Electronic

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1st semester

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Chapter Two
Diode and its Application

Lecture 2

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Diode

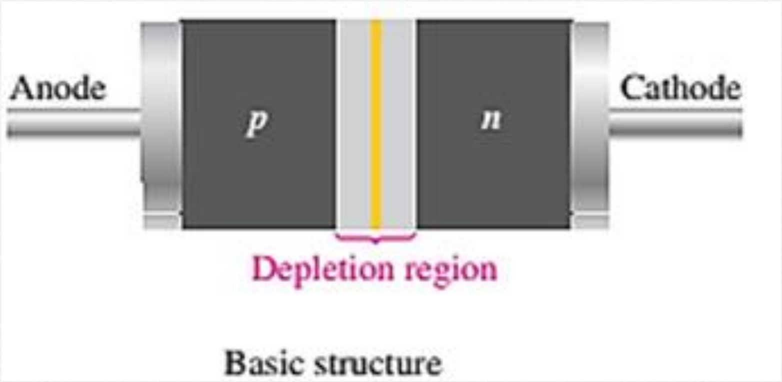
Diode is a **semiconductor** device, **made** from a small piece of semiconductor material, such as **silicon**.

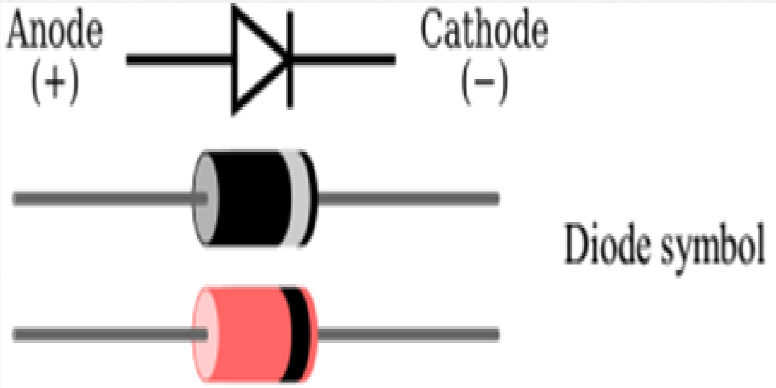
It is consist of **two part** that divided in equal, the **first half** is doped as a p region and **second half** is doped as an n region.

Theses two part with the depletion region in between produced the **pn** junction.

The **p region** is called the **anode** and **n region** is called the **cathode**.

It conducts current in one direction and offers high resistance in other direction. The basic diode structure and symbol are shown in Fig.1.





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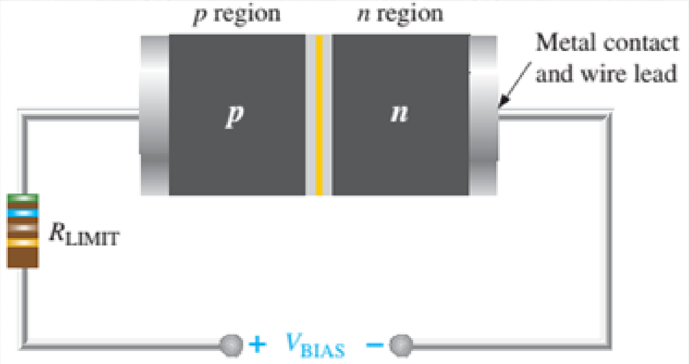
Forward Bias

Bias is the application of a **dc voltage to a diode** to make it either **conduct current or not**.

Forward bias is the condition that allows current through the pn junction. This external bias voltage is designated as VBIAS.

The **resistor limits** the forward current to a value that will not damage the diode.

In the **forward bias**, the negative side of VBIAS is connected to the n region of the diode and the positive side is connected to the p region. The **bias voltage** VBIAS, must be greater than the **barrier potential**; bias must be greater than **0.3V for germanium** or **0.7V for silicon** diodes.



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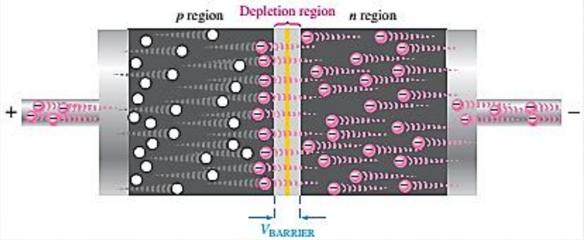
- **Negative side** of bias voltage '**pushes**' free electrons towards pn junction.
- The **negative side of the source** also **provides** a **continuous flow of electrons** through the external connection (conductor) and into the n region as shown in Figure 3.
- The bias-voltage source **imparts** sufficient energy to the **free electrons** for them to overcome the barrier potential of the depletion region and move on through into the p region.



- Since unlike charges attract, the positive side of the bias-voltage source **attracts** the valence electrons toward the left end of the p region.
- The holes in the p region provide the medium for these valence electrons to move through the p region. The holes, (majority in p region), move to the right toward the junction.
- As the electrons flow out of the p region through the external connection (conductor), these electrons become **conduction electrons** in the **metal conductor**.
- As more electrons move into the depletion region, the number of **positive ions is reduced**.
- As more holes flow into the depletion region on the other side of the pn junction, the **number of negative ions is reduced**.
- This **reduction in positive and negative ions causes** the depletion region to narrow.

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Reverse Bias

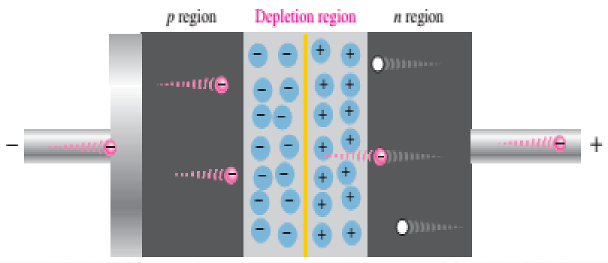
Reverse bias is the condition that essentially **prevents current** through the diode. Figure 4 shows a dc voltage source connected across a diode in the direction to produce reverse bias.

The positive side of VBIAS is connected to the n region of the diode and the **negative side** is connected to the **p region**.

Also, **note** that the depletion region is shown much wider than in **forward bias or equilibrium.**

The **positive side** of the bias-voltage source **pulls** the free electrons, (**majority in n region**), **away** from the pn junction.

As electrons move away from junction, **more positive ions** are created. This **results** in a widening of the depletion region and a depletion of majority carriers.



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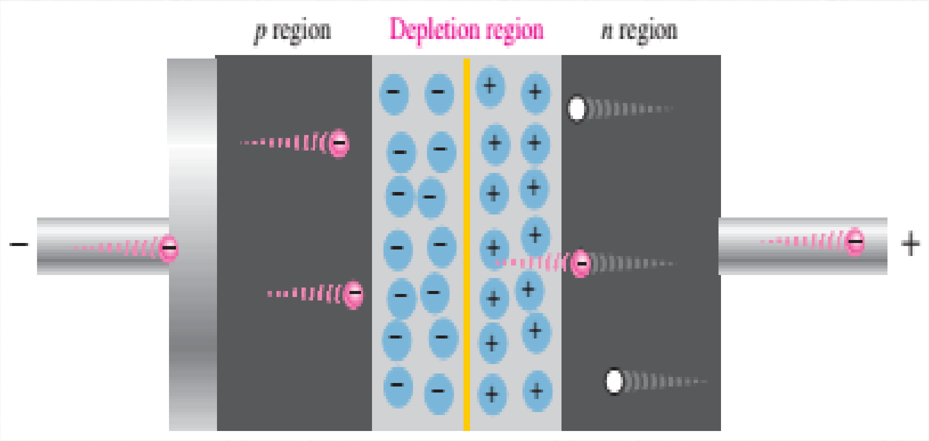
Reverse Bias

In p region, electrons from negative side of battery enter as **valence electrons**. It moves from **hole** to **hole** toward the **depletion region**, creating **more negative ions**.

This can be viewed as **holes being pulled towards** the **negative side**.

The **electric field** increases in strength until the potential **across** the depletion region equals the bias voltage.

At this point, very small **reverse current** exist that can usually be neglected.



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▪ Voltage-Current (V-I) Characteristic of A Diode

▪ V-I Characteristic for Forward Bias

The **current in forward biased** called **forward current** and is **designated** I_f.

At 0V (Vbias) across the diode, there is **no forward current**. Figure 5 illustrates what happens as the forward-bias voltage is increased positively from 0 V.

The **resistor is used** to limit the forward current to a value that will **not overheat the diode and cause damage**.

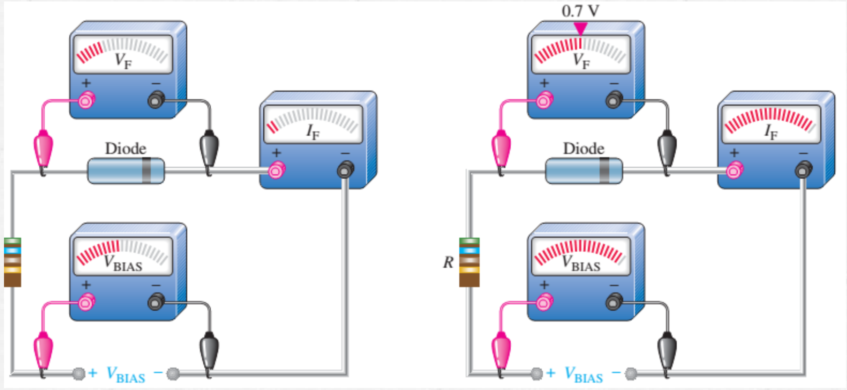
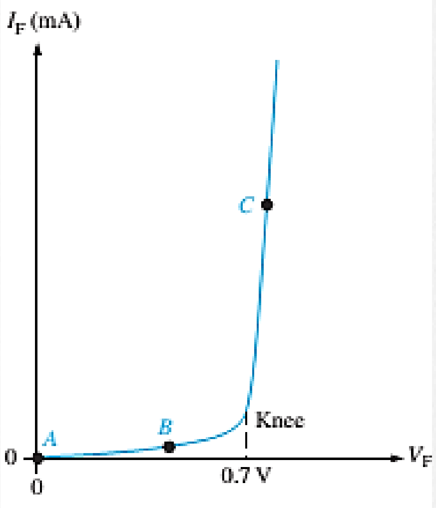


Figure 5: Relationship of voltage and current in a forward-biased diode.



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With **gradual increase of Vbias**, the forward voltage and forward current **increases**.

A portion of **forward-bias voltage (Vf) drops** across the limiting resistor.

Continuing **increase of Vf** causes **rapid increase of forward current**

but the **voltage** across the diode increases only **gradually above 0.7V.**

The **resistance of the forward-biased** diode is not constant **but** it changes over the entire curve.

Therefore, it is **called dynamic resistance.**

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V-I 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 breakdown of diode. The voltage called **breakdown voltage**.

This is not normal mode of operation.

After this point the **reverse voltage remains at approximately VBR** but **IR increase very rapidly**.

Break down voltage depends on **doping level**, set by manufacturer.

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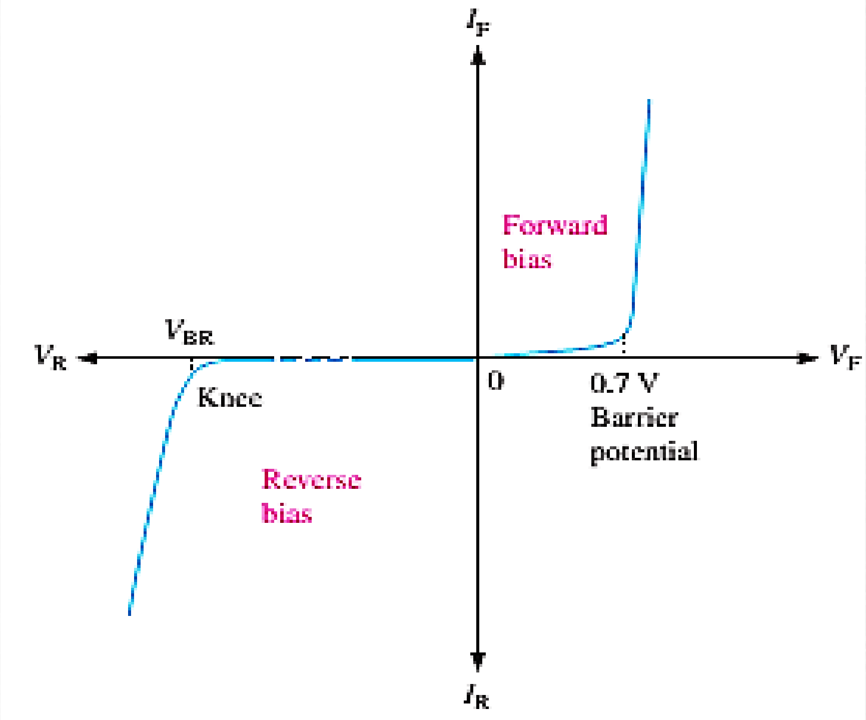
Combine the curves for both forward bias and reverse bias, and you have the **complete V-I characteristic** curve for a diode, as shown in Figure 6.



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Diode models

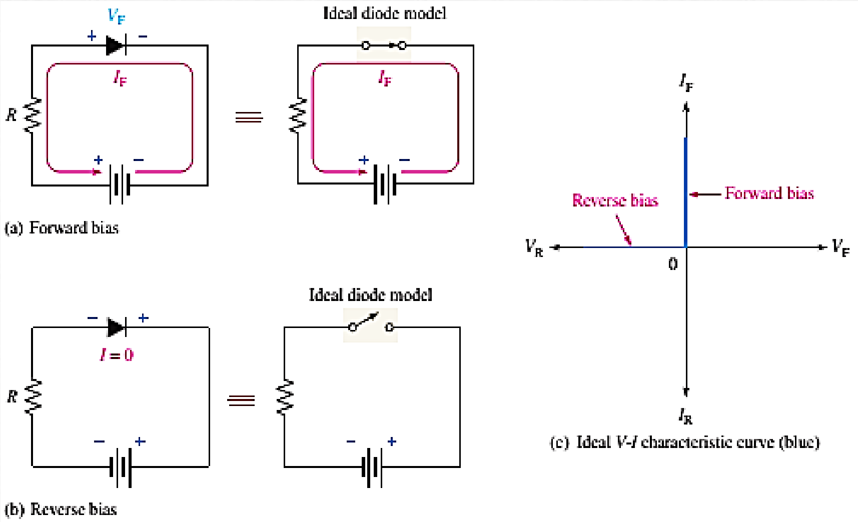
The Ideal Diode Mode

1- When the diode is **forward-biased**, it ideally acts like a **closed (on) switch**, as shown in Figure 7.

2- When the diode is **reverse-biased**, it ideally acts like an **open (off) switch**, as shown in part (**b**).

The barrier potential, the forward dynamic resistance, and the reverse current are all neglected.

In Figure 7c, the ideal V-I characteristic curve graphically depicts the ideal diode operation.



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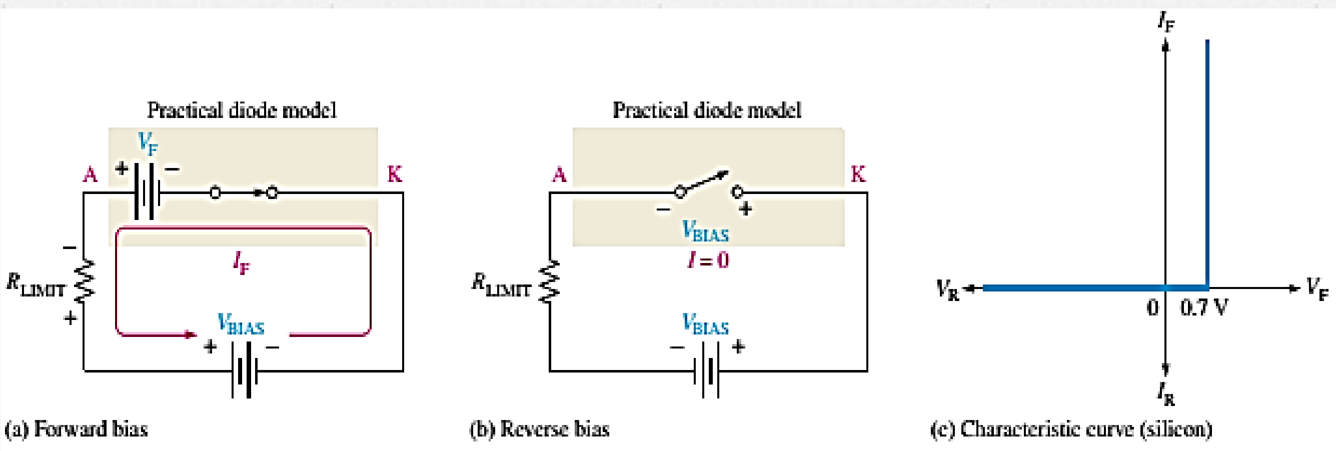
- **The Practical Diode Model**
- The **practical model** includes the **barrier potential**. The characteristic curve for the practical diode model is shown in Figure 8c.
- Since the **barrier potential** is included and **the dynamic resistance is neglected**, the diode is assumed to have a voltage across it when forward-biased, as indicated by the curve to the right of the origin.
- The **practical model** is useful in **lower-voltage circuits** and in **designing basic diode** circuits. The **forward current** is determined using **first Kirchhoff's voltage law** to Figure 8a:



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$$V_{BIAS} - V_F - V_{R_{LIMIT}} = 0$$

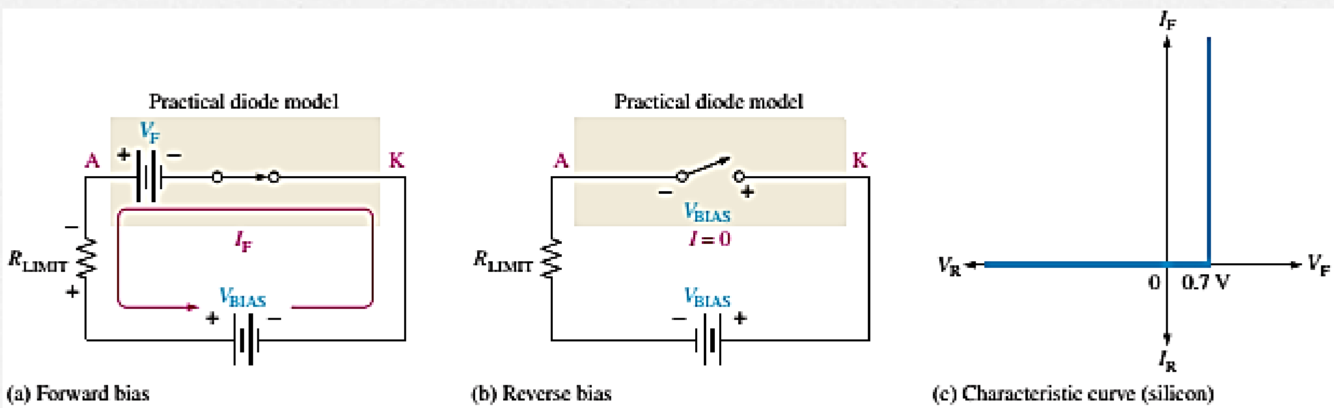
$$V_{R_{LIMIT}} = I_F R_{LIMIT}$$

Substituting and solving for I_F

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$

The diode is assumed to have zero reverse current,

$V_F = 0.7V$, $V_R = V_{BIAS}$, $I_R = 0A$



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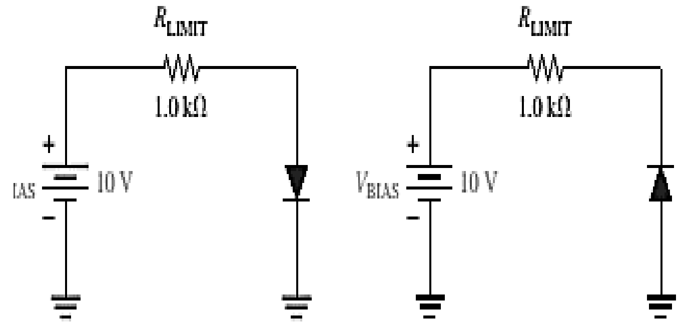
Example 1: (a) Determine the forward voltage and forward current for the diode in Figure 10(a) for each of ideal and practical diode models. Also, find the voltage across the limiting resistor in each case.

(b) Determine the reverse voltage and reverse current for the diode in Figure 10(b) for each of the diode models. Also, find the voltage across the limiting resistor in each case. Assume IR = 1μA. (H.W.)



(b)

(a) Ideal model:

$$V_F = 0\text{ V}$$

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} = \frac{10\text{ V}}{1.0\text{ k}\Omega} = 10\text{ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (10\text{ mA})(1.0\text{ k}\Omega) = 10\text{ V}$$

Practical model:

$$V_F = 0.7\text{ V}$$

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}} = \frac{10\text{ V} - 0.7\text{ V}}{1.0\text{ k}\Omega} = \frac{9.3\text{ V}}{1.0\text{ k}\Omega} = 9.3\text{ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.3\text{ mA})(1.0\text{ k}\Omega) = 9.3\text{ V}$$

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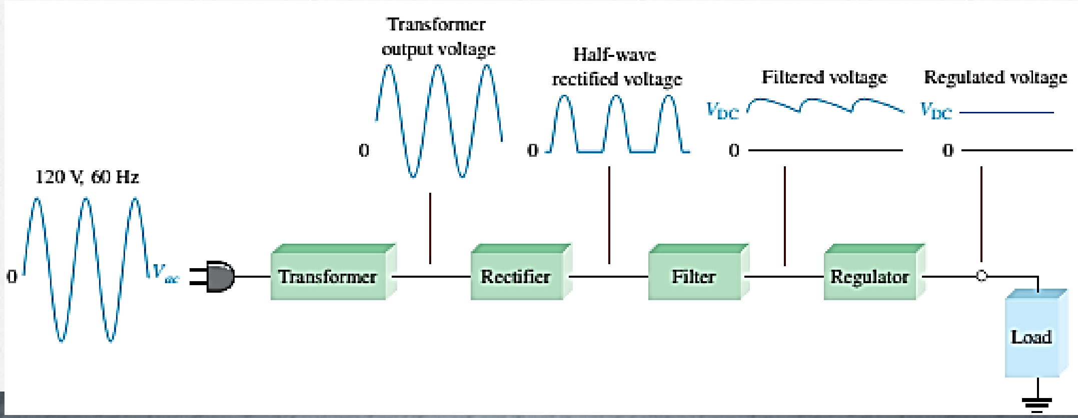
- **The DC power supply**
- A **power supply** is an essential part of each electronic system from the simplest to the most complex. A basic block diagram of the complete power supply is shown in Figure 11.
- The **transformer changes** ac voltages based on the **turns ratio** between the **primary** and **secondary**.
- The **rectifier converts** the ac input voltage to dc voltage.
- The **filter eliminates** the fluctuations in the rectified voltage and produces a **relatively smooth dc voltage.**
- The **regulator** is a circuit that maintains a constant dc voltage for variations in the input line voltage or in the load.



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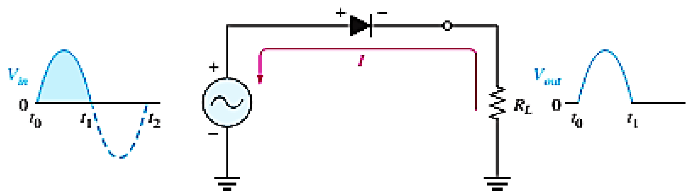
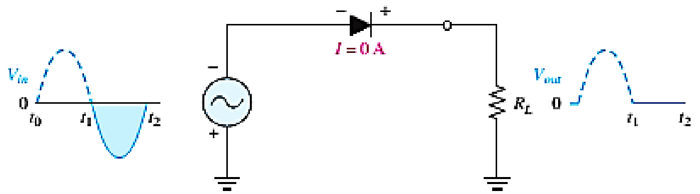
- **Half-Wave Rectifiers**
- Because of their **ability** to conduct current in one direction and block current in the other direction, diodes are used in circuits called rectifiers that convert **AC** voltage into **DC** voltage.
- **Rectifiers** are found in all **dc power** supplies that operate from an ac voltage source.
- When connected with ac voltage, **diode** only allows half cycle passing through it and hence convert ac into dc.
- As the half of the wave get rectified, the process called half-wave rectification. The output frequency is the same as the input.



(a) During the positive alternation of the 60 Hz input voltage, the output voltage looks like the positive half of the input voltage. The current path is through ground back to the source.



(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.

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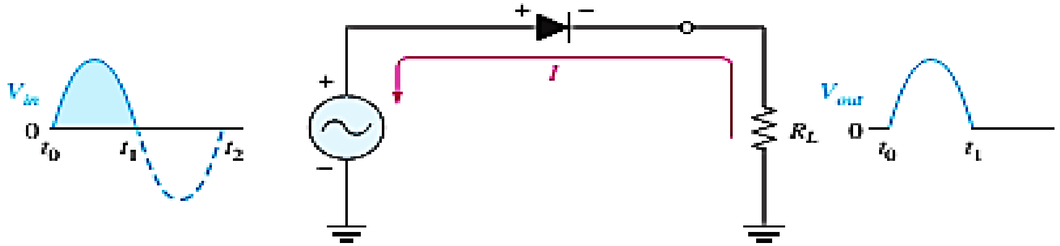
- The **average value** (VAVG) of **half-wave rectified voltage if** its peak amplitude is 50 V is

VAVG = VP/π = 50/3.14 = 15.9V , VAVG is approximately 31.8% of Vp

PIV= Vp(in)



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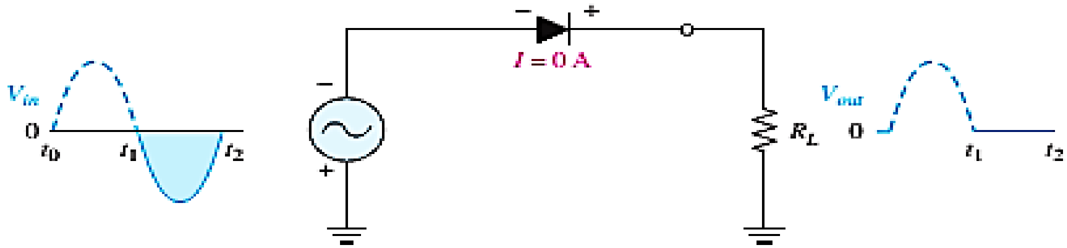

(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.

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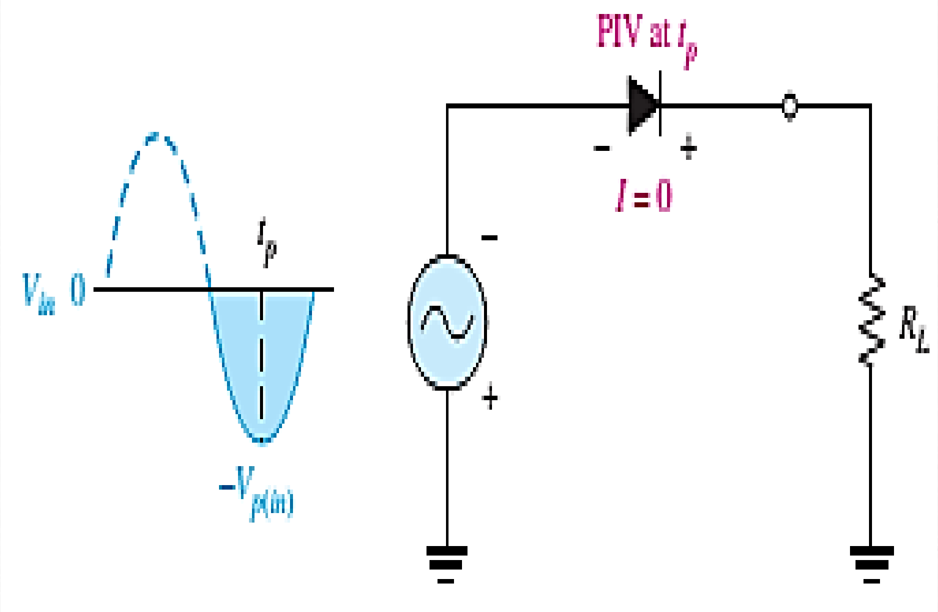
- **PIV**: Peak inverse voltage = is the maximum voltage occurs at the peak of each half-cycle of the input voltage when the diode is reverse-biased.

- The diode must be **capable of withstanding** this amount voltage.

Figure 13



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Full wave rectifiers

Although half-wave rectifiers have some applications, the full-wave rectifier is the most commonly used type in **dc power supplies**.

A full-wave rectifier **allows** unidirectional (one-way) current through the load during the entire of the input cycle.

Whereas, a **half-wave rectifier** allows current through the load only during one-half of the cycle.

The output voltage have twice the input frequency.

VAVG = 2VP/π= VAVG is approximately 63.7 % of Vp

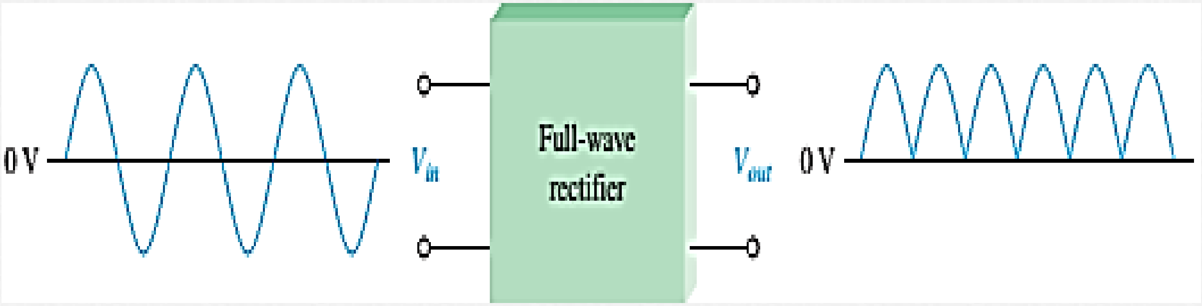

Figure 14

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Center-Tapped Full-Wave Rectifier Operation

A **center-tapped rectifier** is used two diodes that connected to the secondary of a center-tapped transformer, as shown in Figure 14.

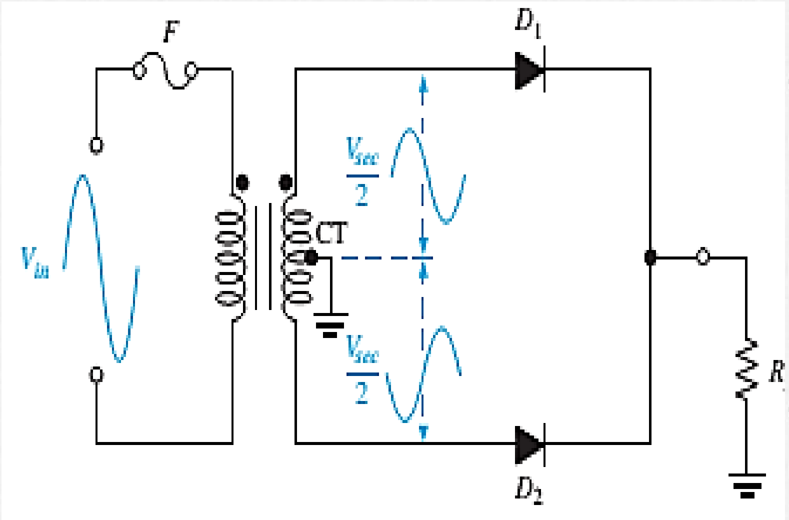
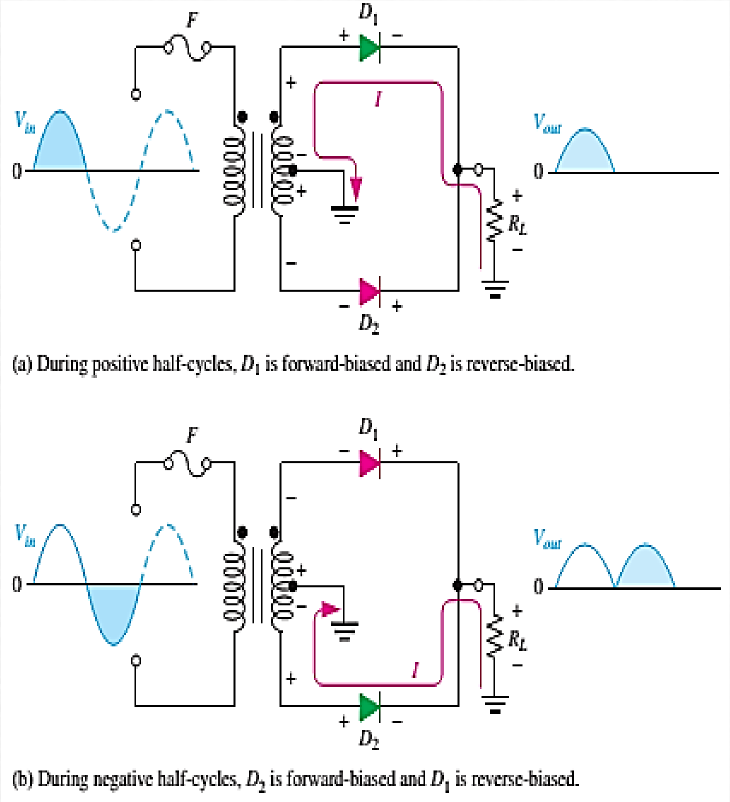


Figure 16: Basic operation of a center-tapped full-wave rectifier.



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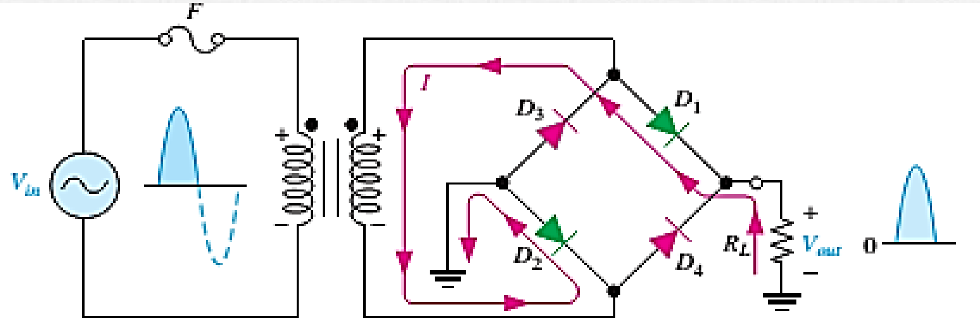
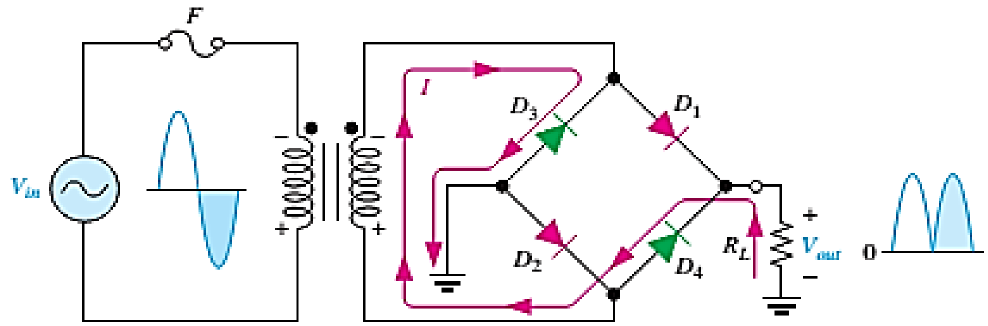
The Bridge Full-wave rectifiers

The Bridge Full-Wave rectifier uses **four diodes** connected across the entire secondary as shown in Figure 16



(a) During the 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 the 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.

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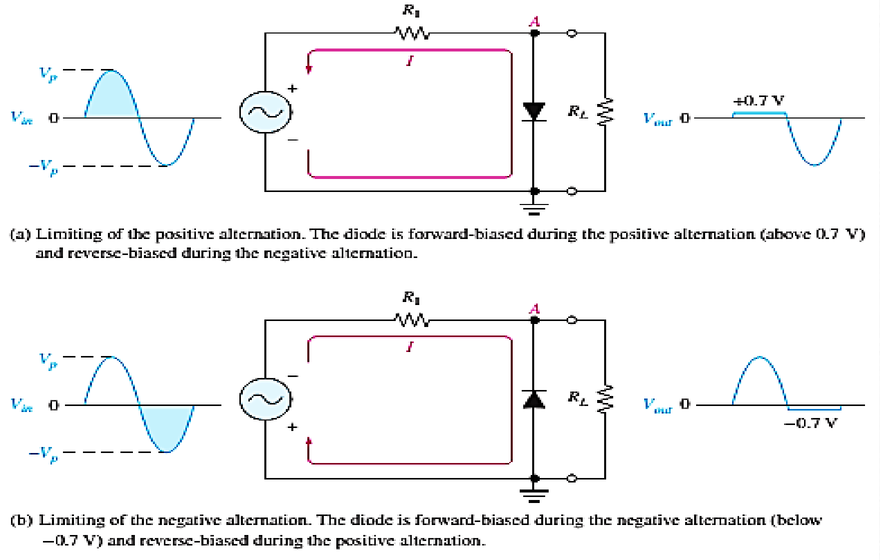
Diode Limiters

Diode circuits, called **limiters or clippers**, are used to **clip off portions of signal voltages above** or **below certain levels**.

Point A is limited to +0.7V when the input voltage exceeds this value (Figure 18(a)).

If the diode is **turned around**, as in Figure 18(b), the negative part of the input voltage is clipped off. When the diode is forward-biased during the negative part of the input voltage, **point A** is held at -0.7V by the diode drop.

Figure 18: Examples of diode limiters (clippers).



(a) Limiting of the positive alternation. The diode is forward-biased during the positive alternation (above 0.7 V) and reverse-biased during the negative alternation.

(b) Limiting of the negative alternation. The diode is forward-biased during the negative alternation (below −0.7 V) and reverse-biased during the positive alternation.

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The **desired amount of limitation** can be attained by **a power supply or voltage divider.**

The **amount clipped** can be adjusted with different levels of VBIAS.

The peak output voltage across **RL** is **determine** by the following equation:

$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right) V_{in}$$

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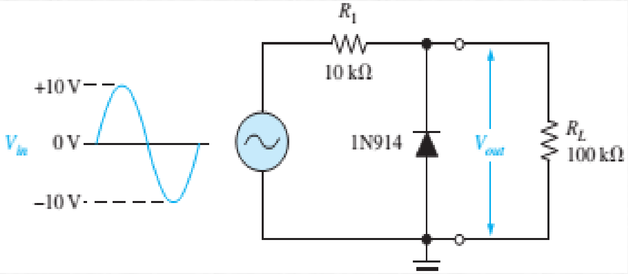
Example 2: What would you expect to see displayed on an oscilloscope connected across RL in the limiter shown in following Figure.

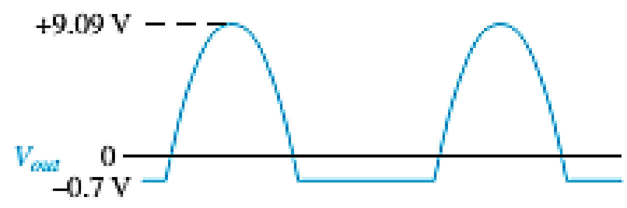


Solution: The diode is forward-biased and conducts when the input voltage goes below -0.7V. So, for the negative limiter, determine the peak output voltage across RL by:

$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right) V_{in} = \left(\frac{100\text{k}\Omega}{110\text{k}\Omega}\right) 10\text{V} = 9.09\text{V}$$

V_out=(R_L/(R_1+R_L)) V_in=(100kΩ/110kΩ)10V=9.09V

The scope will display an output waveform as shown in following Figure



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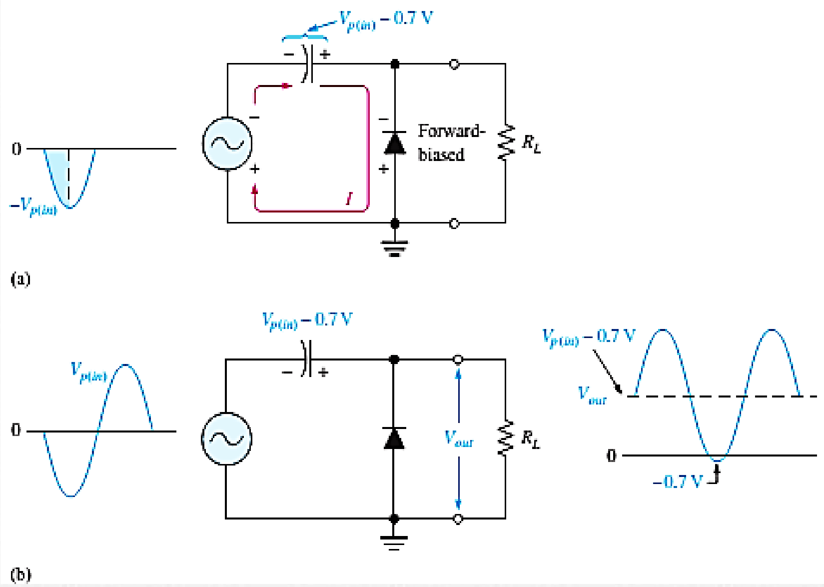
Diode Clampers

Another type of diode circuit, called **a clamper**, is used to **add or restore a dc level to an electrical signal**.

The **capacitor charges to the peak of the supply minus the diode drop**. **Once charged the capacitor acts like a battery** in series with the input voltage.

The **AC voltage** will "ride" along with the DC voltage. The polarity arrangement of the diode determines whether the DC voltage is negative or positive.



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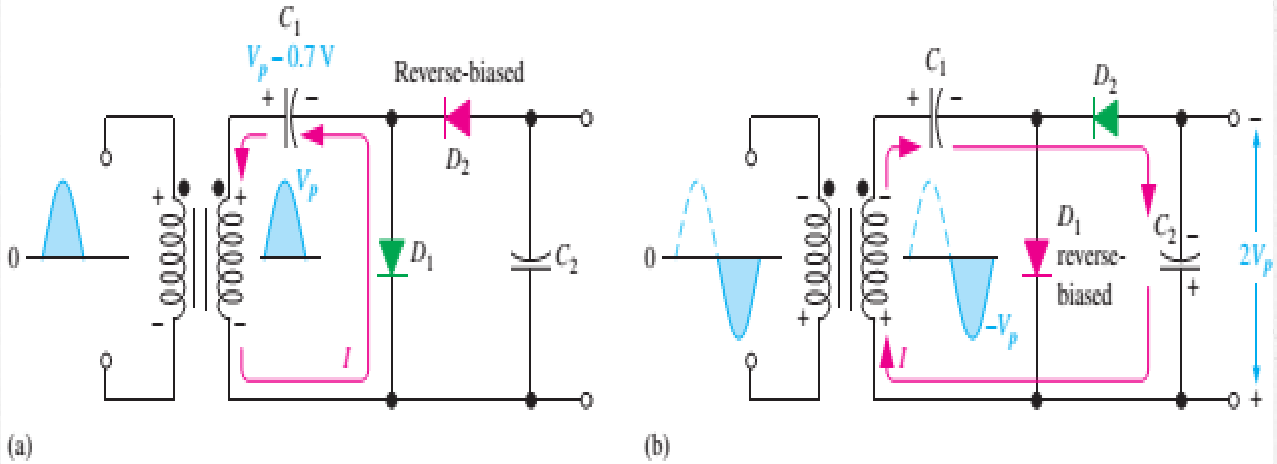
Voltage Multiplier

Voltage multipliers use **clamping action** to increase peak rectified voltages **without the necessity of increasing the transformer's voltage rating**.

Multiplication factors of two, three, and four are common. Voltage multipliers are **used** in high-voltage, low-current applications such as cathode-ray tubes (CRTs) and particle accelerators.

In the Figure 20 a **half-wave voltage doubler**, a voltage doubler is a voltage multiplier with a multiplication factor of two.

Once C1 and C2 charges to the peak voltage they **act like two batteries** in series, effectively doubling the voltage output. The current capacity for voltage multipliers is low.



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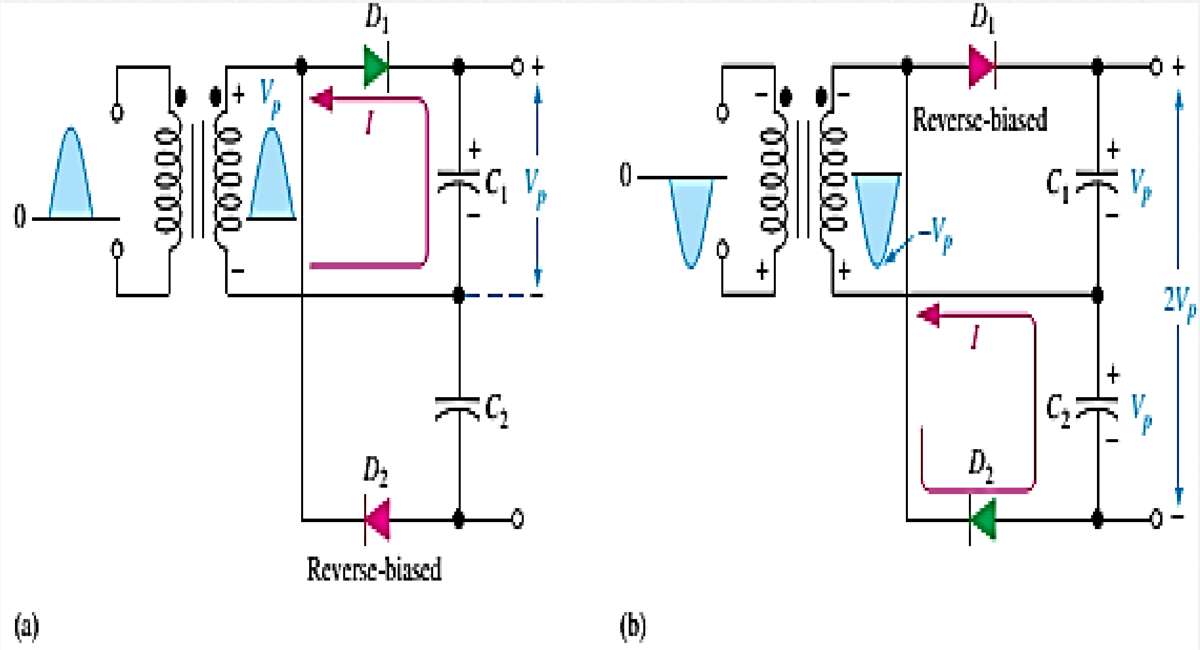
The full-wave voltage doubler arrangement of diodes and capacitors takes advantage of both positive and negative peaks to charge the capacitors giving it more current capacity.

Voltage triplers and quadruplers utilize three and four diode-capacitor arrangements, respectively.



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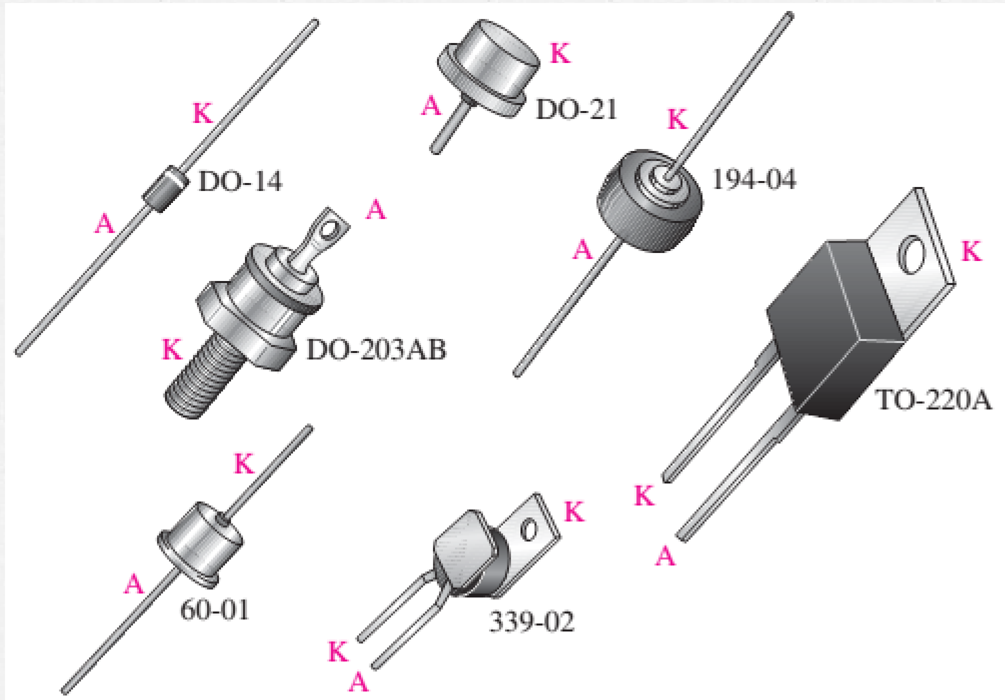

Typical diode packages with terminal identification. The letter K is used for cathode to avoid confusion with certain electrical quantities that are represented by C. Case type numbers are indicated for each diode.

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