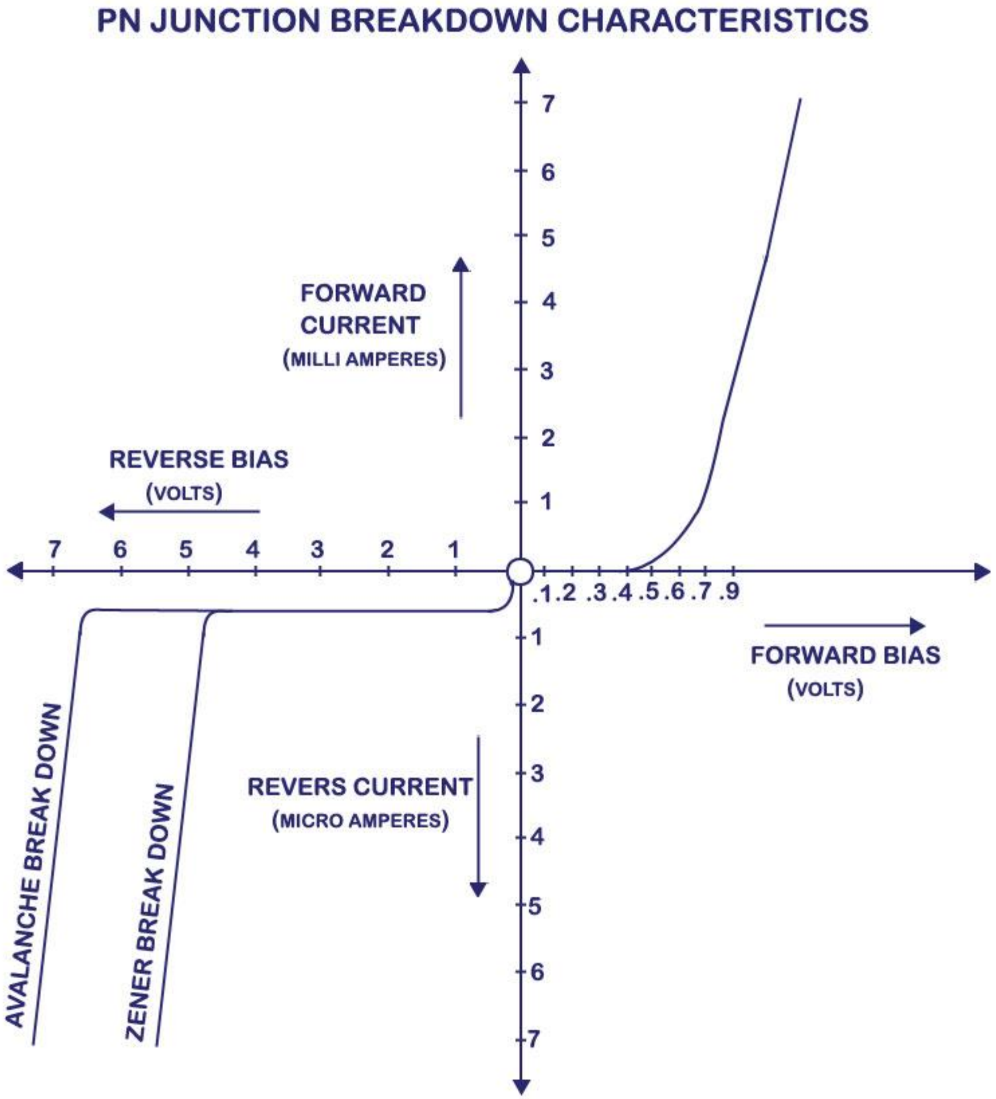


In reverse basing diode behaves like an **open** switch

Breakdown Mechanisms in Junction Diode

If the reverse voltage is increased beyond particular value, a large reverse current can flow damaging the diode. This is called the **reverse breakdown of the diode**. Such a reverse breakdown of a diode can take place due to the following two effects,

1. Avalanche effect, and
2. Zener effect



Breakdown of Diode due to Avalanche Effect

- If the reverse voltage is increased, at a particular value, the velocity of minority carriers increases. Due to the kinetic energy associated with the minority carriers, more minority carriers are generated when there is a collision of minority carriers with the atoms. The collision makes the electrons to break the covalent bonds.

- These electrons are available as minority carriers and get accelerated due to high reverse voltage. They again collide with other atoms to generate more minority carriers. This is called the carrier multiplication.

- Finally, a large number of minority carriers move across the junction, breaking the p-n junction. These large number of minority carriers give rise to a very high reverse current.

- This effect is called the Avalanche effect and the mechanism of destroying the junction is called the reverse breakdown of a p-n junction. The voltage at which the breakdown of a p-n junction occurs is called the reverse breakdown voltage.

Breakdown of Diode due to Zener Effect

- **When a p-n junction is heavily doped the depletion region is very narrow**. Due to the narrow depletion region on high reverse voltage, the electric field becomes very intense across the depletion region. Such an intense field is enough to pull the electrons out of the valence bands of the stable atoms.

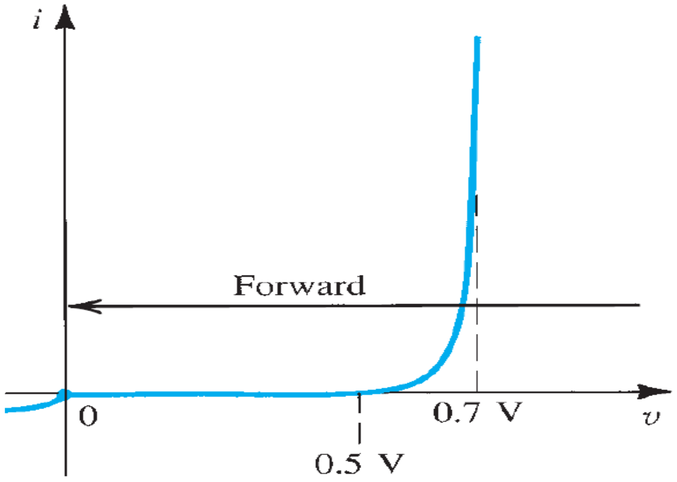
- Such a creation of free electrons is called the Zener effect which is different from the avalanche effect. These minority carriers constitute a very large current and the mechanism is called Zener breakdown of the diode.

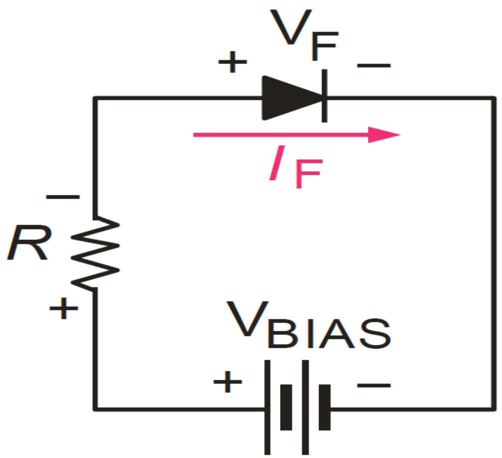
- These effects are required to be considered for special diodes such as Zener diodes as such diodes are always operated in reverse breakdown condition.

Diode V-I characteristics

VI Characteristic for forward bias:

- The current in forward biased called forward current
- At 0V (V_{BIAS}) across the diode, there is no forward current.
- With gradual increase of V_{BIAS}, the forward voltage and forward current increases.
- A resistor in series will limit the forward current in order to protect the diode from overheating and permanent damage.
- A portion of forward-bias voltage drops across the limiting resistor.
- Continuing increase of V_{BIAS} causes rapid increase of forward current but only a gradual increase in voltage across diode.

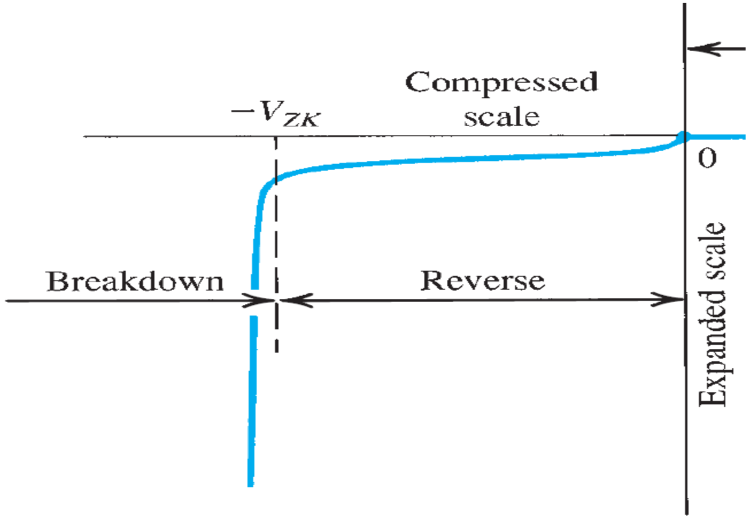


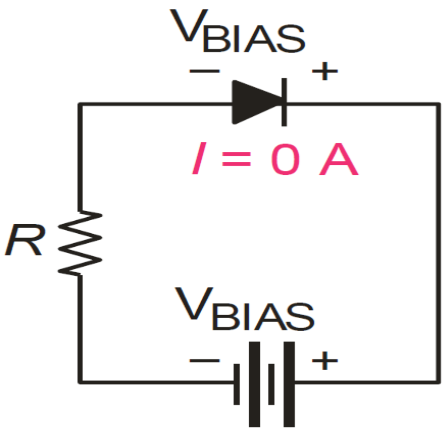


Diode V-I characteristics

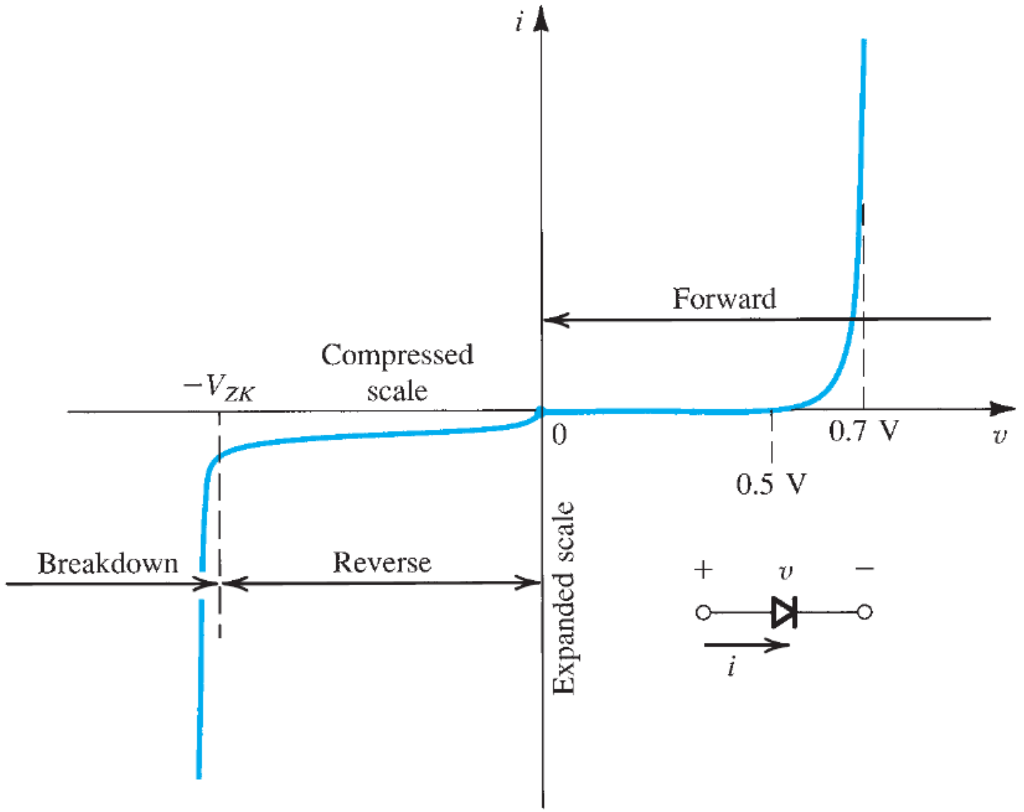
VI Characteristic for reverse bias:

- With 0V reverse voltage there is no reverse current.
- There is only a small current through the junction as the reverse voltage increases.
- At a point, reverse current shoots up with the break down of diode. The voltage called break down voltage (V_{BR}) This is not normal mode of operation.
- After this point the reverse voltage remains at approximately V_{BR} but I_R increase very rapidly.





Complete V-I characteristics



- ✓ The forward-bias region, determined by $v > 0$
- ✓ The reverse-bias region, determined by $v < 0$
- ✓ The breakdown region, determined by $v < -V_{ZK}$

The Forward Bias Region

- The forward-bias—or simply forward—region of operation is entered when the terminal voltage v is positive.
- I-V relationship is approximated as:

$$i = I_S(e^{\frac{v}{v_T}} - 1)$$

- I_S is is a constant for a given diode at a given temperature and termed as the Saturation Current which is directly proportional to the cross-sectional area of the diode
- v_T is called the thermal voltage

$$v_T = \frac{kT}{q}$$

k= Boltzmann's constant
T= Temperature in Kelvin
q=electron charge

- At 20^oC $v_T \sim 25mV$

The Forward Bias Region

- For $i \gg I_S$

$$i \approx I_S e^{\frac{v}{v_T}}$$

Example Problem:
A silicon diode said to be a 1-mA device displays a forward voltage of 0.7 V at a current of 1 mA. Evaluate the junction scaling constant I_S. What scaling constants would apply for a 1-A diode of the same manufacture that conducts 1 A at 0.7 V?

The Reverse Bias Region

- When v is negative and $|v| \gg v_T$

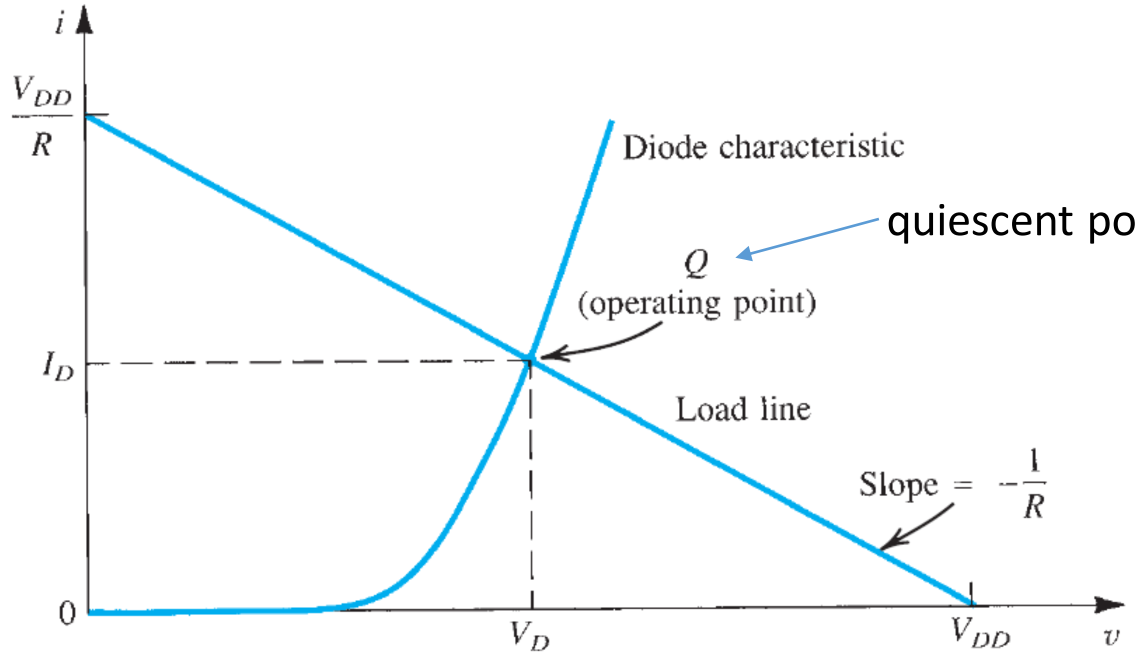
$$i \approx -I_S$$

- Implies that, current in the reverse direction is constant and equal to I_S. Due to this constancy, this current is called the Saturation current
- This reverse current is also called leakage current

The Breakdown Region

- The breakdown region is entered when the magnitude of the reverse voltage exceeds a threshold value that is specific to the particular diode, called the breakdown voltage.
- This is the voltage at the "knee" of the i–v curve and is denoted v_{ZK}, where the subscript Z stands for Zener and K denotes knee.
- As can be seen in the breakdown region the reverse current increases rapidly, with the associated increase in voltage drop being very small.

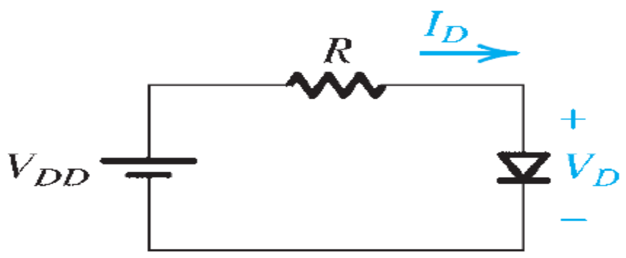
Graphical Analysis using the exponential model



quiescent point or operating point

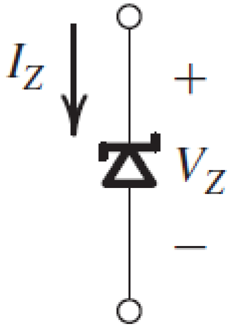
Example

Determine the current I_D and the diode voltage V_D for the circuit in Fig. 4.10 with $V_{DD} = 5$ V and $R = 1k\Omega$. Assume that the diode has a current of 1 mA at a voltage of 0.7 V.

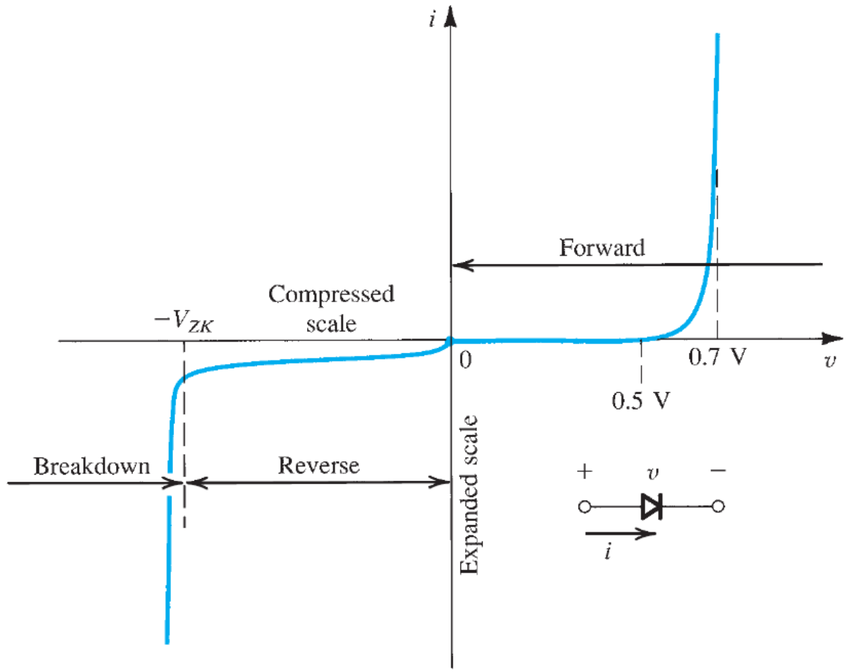


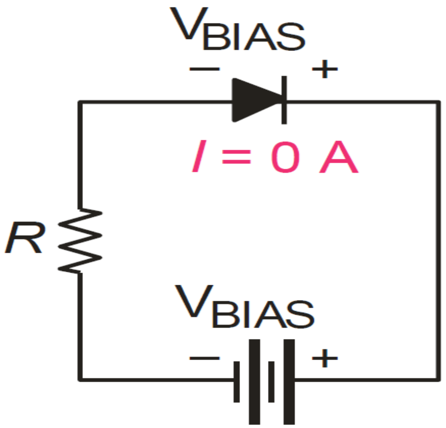
Zener Diode

- Zener diodes are specifically designed to operate in breakdown region
- Useful for designing voltage regulator



Zener Diode



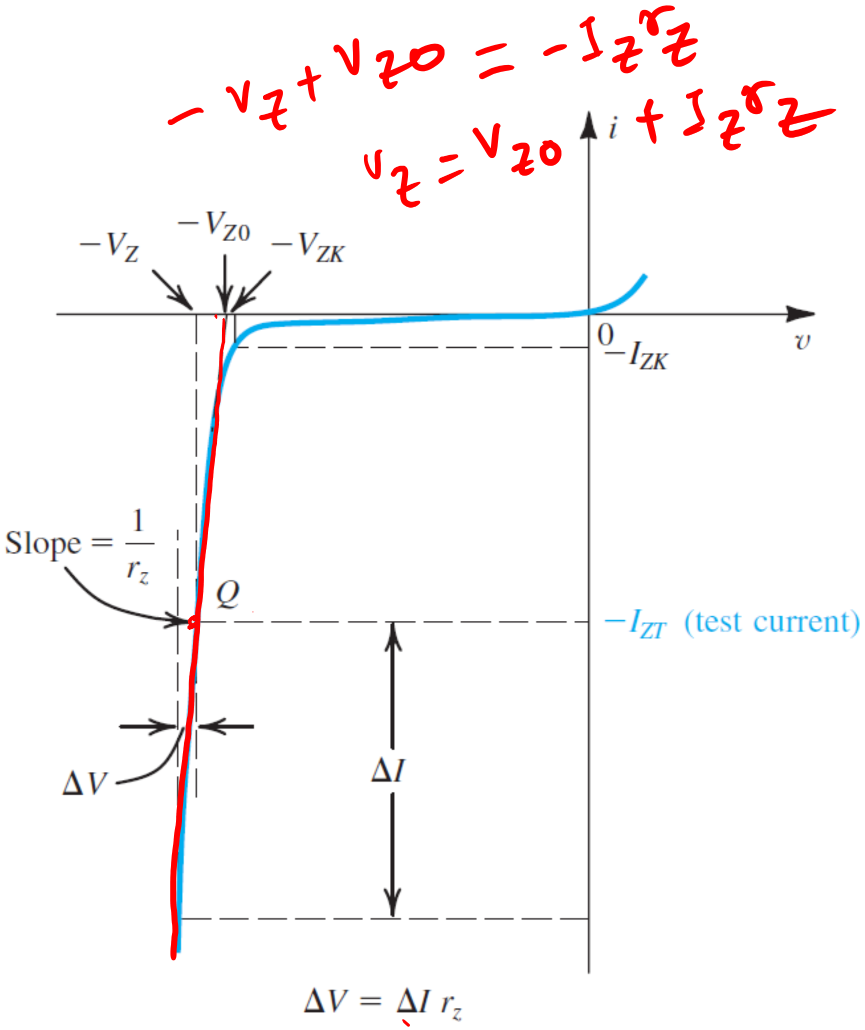


Zener Diode operation

Operates in the break-down region

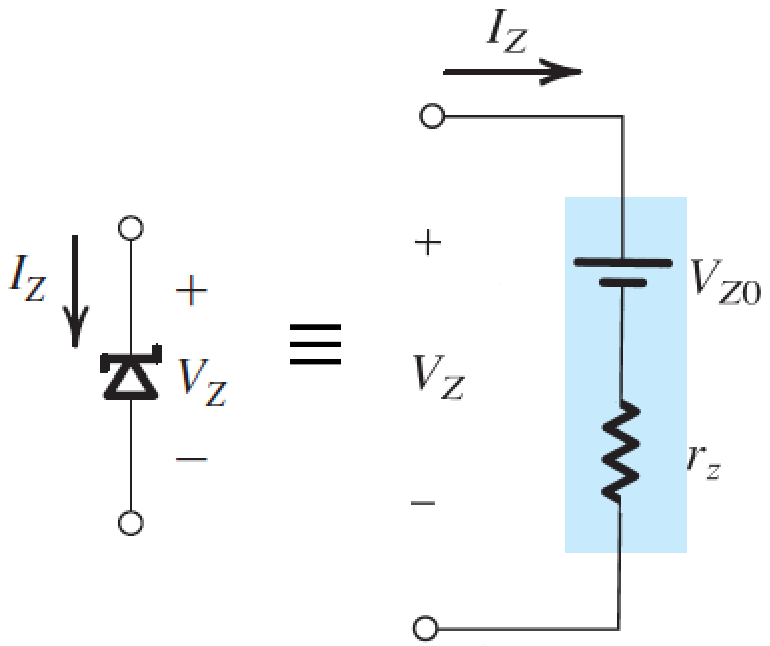
- The very steep i–v curve that the diode exhibits in the breakdown region and the almost-constant voltage drop suggest that diodes operating in the breakdown region can be used in the design of voltage regulators.
- Voltage regulators are circuits that provide a constant dc output voltage **irrespective of changes** in their load current (with certain limits)
- Such diodes are called breakdown diodes or, more commonly, as noted earlier, **Zener diodes**

i-v relationship



- The Figure shows details of the diode i–v characteristic in the breakdown region
- It can be observed that for a reverse current greater than the knee current I_{ZK}(usually specified on the data sheet of the Zener diode), the i–v characteristic is almost a straight line. The manufacturer usually specifies the voltage across the Zener diode V_z at a specified test current, I_{ZT}.

i-v relationship



- Zener diode model:

$$\Delta V = r_z \Delta I$$

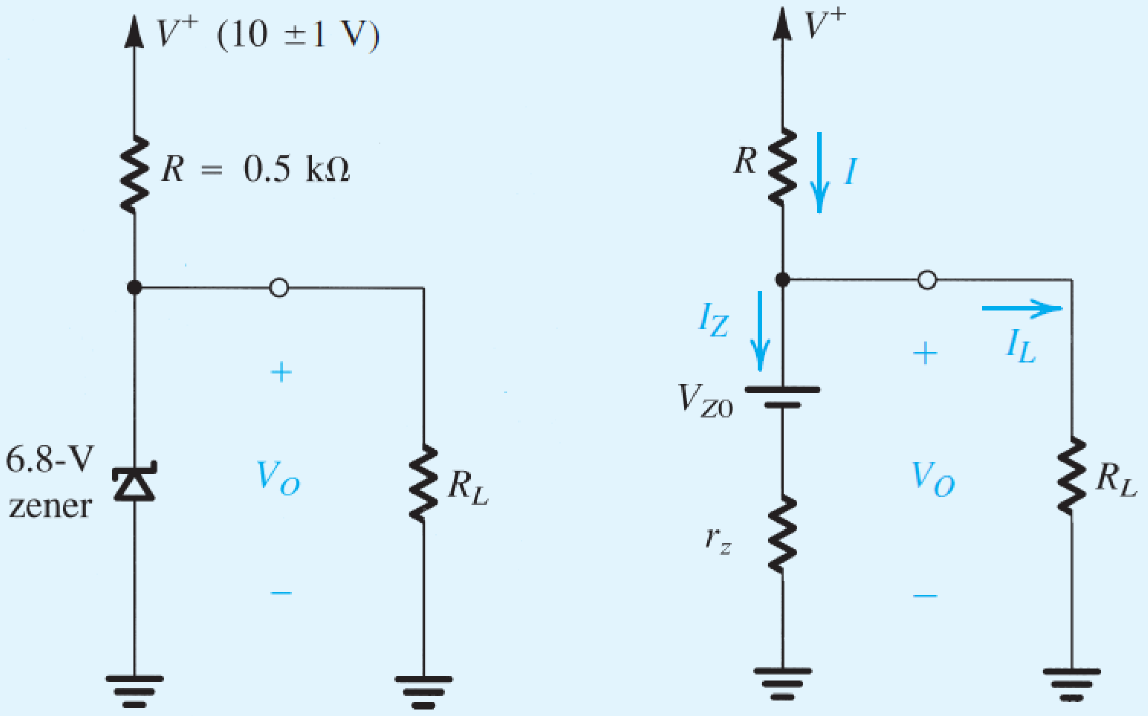
- r_Z is the inverse of the slope of the almost-linear i–v curve at point Q.
- Resistance r_Z is the incremental resistance of the zener diode at operating point Q
- The lower the value of r_Z, the more constant the zener voltage remains as its current varies, and thus the more ideal its performance becomes in the design of voltage regulators.
- Equivalent Model:

$$V_Z = V_{Z0} + r_z I_Z$$

it applies for $I_Z > I_{ZK}$ and, obviously, $V_Z > V_{Z0}$

Example

The 6.8-V zener diode in the circuit of Fig. 4.19(a) is specified to have $V_Z = 6.8$ V at $I_Z = 5$ mA, $r_z = 20\ \Omega$, and $I_{ZK} = 0.2$ mA. The supply voltage V^+ is nominally 10 V but can vary by ±1 V.



(a)

(b)

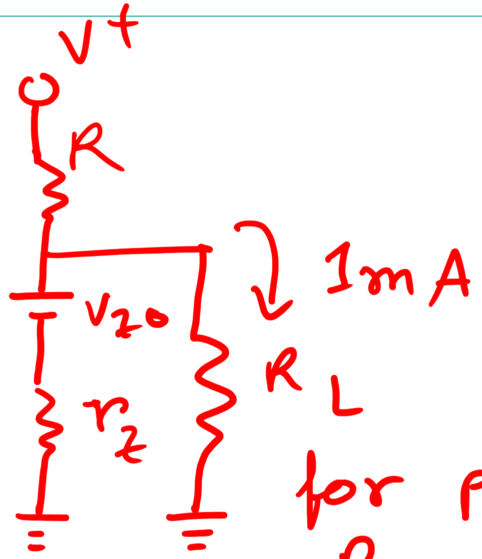
Example

(a) Find V_O with no load and with V^+ at its nominal value.
(b) Find the change in V_O resulting from the ±1-V change in V^+. Note that $(\Delta V_O/\Delta V^+)$, usually expressed in mV/V, is known as **line regulation**.
(c) Find the change in V_O resulting from connecting a load resistance R_L that draws a current I_L = 1 mA, and hence find the **load regulation** $(\Delta V_O/\Delta I_L)$ in mV/mA.
(d) Find the change in V_O when $R_L = 2$ kΩ.
(e) Find the value of V_O when $R_L = 0.5$ kΩ.
(f) What is the minimum value of R_L for which the diode still operates in the breakdown region?

Example cont.

Example cont.

c) $\Delta V_o = \Delta I_z r_z$ $\qquad V_o = V_{Z0} + I_z r_z$



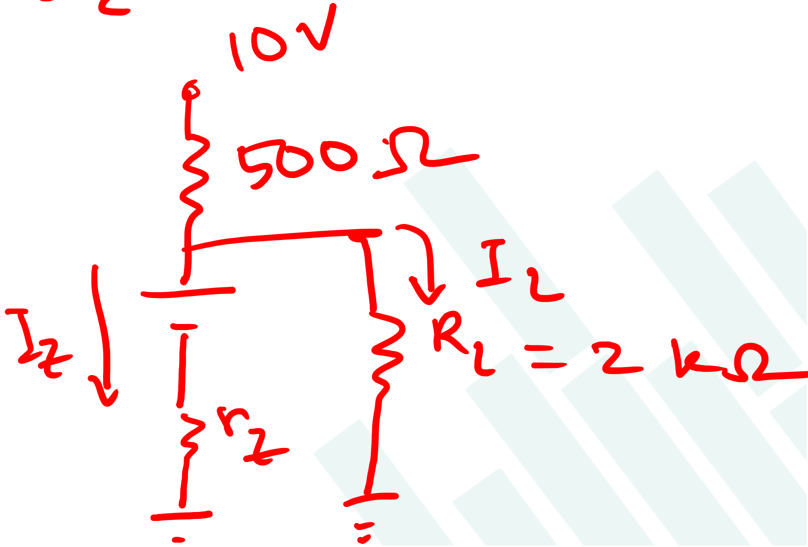
1 mA load

$\Delta V_o = 20 \times -1 \text{ mA} = -20 \text{ mV}$

$\text{Load regulation} = \dfrac{\Delta V_o}{\Delta I_L} = -20 \text{ mV/mA}$

for part d $R_L = 2k\Omega$

d) $V_o = I_L \times 2k\Omega \longrightarrow I_L \times 2k\Omega = V_{Z0} + I_z r_z$



$$I_z + I_L = \frac{10 - I_L \times 2k\Omega}{500}$$

$$500 I_z + 2500 I_L = 10$$

$$-20 I_z + 2000 I_L = 6.7$$

$$I_z = 3.1 \text{ mA}, \quad I_L = 3.4 \text{ mA}$$

Example cont.

$V_o = I_L \times 2k\Omega = 6.7619\,V$

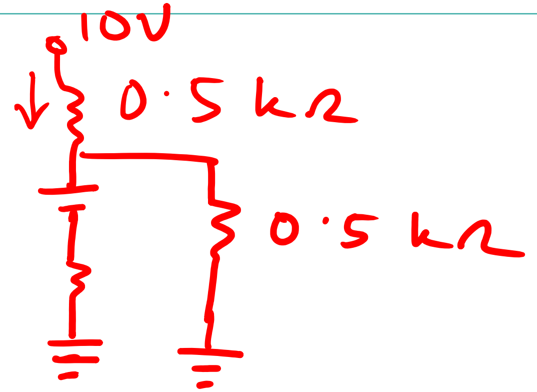
$\Delta V_o = (6.83 - 6.7619)\,V = 68.1\,mV$

e) Approx

$$I_L = \frac{6.8}{0.5} = 13.6\ mA$$

Our assumption that the diode is on is wrong

$V_o = 5V$



f) $V_Z \simeq V_{Z0} = 6.7V$ at $I_{ZK} \to 0.2mA$

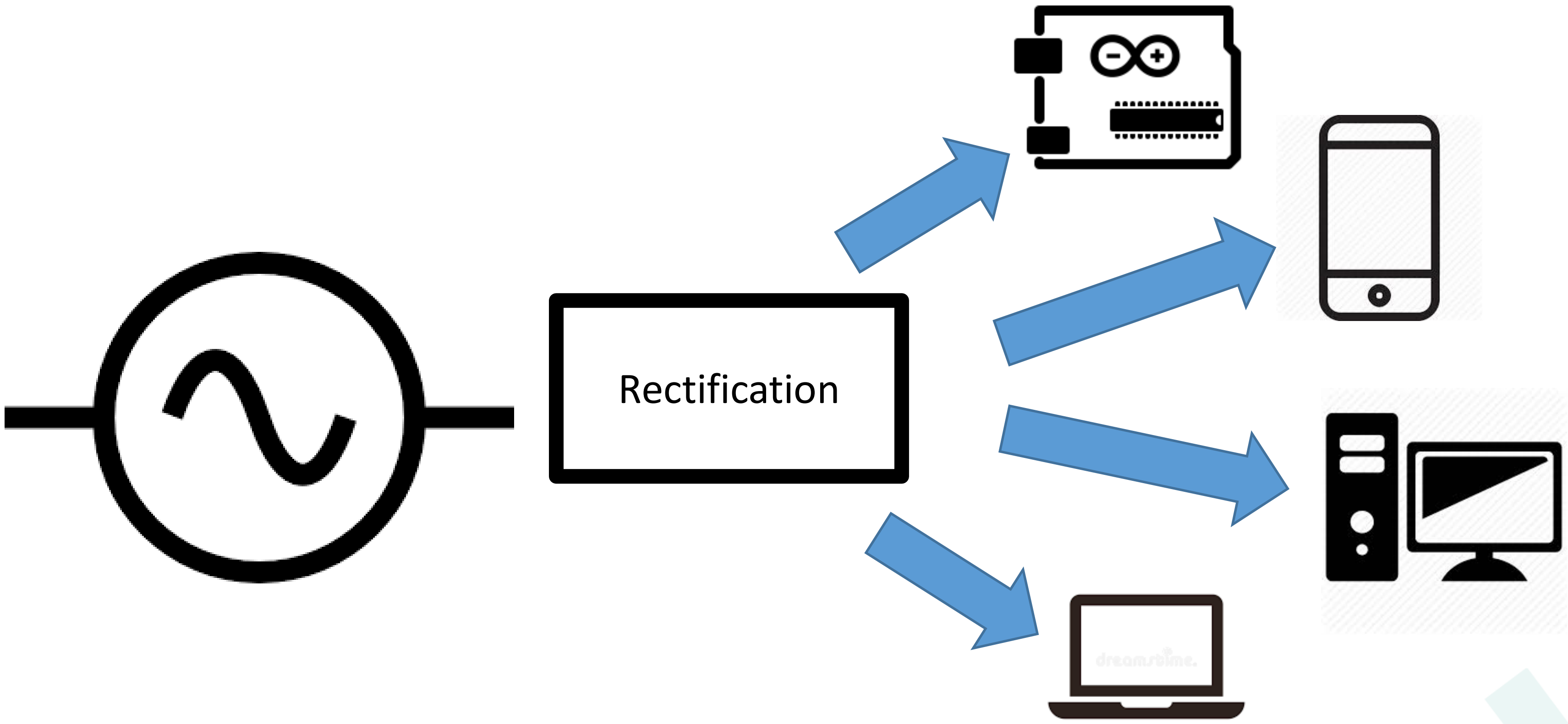
$$I = \frac{9 - 6.7}{0.5} = 4.6mA$$

Load current $= 4.6 - 0.2 = 4.4mA$

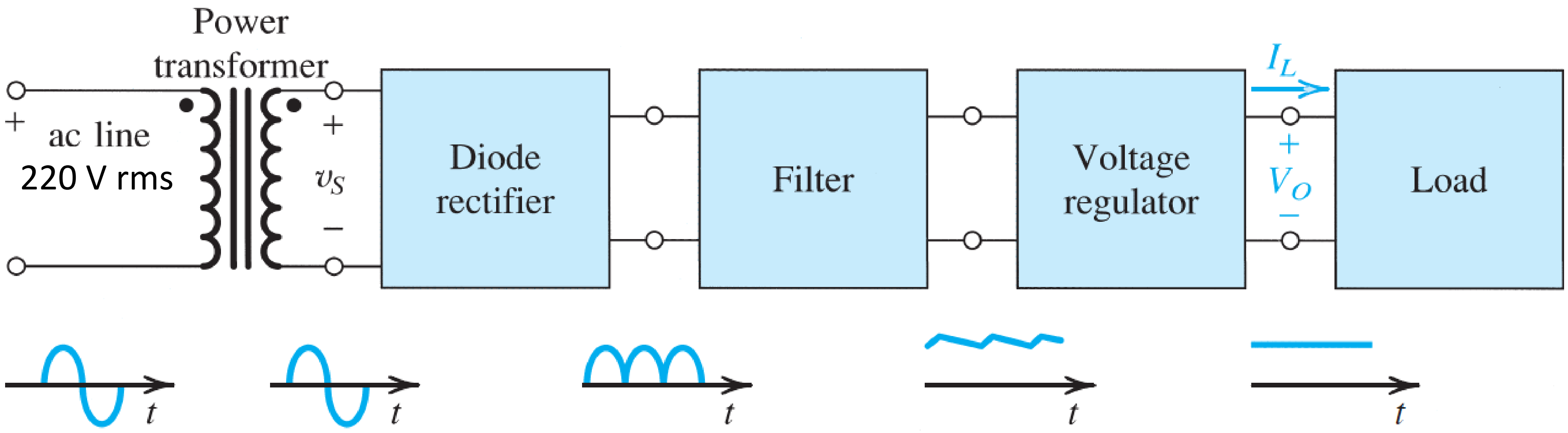
$R_L = 6.7/4.4 \cong 1.5\,k\Omega$

Rectifier circuits

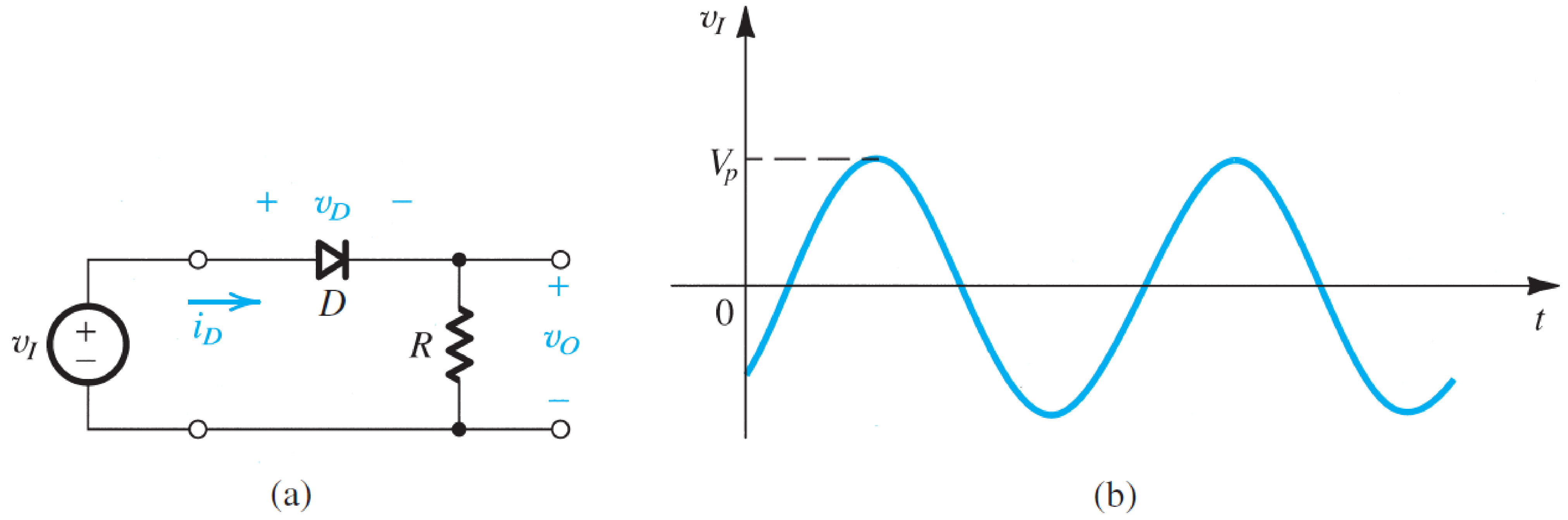
- Rectifier circuit converts AC supply to DC supply
- Essential for any DC power supply equipment



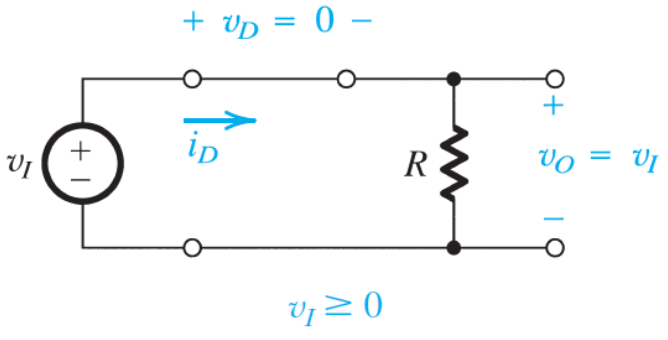
Rectifier Circuit



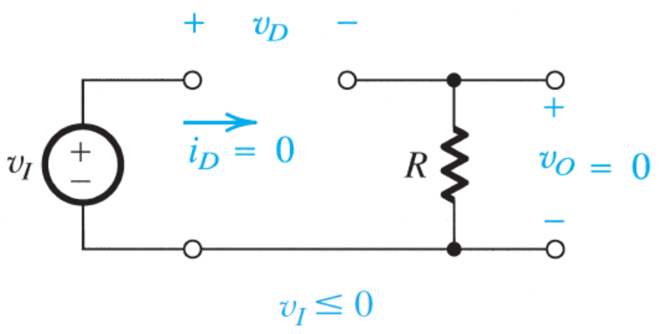
Simple Half Wave Rectifier



Simple Half Wave Rectifier



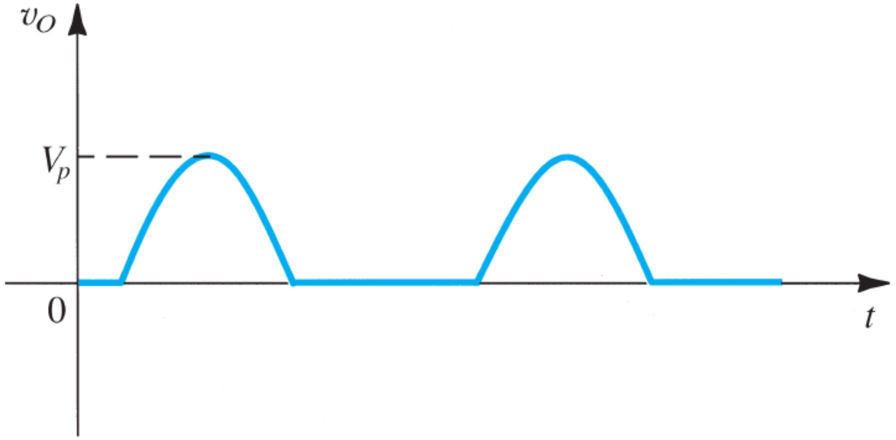
(c)



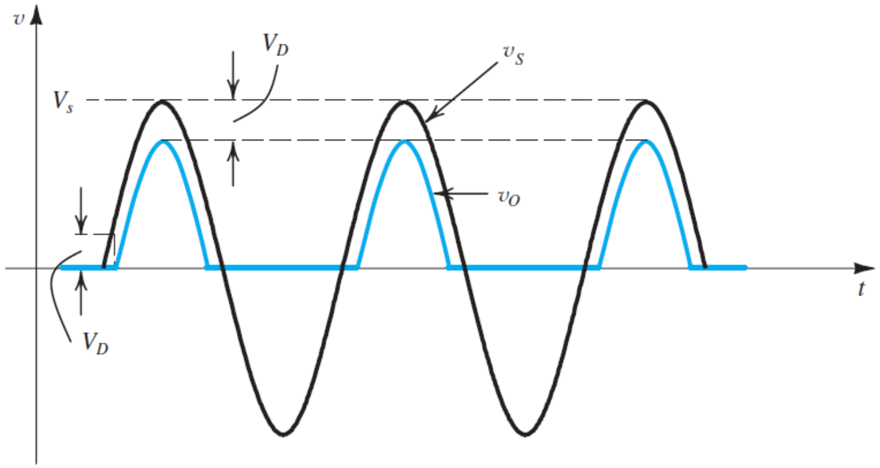
(d)

$$v_O = 0, \qquad v_S < V_D$$

$$v_O = v_S - V_D, \qquad v_S \geq V_t$$



(e)



Average output voltage of a half wave rectifier

the average voltage, V_{dc}, of the pulsating DC output of a half wave rectifier

If input voltage is

$V(t) = V_m \sin(\omega t)$

Then output is $V_{\text{o}}(t) = \begin{cases} V_m \sin(\omega t), & 0 \le t \le T/2 \\ 0, & T/2 \le t \le T \end{cases}$

$$
\begin{aligned}
V_{\text{dc}} &= \frac{1}{T}\int_0^T V_{\text{o}}(t)\mathrm{d}t \\
&= \frac{1}{T}\int_0^{T/2} V_m \sin(\omega t)\mathrm{d}t + \frac{1}{T}\int_{T/2}^{T} 0\ \mathrm{d}t \\
&= \frac{V_m}{T}\int_0^{T/2} \sin(\omega t)\mathrm{d}t \\
&= \frac{V_m}{T}\left[-\frac{\cos(\omega t)}{\omega}\right]_0^{T/2} \\
&= \frac{V_m}{\omega T}\{-\cos(\omega T/2) + \cos(0)\} \\
&= \frac{V_m}{\pi}.
\end{aligned}
$$

RMS value of the output voltage of a half wave rectifier

RMS value of the output voltage, $V_{\rm rms}$, of the pulsating DC output

$$
\begin{aligned}
V_{\rm rms}^2 &= \frac{1}{T}\int_0^T V_{\rm o}^2(t)\mathrm{d}t \\
&= \frac{V_m^2}{T}\int_0^{T/2} \sin^2(\omega t)\mathrm{d}t + \frac{V_m^2}{T}\int_{T/2}^{T} 0\ \mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} 2\sin^2(\omega t)\mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} \{1-\cos(2\omega t)\}\,\mathrm{d}t \\
&= \frac{V_m^2}{2T}\int_0^{T/2} \mathrm{d}t - \frac{V_m^2}{T}\int_0^{T/2} \cos(2\omega t)\mathrm{d}t \\
&= \frac{V_m^2}{2T}\Big[T\Big]_0^{T/2} - \frac{V_m^2}{2T}\left[\frac{\sin(2\omega t)}{2\omega}\right]_0^{T/2} \\
&= \frac{V_m^2}{4} - \frac{V_m^2}{\omega T}\Big\{\sin(2\omega T)-\sin(0)\Big\} \\
&= \frac{V_m^2}{4}.
\end{aligned}
$$

Hence for the half wave rectifier

$$\boxed{V_{\rm rms} = \frac{V_m}{2}.}$$

Ripple factor of half wave rectifier

Ripple is the unwanted AC component remaining when converting the AC voltage waveform into a DC waveform. Even though we try out best to remove all AC components, there is still some small amount left on the output side which pulsates the DC waveform. This undesirable AC component is called ripple.

Note that **to construct a good rectifier, one should keep the ripple factor as low as possible.** This is why capacitors and inductors as filters are used to reduce the ripples in the circuit.

To quantify how well the half wave rectifier can convert the AC voltage into DC voltage, we use what is known as the ripple factor (represented by γ).

The ripple factor is the ratio between the RMS value of the AC voltage and the DC voltage of the rectifier.

$$\boxed{\gamma = \frac{\text{RMS value of the AC component}}{\text{value of DC component}} = \frac{V_{\mathrm{r(rms)}}}{V_{\mathrm{dc}}}.}$$

Note that the RMS value of the AC component of the signal is $V_{r(rms)}$ and V_{rms} is the RMS value of the whole voltage signal.

Ripple factor of half wave rectifier

To calculate $V_{r(rms)}$, the RMS value of the AC component present in the output of the half wave rectifier we write the output voltage as

$$V_o(t) = V_{ac} + V_{dc}$$

where V_{ac} is the AC component remaining when converting the AC voltage waveform into a DC waveform.

The RMS value of the AC component present in the output of the half wave rectifier is given by

$$V_{r(rms)} = \left[\frac{1}{T}\int_0^T V_{ac}^2 \, dt\right]^{1/2}$$

$$\begin{aligned} V_{r(rms)}^2 &= \frac{1}{T}\int_0^T (V_o - V_{dc})^2 \, dt \\ &= \frac{1}{T}\int_0^T (V_o^2 - 2V_oV_{dc} + V_{dc}^2) \, dt \\ &= \frac{1}{T}\int_0^T V_o^2 \, dt - \frac{2V_{dc}}{T}\int_0^T V_o \, dt + V_{dc}^2 \\ &= V_{rms}^2 - 2V_{dc}^2 + V_{dc}^2 \\ &= V_{rms}^2 - V_{dc}^2. \end{aligned}$$

Hence the formula to calculate the ripple factor can be written as

$$\gamma = \frac{V_{r(rms)}}{V_{dc}} = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

Using the values of V_{dc} and V_{rms}

$$\gamma = \sqrt{\left(\frac{V_m}{2} \times \frac{\pi}{V_m}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} \approx 1.21.$$

Efficiency of half wave rectifier

The ratio of the DC power available at the load to the applied input AC power is known as the efficiency, η. Mathematically it can be given as:

$$\boxed{\eta = \frac{\text{DC power output}}{\text{AC power input}} = \frac{P_{\mathrm{dc}}}{P_{\mathrm{ac}}}.}$$

Let r_f and R_L be the forward resistance and load resistance of the diode. During the conduction period the instantaneous value of the current is given by the equation:

$$I(t) = \frac{V(t)}{R_L + r_f} = \frac{V_m}{R_L + r_f}\sin(\omega t) = I_m \sin(\omega t)$$

with $I_m = V_m/(r_f + R_L)$ being the maximum current.

Now, the AC power input to the load is given as,

$$P_{\mathrm{ac}} = I_{\mathrm{rms}}^2 (R_L + r_f) = \frac{V_{\mathrm{rms}}^2}{R_L + r_f}.$$

Since the output is obtained across R_L, the DC power output is given by $P_{\mathrm{dc}} = I_{\mathrm{dc}}^2 R_L = \dfrac{V_{\mathrm{dc}}^2}{R_L}$

Efficiency of half wave rectifier

The half wave rectifier efficiency is then

$$\begin{aligned}
\eta &= \frac{P_{\mathrm{dc}}}{P_{\mathrm{ac}}} \\
&= \frac{V_{\mathrm{dc}}^2}{R_L} \times \frac{R_L + r_f}{V_{\mathrm{rms}}^2} \\
&= \frac{V_{\mathrm{dc}}^2}{V_{\mathrm{rms}}^2} \times \frac{R_L + r_f}{R_L} \\
&= \left(\frac{V_{\mathrm{dc}}}{V_{\mathrm{rms}}}\right)^2 \times \left(1 + \frac{r_f}{R_L}\right) \\
&= \left(\frac{V_m/\pi}{V_m/2}\right)^2 \times \left(1 + \frac{r_f}{R_L}\right) \\
&\approx 0.4053\left(1 + \frac{r_f}{R_L}\right)
\end{aligned}$$

In reality r_f is much smaller then R_L. If we neglect r_f compare to R_L then the efficiency of the rectifier is maximum. Therefore,

$$\boxed{\eta_{\max} \approx 0.4053 = 40.53\%.}$$

This indicates that the half wave rectifier can convert maximum 40.53% of AC power into DC power, and the remaining power of 59.47% is lost in the rectifier circuit. In fact, 50% power in the negative half cycle is not converted and the remaining 9.47% is lost in the circuit.

Applications of half wave rectifier

Half wave rectifier is not so good as compared to Full-wave or Bridge rectifier, but sometimes we require this rectifier depending on the requirements. Some of the applications of half-wave rectifier are

- It is used for the detection of amplitude modulated radio signals.
- For the welding purpose, it supplies polarized voltage.
- It is used in many signal demodulation processes.

Advantages of half wave rectifier

The main advantage of half-wave rectifiers is in their simplicity. As they do not require as many components, they are simpler and cheaper to setup and construct. As such, the main advantages of half-wave rectifiers are:

- Simple (lower number of components)
- Cheaper up front cost (as their is less equipment. Although there is a higher cost over time due to increased power losses)

Disadvantages of half wave rectifier

The disadvantages of half-wave rectifiers are:

- They only allow a half-cycle through per sinewave, and the other half-cycle is wasted. This leads to power loss.
- They produces a low output voltage.
- The output current we obtain is not purely DC, and it still contains a lot of ripple (i.e. it has a high ripple factor)

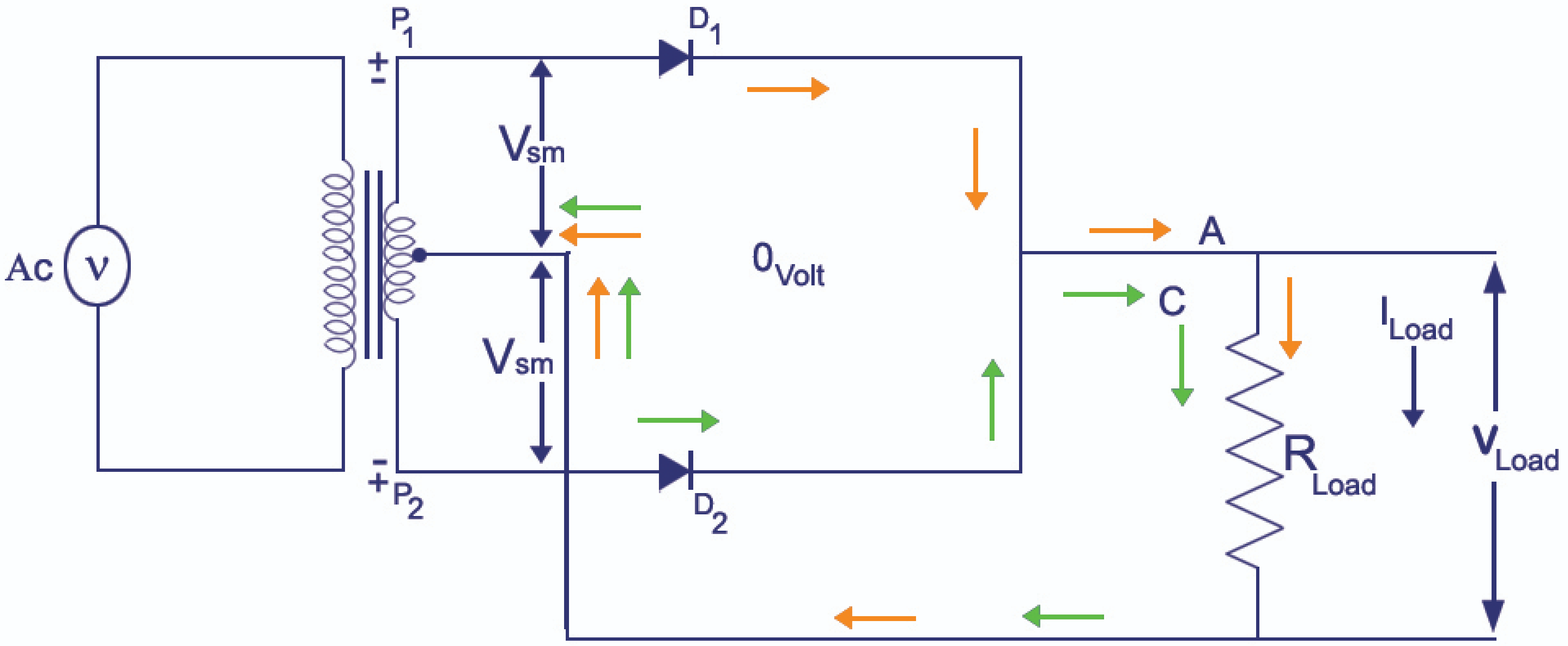
Example problem

For the half-wave rectifier circuit in Fig. 4.21(a), show the following: (a) For the half-cycles during which the diode conducts, conduction begins at an angle $\theta = \sin^{-1}(V_D/V_s)$ and terminates at $(\pi - \theta)$, for a total conduction angle of $(\pi - 2\theta)$. (b) The average value (dc component) of v_O is $V_O \simeq (1/\pi)V_s - V_D/2$. (c) The peak diode current is $(V_s - V_D)/R$.

Find numerical values for these quantities for the case of 12-V (rms) sinusoidal input, $V_D \simeq 0.7$ V, and $R = 100\ \Omega$. Also, give the value for PIV.

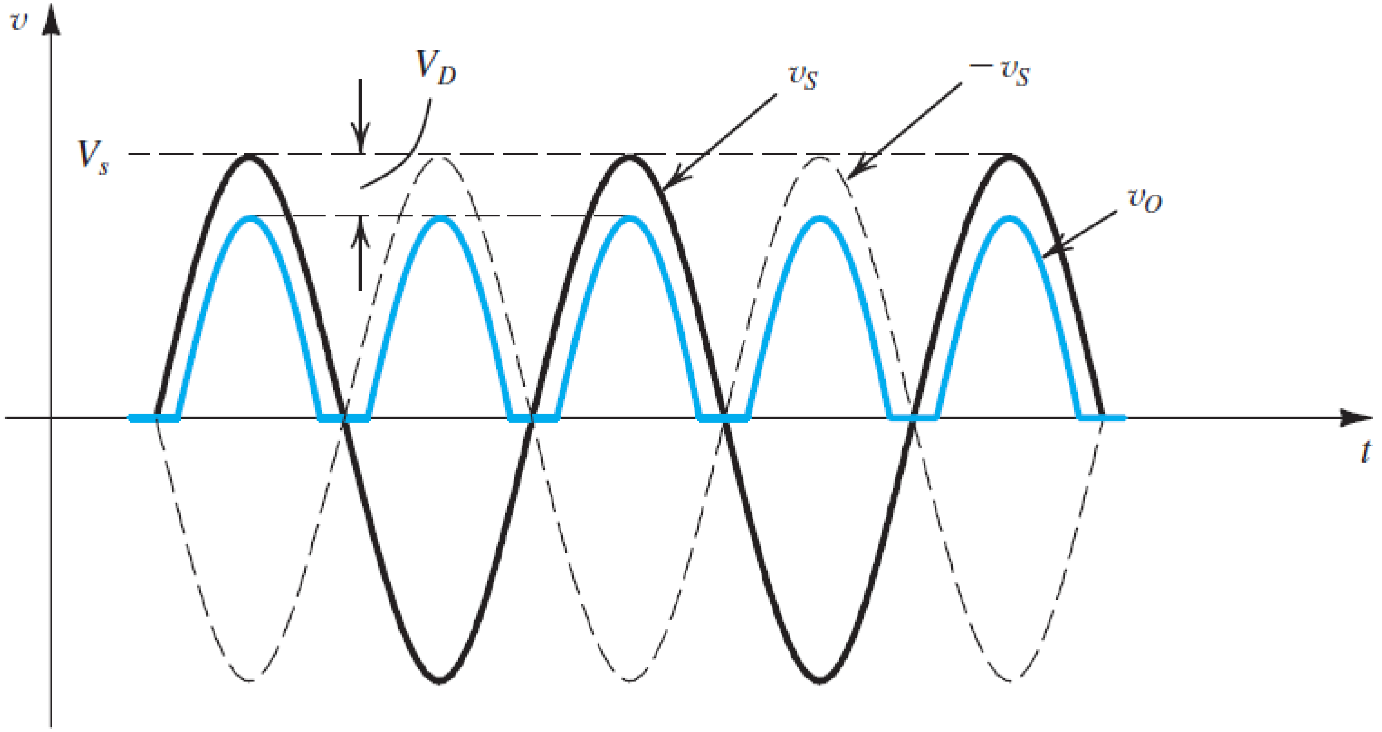
Full wave rectifier with center tap

A full wave rectifier converts both halves of each cycle of an alternating wave (AC signal) into pulsating DC signal. Figure shows the circuit diagram a center tapped full wave rectifier.



CENTRE - TAP FULL- WAVE RECTIFIER CIRCUIT

Full wave rectifier with center tap



The waveform of the output voltage of a full wave rectifier can be written as (for an ideal diode)

$$V_o(t) = \begin{cases} V_m \sin(\omega t), & 0 \le t \le T/2 \\ V_m \sin(\omega t - \pi), & T/2 \le t \le T \end{cases}$$

Average output voltage, rms voltage, ripple factor and efficiency of a full wave rectifier

Average/DC output voltage

$$\begin{aligned} V_{\mathrm{dc}} &= \frac{1}{T}\int_0^T V_{\mathrm{o}}(t)\mathrm{d}t \\ &= \frac{1}{T/2}\int_0^{T/2} V_m \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{T}\int_0^{T/2} \sin(\omega t)\mathrm{d}t \\ &= \frac{2V_m}{\pi}. \end{aligned}$$

RMS value of the output voltage

$$\begin{aligned} V_{\mathrm{rms}} &= \left[\frac{1}{T}\int_0^T V_{\mathrm{o}}^2(t)\mathrm{d}t\right]^{1/2} \\ &= \left[\frac{V_m^2}{T/2}\int_0^{T/2} \sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\ &= \left[\frac{V_m^2}{T}\int_0^{T/2} 2\sin^2(\omega t)\mathrm{d}t\right]^{1/2} \\ &= \frac{V_m}{\sqrt{2}}. \end{aligned}$$

Ripple factor of full wave rectifier

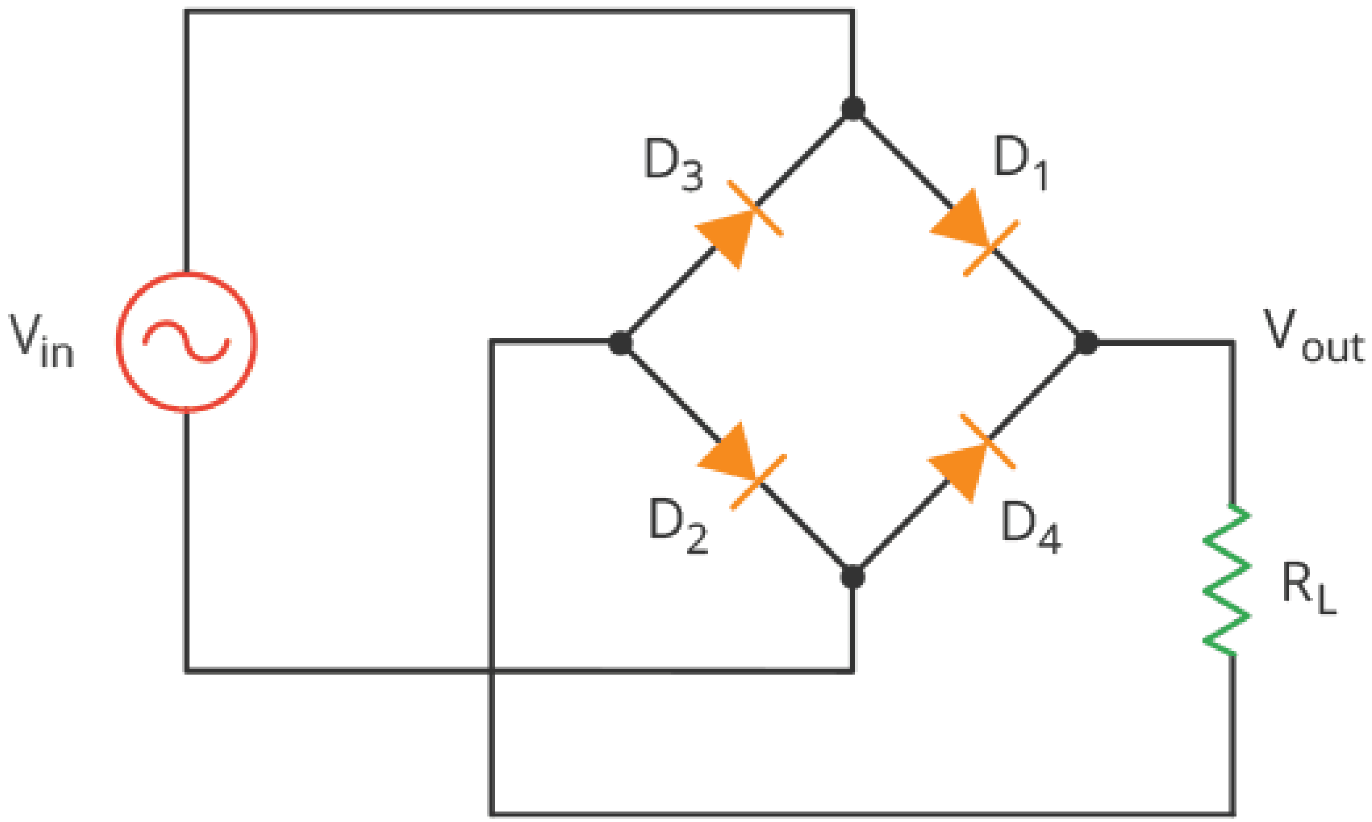
$$\begin{aligned} \gamma &= \sqrt{\left(\frac{V_{\mathrm{rms}}}{V_{\mathrm{dc}}}\right)^2 - 1} \\ &= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} \\ &\approx 0.48 \end{aligned}$$

Efficiency of full wave rectifier

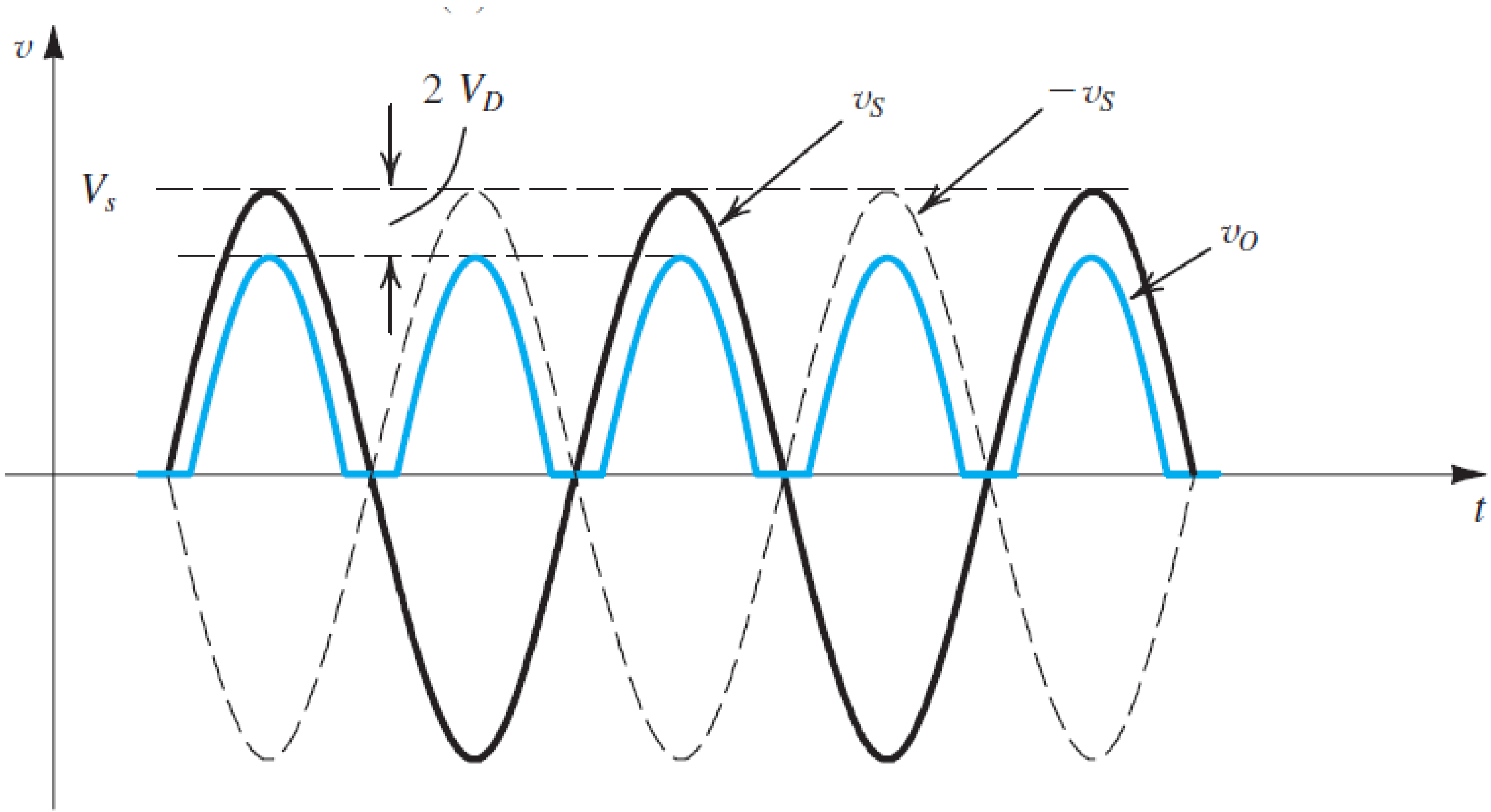
$$\begin{aligned} \eta &= \frac{P_{\mathrm{dc}}}{P_{\mathrm{dc}}} \\ &= \left(\frac{V_{\mathrm{dc}}}{V_{\mathrm{rms}}}\right)^2 \times \left(1 + \frac{r_f}{R_L}\right) \\ &\approx 0.8106\left(1 + \frac{r_f}{R_L}\right) \end{aligned}$$

$$\boxed{\eta_{\max} \approx 0.8106 = 81.06\%.}$$

The Bridge Rectifier



The Bridge Rectifier



Applications of full wave rectifier

Full wave rectifier is of two types; center tapped and bridge rectifier. Both these rectifiers are used for following purposes depends upon the requirement. Following of full wave rectifier applications are:

- It can be used to detect the amplitude of modulated radio signal.
- It can be used to supply polarized voltage in welding.
- The Bridge Rectifier circuits are widely used in power supply for various appliances, as they are capable of converting the High AC voltage into Low DC voltage.

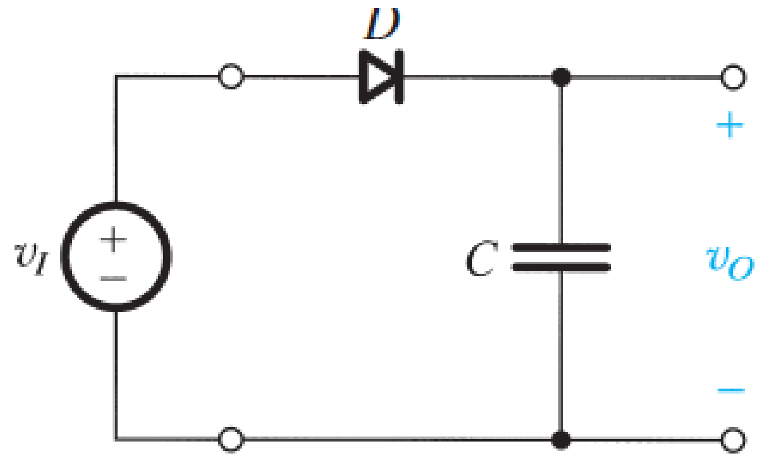
Advantages of full wave rectifier

- Full wave rectifiers have higher rectifying efficiency than half-wave rectifiers. This means that they convert AC to DC more efficiently.
- They have low power loss because no voltage signal is wasted in the rectification process.
- The output voltage of center tapped full wave rectifier has lower ripples than a half wave rectifiers.

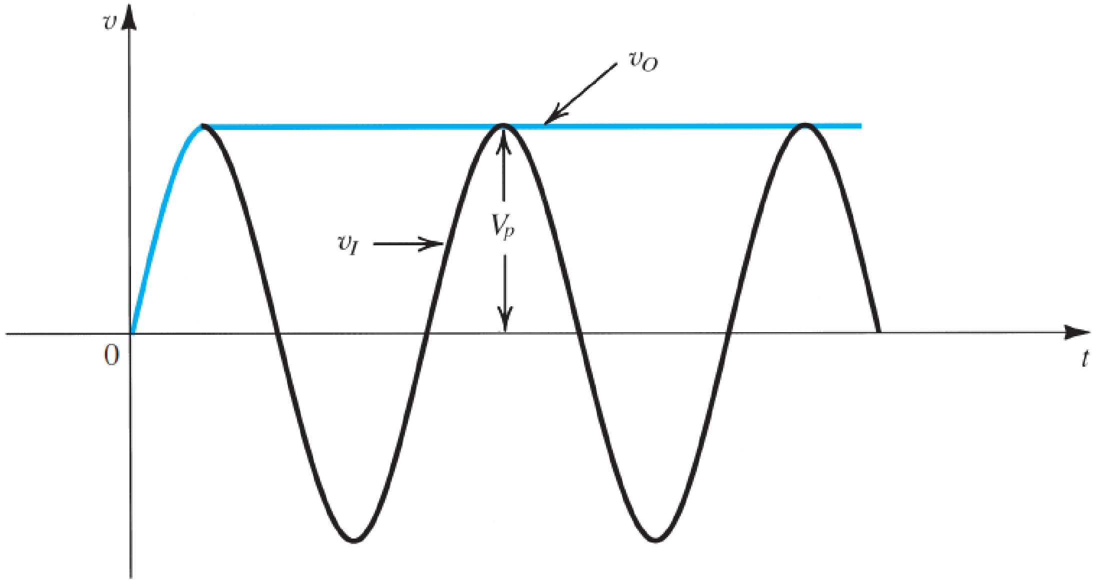
Disadvantages of full wave rectifier

- The center tapped rectifier is more expensive than half-wave rectifier and tends to occupy a lot of space.

Rectifier with a filter capacitor

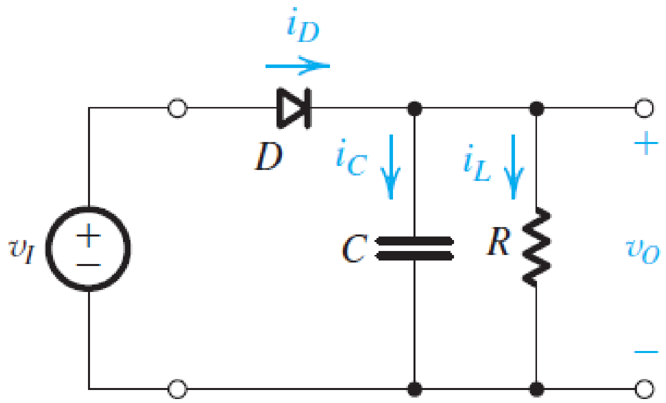


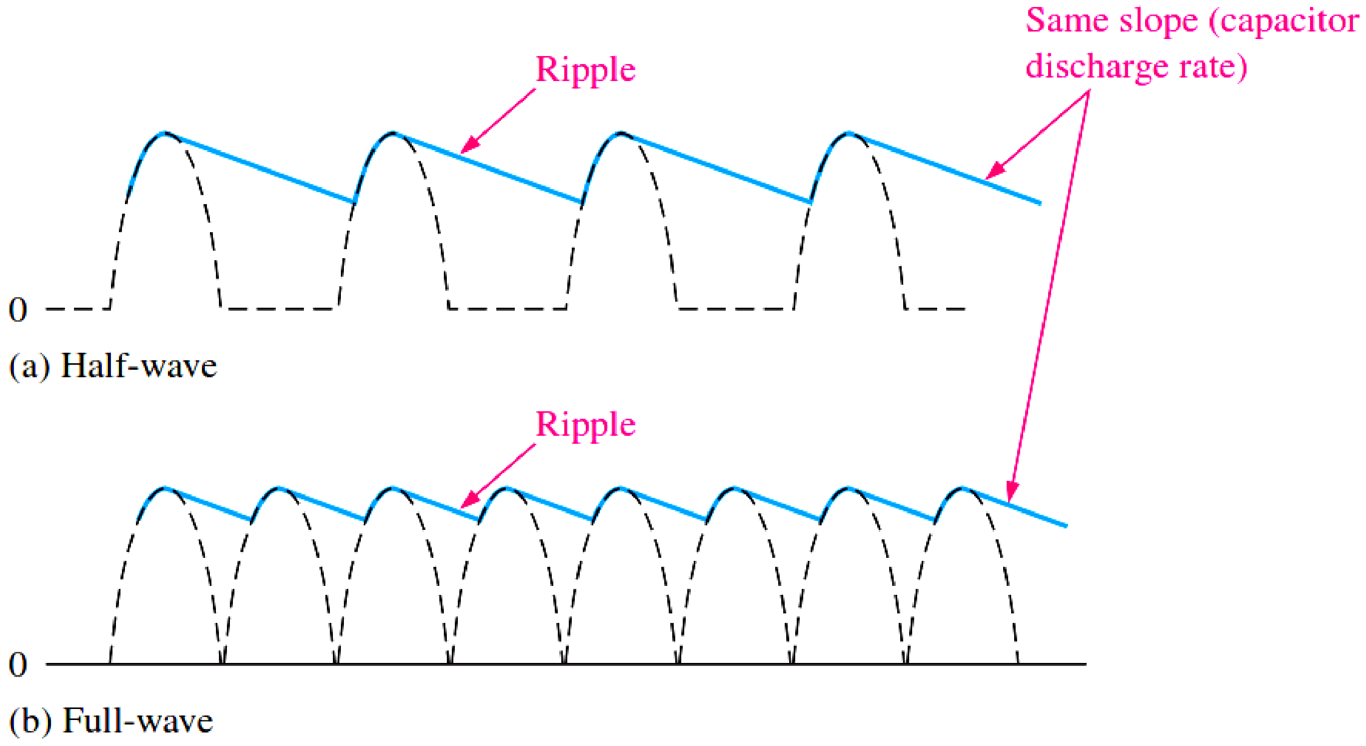
***Assume ideal diode**

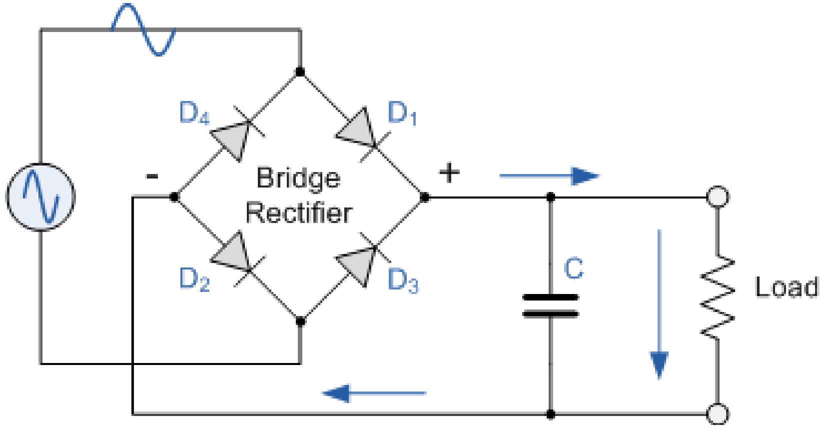


Rectifier with a filter capacitor

*Assume ideal diode







- Time constant of capacitor discharge is CR, so CR is chosen large compare to the period of input a.c.
- Since the reactance of the capacitor is 1/ωC is small than load R, we may think that the a.c. components in rectifier output prefers to bypass through capacitor, on other hand d.c. cannot pass through C and remains in the load resistor

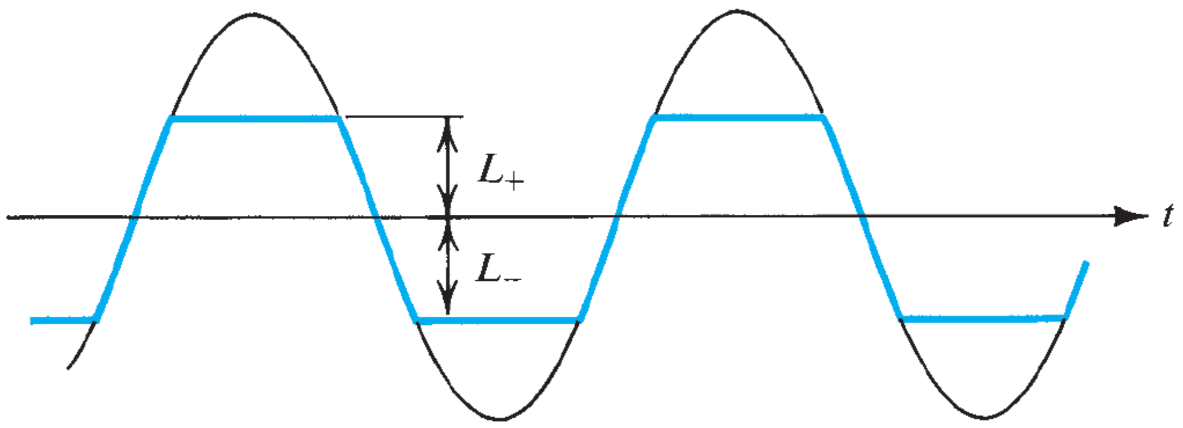
Example

Consider a peak rectifier fed by a 60-Hz sinusoid having a peak value $V_p = 100$ V. Let the load resistance $R = 10$ kΩ. Find the value of the capacitance C that will result in a peak-to-peak ripple of 2 V. Also, calculate the fraction of the cycle during which the diode is conducting and the average and peak values of the diode current.

Limiter/Clipper

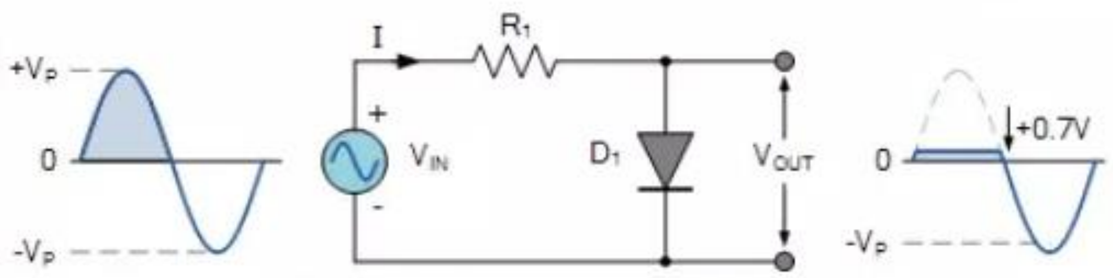
- Clipper circuits, also called limiter circuits, are used to eliminate portion of a signal that are above or below a specified level – clip value.
- The purpose of the diode is that when it is turn on, it provides the clip value
- As these circuits are used only for clipping input waveform as per the requirement and for transmitting the waveform, they do not contain any energy storing element like a capacitor.
- Half wave rectifiers is an example of a diode clipper

Limiter/Clipper

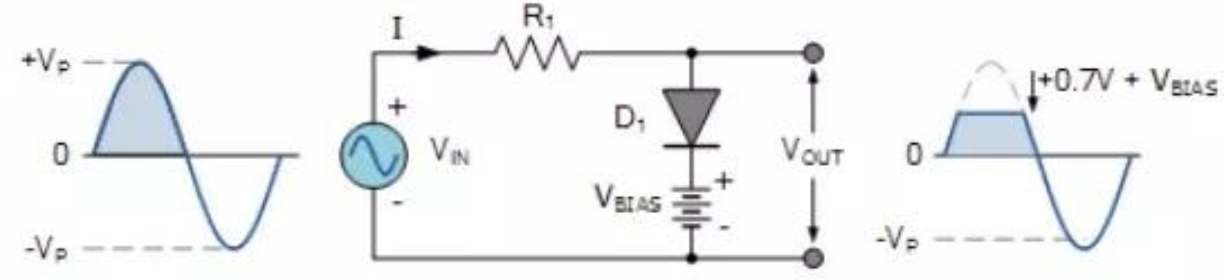


Limiter/Clipper

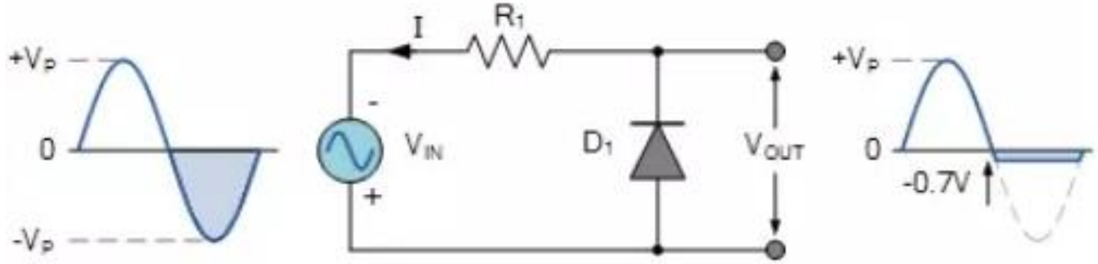
Positive Diode Clipping Circuit



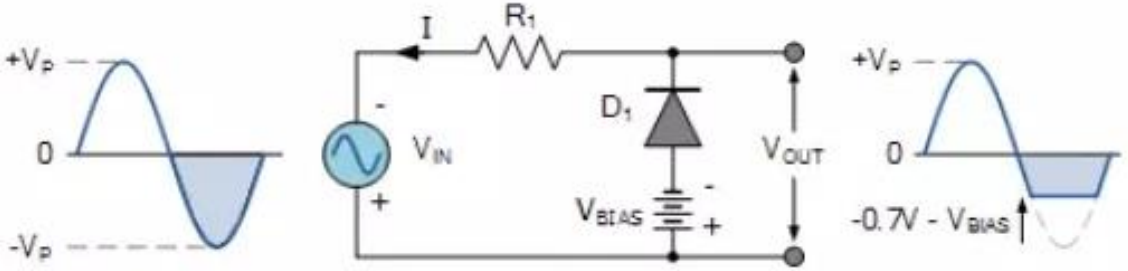
Positive Biased Diode Clipper



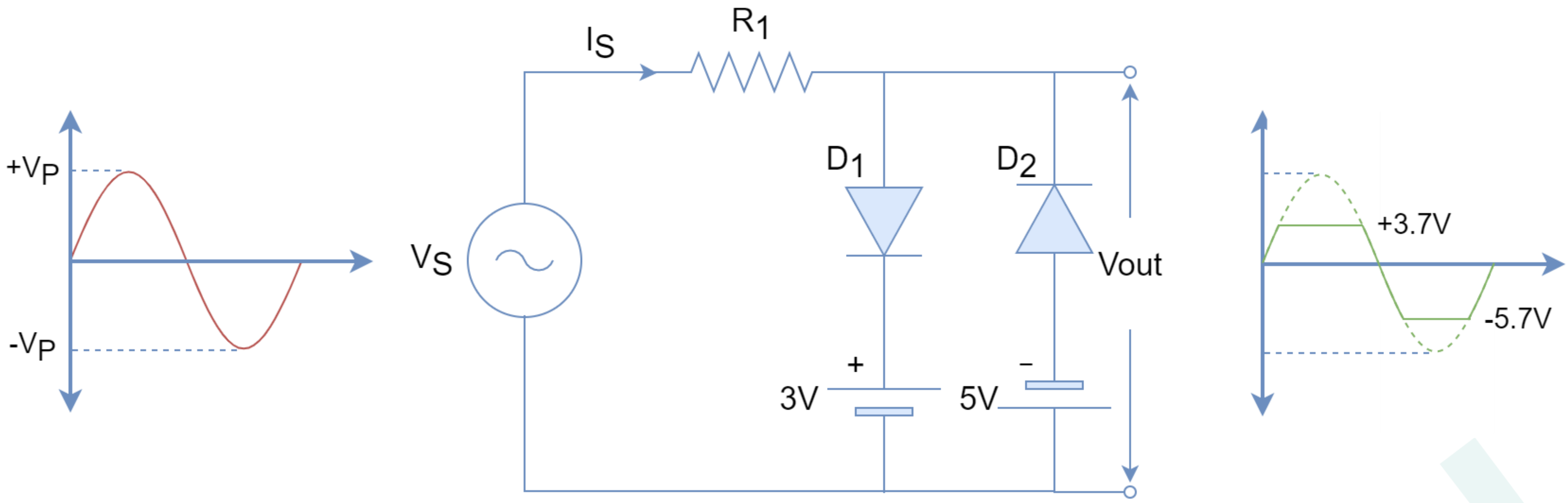
Negative Clipping Circuit



Negative Biased Diode Clipper



Limiter/Clipper



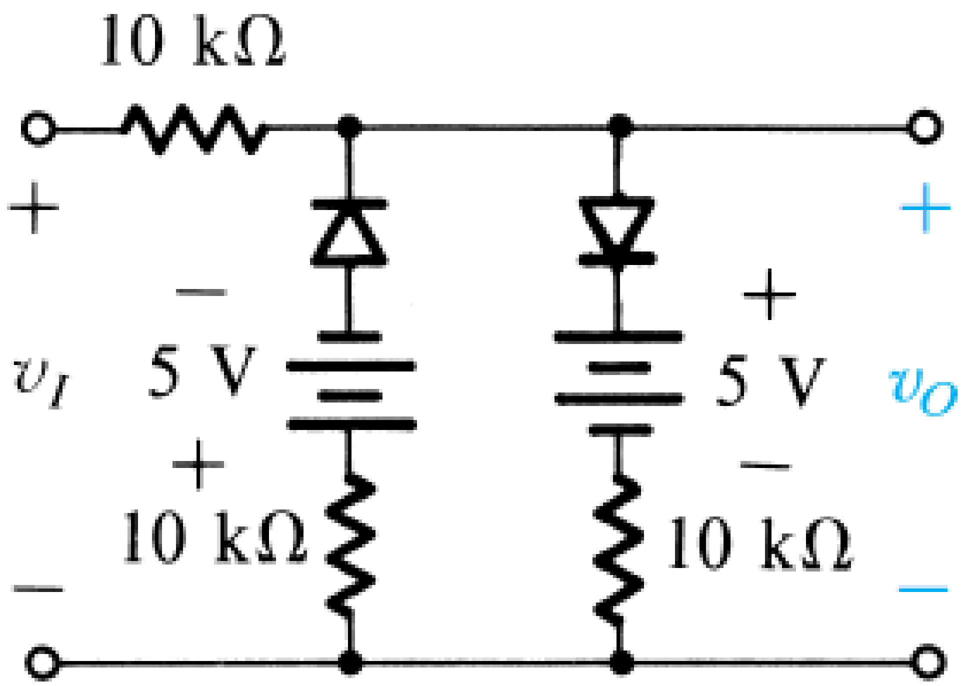
Clipper

Two main Applications

- Changing the shape of a waveform
  - For the generation of new waveforms or shaping the existing waveform, clippers are used.
  - Frequently used half wave rectifier in power supply kits is a typical example of a clipper. It clips either positive or negative half wave of the input.
- Circuit transient protection
  - The excessive noise spikes above a certain level can be limited or clipped in communication transmitters by using the series clippers.
  - The typical application of diode clipper is for the protection of transistor from transients
  - Clippers can be used as voltage limiters and amplitude selectors

Example problem

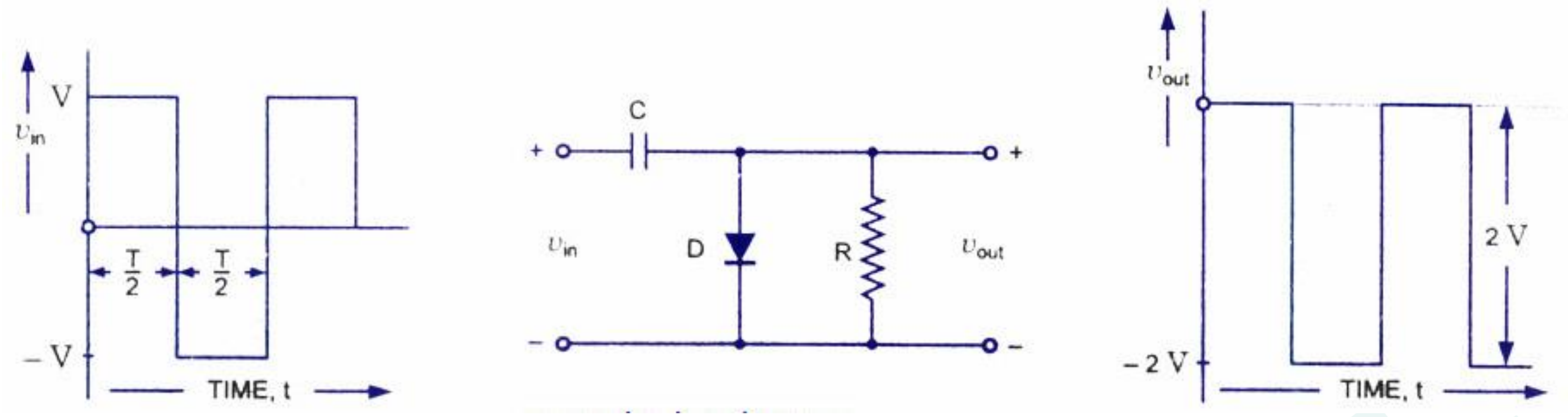
Assuming the diodes to be ideal, describe the transfer characteristic of the circuit shown in Fig.



Clamper circuit

- A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal. In other words, the clamper circuit moves the whole signal up or down to set either the positive peak or negative peak of the signal at the desired level.
- The dc component is simply added to the input signal or subtracted from the input signal. A clamper circuit can add the positive dc component to the input signal to push it to the positive side. Similarly, a clamper circuit can add the negative dc component to the input signal to push it to the negative side.
- The output waveform will have a finite average value or dc component. This dc component is entirely unrelated to the average value of the input waveform.

Clamper circuit



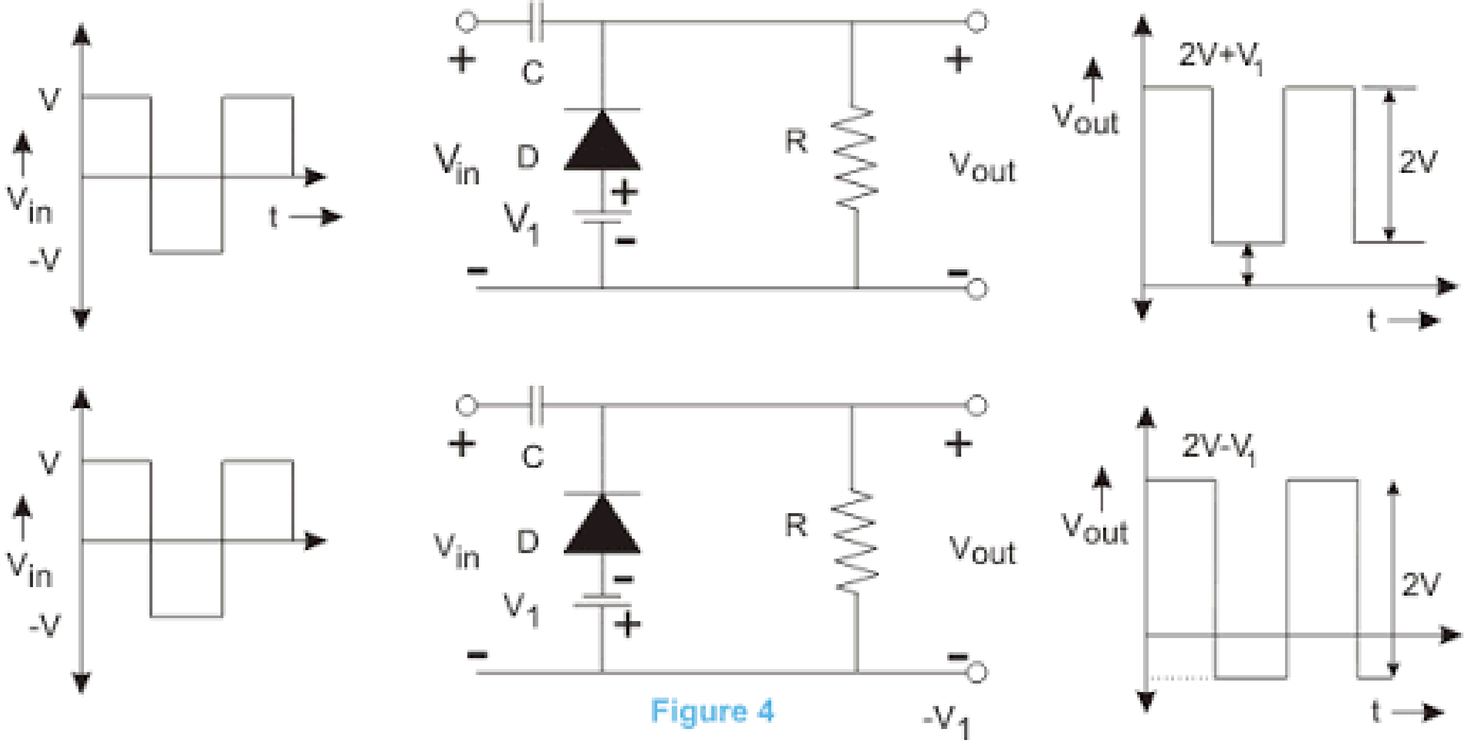
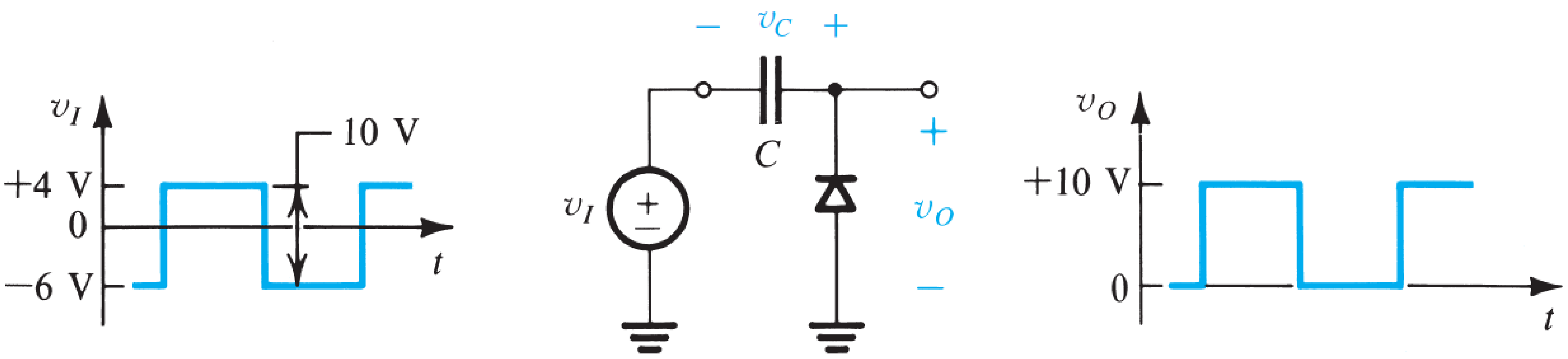
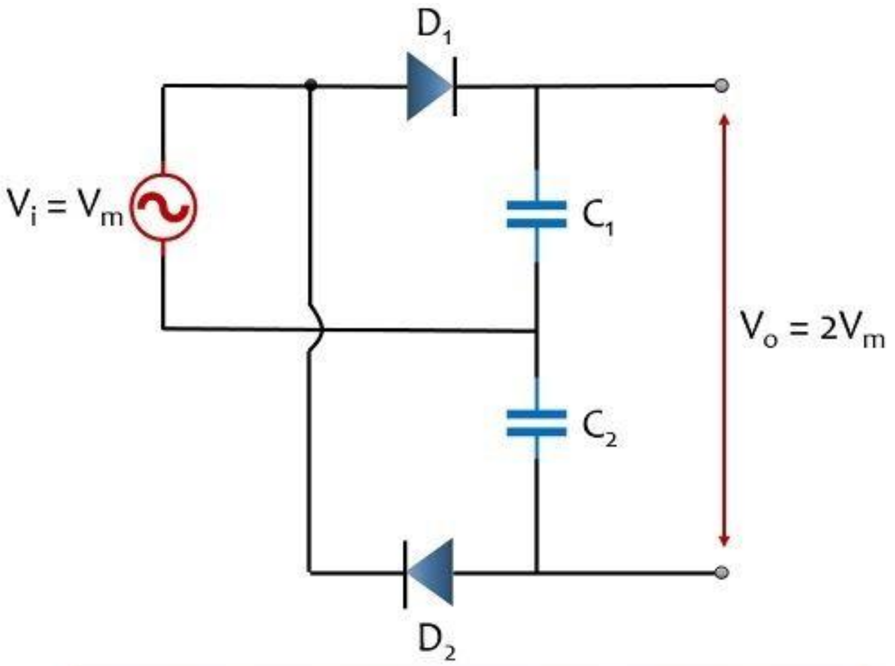


Figure 4

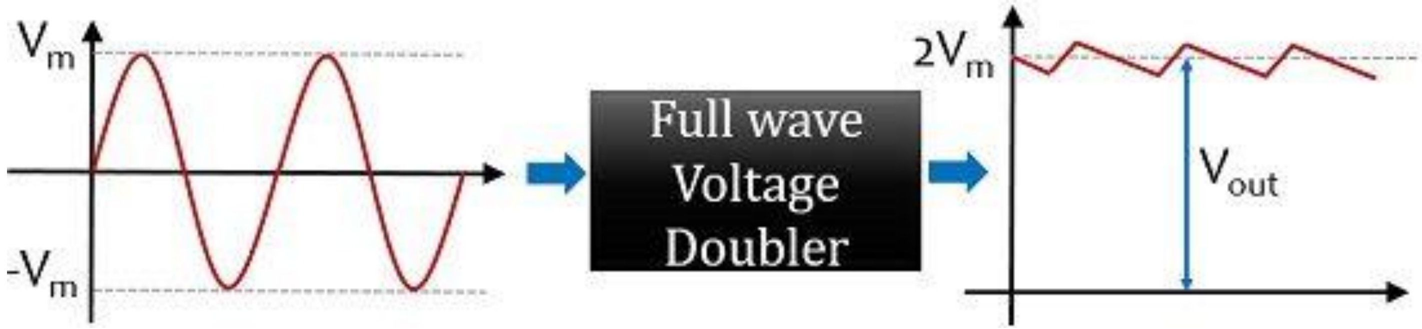
Clamper circuit



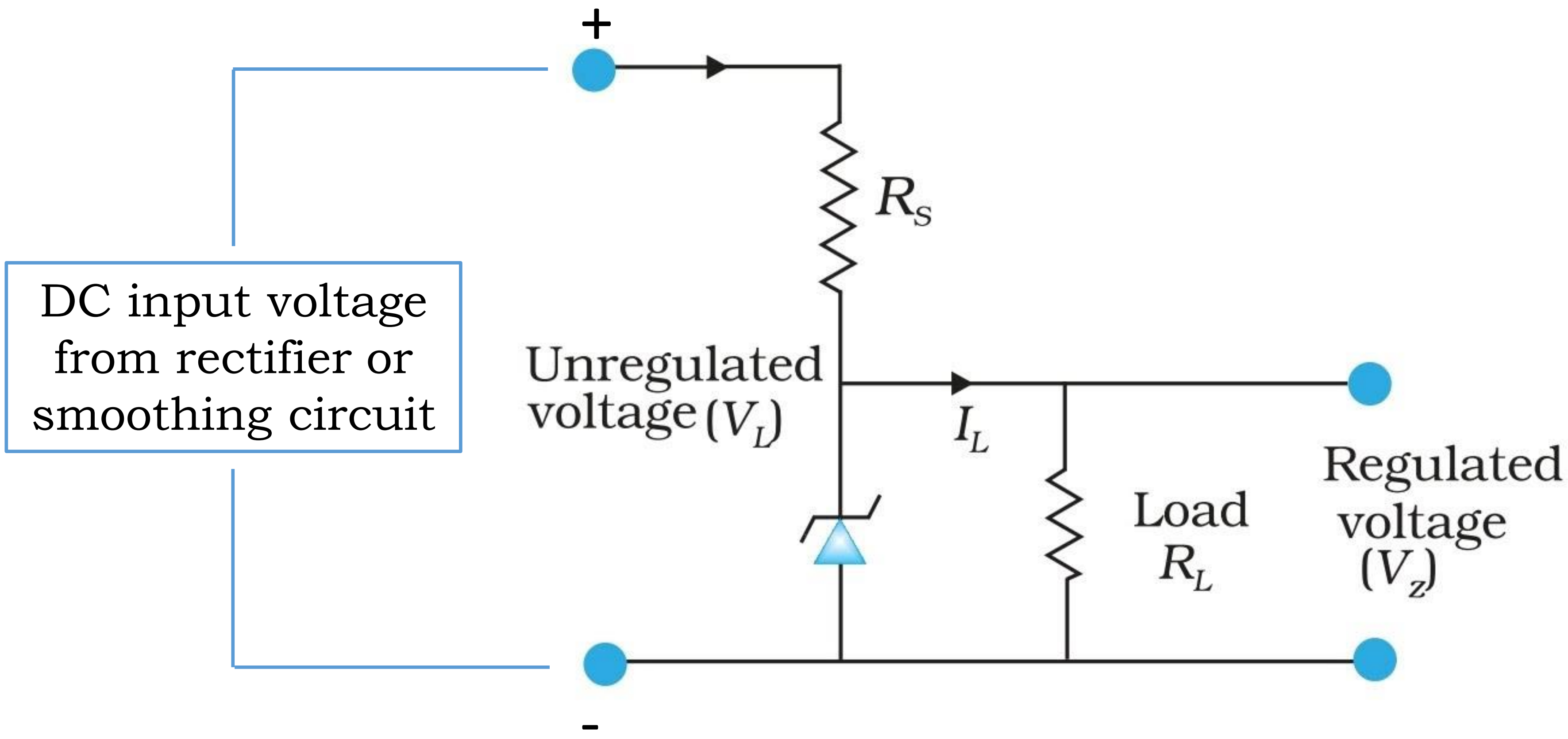
Voltage doubler



Circuit of full wave voltage doubler



Voltage regulator using Zener diode



A reliable voltage source