Maio de 2025

6872 Foundations of Electronics

Lecture 5: Semiconductor Diode

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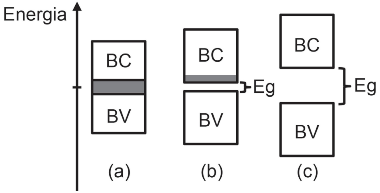
Abstract

- Introduction to Semiconductor Physics
- Rectifier Diode
- Clipping and Limiting Circuits
- Clamping Circuits
- Zener Diode
- Light-Emitting Diode (LED)
- Photo-Diode
- Other Special Diodes

Semiconductor Materials



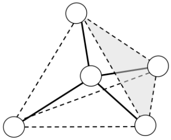
- Conductor (of electricity)
  - Easy flow of electric charges (low resistivity)
  - Valence Band (BV) and Conduction Band (BC) overlap
  - Examples: copper, silver, and gold
- Insulators (of electricity)
  - Difficult flow of electric charges (high resistivity)
  - Bandgap Energy (Eg) is large
  - Examples: bromine and sulphur
- Semiconductors
  - Show characteristics between conductors and insulators

Resistivity ρ at 20^oC		
Conductor	**Semiconductor**	**Insulators**
1.7×10^{-8} Ωm (copper)	4.6×10^{-1} Ωm (germanium)	10^{10} Ωm (bromine)
1.6×10^{-8} Ωm (silver)	6.4×10^{2} Ωm (silicon)	10^{15} Ωm (sulphur)

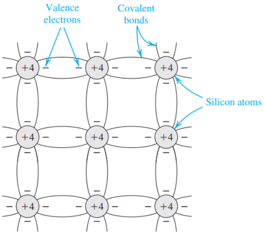
Semiconductor Materials: Ge and Si

$V_D = 0{,}7V$
$V_{BE} = 0{,}7V$

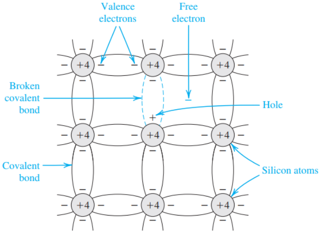
- Germanium (atomic number 32) and Silicon (atomic number 14)
  - Valence band with 4 electrons
  - Organized in regular, three-dimensional crystalline structure
    - Each atom bonds to its 4 neighbors
    - Pairs of atoms share 2 electrons in a covalent bond
    - At temperature 0 K (absolute zero), all covalent bonds are intact and there are no free electrons to conduct electricity
    - At room temperature, there is enough energy to break some covalent bonds, generating **free electrons**



Three-dimensional



Simplified



Room Temperature

Semiconductor Materials: Intrinsic (Pure) Silicon

- For every free electron generated, it is also produced a **hole**, which behaves like a positive electric charge
- How many free electrons n_I (or free holes p_I) are generated per cm^3 of silicon?

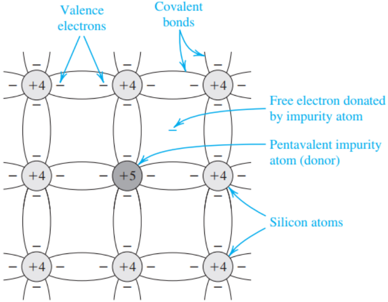
$$n_I = p_I = BT^{3/2} \exp\left(-\frac{E_g}{2kT}\right)$$

T is the temperature, B is a material-dependent parameter (7.3×10^{15} cm^{-3}K$^{-3/2}$ for silicon), E_g is the bandgap energy (1.12 eV for silicon), and $k = 8.62 \times 10^{-5}$ eV/K is the Boltzmann's constant

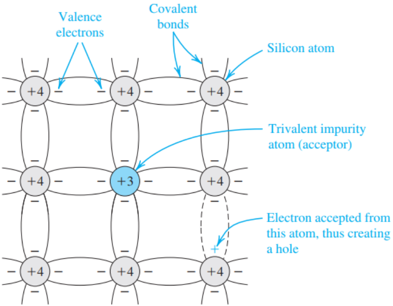
- For $T = 288.15$ K $= 15\ ^oC$, $n_I = 5.8 \times 10^9$
  For $T = 323.15$ K $= 50\ ^oC$, $n_I = 7.9 \times 10^{10}$
  For $T = 348.15$ K $= 75\ ^oC$, $n_I = 3.7 \times 10^{11}$
- Note that:
  - almost $64\times$ increase in n_I if T goes from 15 ^{o}C to 75 ^{o}C
  - conductivity strongly depends on temperature (not a desirable property)
  - silicon has 5×10^{22} atoms/cm^3; thus at 15 ^{o}C only one in about 10^{13} atoms is ionized

Semiconductor Materials: Doped Silicon

- **Doping** introduces impurity atoms into the silicon crystal with little or no change in the crystal properties
  - It allows substantial change in the concentration of either free electrons or holes in a precisely controlled manner
  - To increase the concentration of free electrons, silicon is doped with an element with a valence of 5, such as phosphorus, producing **N-type silicon**
  - To increase the concentration of holes, silicon is doped with an element having a valence of 3, such as boron, producing **P-type silicon**



n type



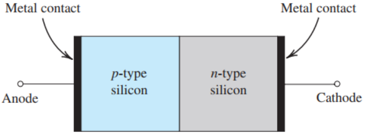
p type

Semiconductor Materials

- N-Type Silicon
  - Impurity atoms are called donors since they donate free electrons
  - If the concentration of donor atoms n_D is such that $n_D \gg n_I$, the concentration of free electrons is determined by doping concentration and not by temperature
  - However, holes are generated by thermal ionization, and their number strongly depends on temperature
  - Therefore, for N-type silicon: electrons are **majority** charge carriers, and holes are **minority** charge carriers
- P-Type Silicon
  - Impurity atoms are called acceptors since they accept free electrons
  - If the concentration of acceptor atoms n_A is such that $n_A \gg n_I$, the concentration of holes is determined by doping concentration and not by temperature
  - However, electrons are generated by thermal ionization, and their number strongly depends on temperature
  - Therefore, for P-type silicon: holes are **majority** charge carriers, and electrons are **minority** charge carriers

PN Junction: Operation with Open-Circuit Terminals

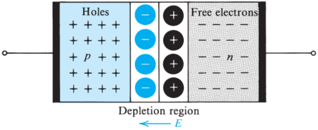
- **Diffusion Current**
  - Concentration of holes is high in the P region and low in the N region
  - Holes diffuse across the junction from the P side to the N side
  - Similarly, electrons diffuse across the junction from the N side to the P side
  - These two components add together to form the diffusion current, whose direction is from the P side to the N side

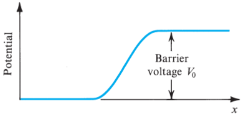


- **Depletion Region**
  - Holes that diffuse across the junction into the N region quickly recombine with electrons present there
  - Recombination takes place close to the junction
  - This creates a region close to the junction that shows a net positive charge
  - Similarly, electrons that diffuse across the junction into the P region quickly recombine with holes present there
  - Recombination takes place close to the junction
  - This creates a region close to the junction that shows a net negative charge

PN Junction: Operation with Open-Circuit Terminals

- **Depletion Region** (cont.)
  - Charges on both sides of the depletion region cause an electric field E to be established across the region
  - Result is a potential difference across the depletion region, with the N side at a positive voltage relative to the P side
  - Electric field opposes the diffusion of holes into the N region and electrons into the P region
  - Voltage drop (V_0) across the depletion region acts as a barrier for holes to diffuse into the N region and electrons to diffuse into the P region
  - The larger the barrier voltage, the smaller the number of carriers crossing the junction





$$V_0 = V_T \ln\left(\frac{n_A n_D}{n_I^2}\right)$$

V_T is known as thermal voltage

($V_T = kT/q \approx 25.9$ mV at 300 K),

and q is the magnitude of electron charge ($q = 1.6 \times 10^{-19}$ C).

For silicon and room temperature: $0.6\text{ V} \leq V_0 \leq 0.9\text{ V}$.

PN Junction: Operation with Open-Circuit Terminals

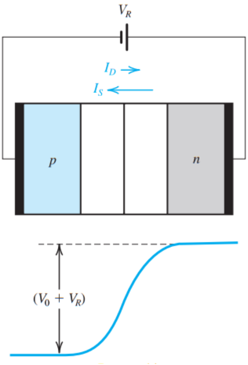
- **Drift Current**
  - Component due to minority-carrier drift across the junction
  - Some of the thermally generated holes in the N material move toward the junction and get swept by the electric field across the region into the P side
  - Similarly, some of the minority thermally generated electrons in the P material get swept into the N side
  - These two components add together to form the drift current, whose direction is from the N side to the P side of the junction

- **Equilibrium**
  - Under open-circuit conditions no external current exists
  - Therefore the two opposite currents across the junction (diffusion and drift) must have same magnitude
  - Voltage V_0 does not appear between the junction terminals because of the contact voltages existing at the metal-semiconductor junctions

PN Junction: Operation with an Applied Voltage

- **Reverse-bias:** DC voltage applied to make the N side more positive than the P side

- - Applied reverse-bias voltage V_R adds to the barrier voltage increasing the effective barrier voltage to $V_0 + V_R$
  - Number of holes that diffuse into the N region and electrons that diffuse into the P region is reduced to zero
  - The only current across the junction and through the external circuit is the drift current
  - Drift current is produced by thermally generated minority carriers and it is expected to be very small and strongly dependent on temperature

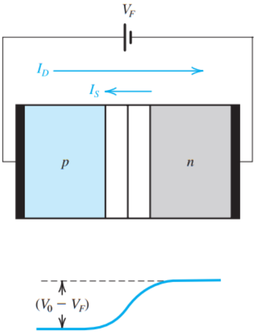


- **Conclusion:** in the reverse direction, the PN junction conducts a very small and almost-constant current

PN Junction: Operation with an Applied Voltage

- **Forward-bias:** DC voltage applied to make the P side more positive than the N side

-
  - Applied voltage V_F is subtracts from the barrier voltage reducing the effective barrier voltage to $V_0 - V_F$
  - This reduces the depletion-region width and enables more holes to diffuse from P to N and more electrons to diffuse from N to P
  - The diffusion current increases substantially and can become many orders of magnitude larger than the drift current



- **Conclusion:** in the forward direction, the PN junction can conduct substantial current, mostly diffusion current, whose value is determined by V_F

PN Junction: Operation with an Applied Voltage

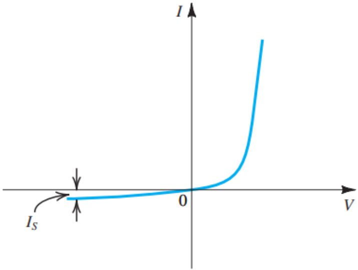
- Given the applied voltage V
- The total current I across the PN junction is

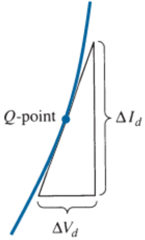
$$I = I_S \left(e^{V/V_T} - 1\right)$$

I_S is the drift current and V_T is the thermal voltage

Typical values for I_S range from 10^{-12} A to 10^{-18} A

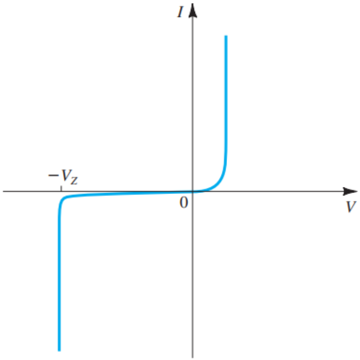
- If $V < 0$ (reverse-bias), $e^{V/V_T} \to 0$ and $I \to -I_S$
- If $V > 0$ (forward-bias), I is an exponential-like function of V
- Resistance: $r_d = \frac{dV_D}{dI_D} \approx \frac{V_T}{I_D} \approx \frac{26\ \text{mV}}{I_D}$





PN Junction: Junction Breakdown

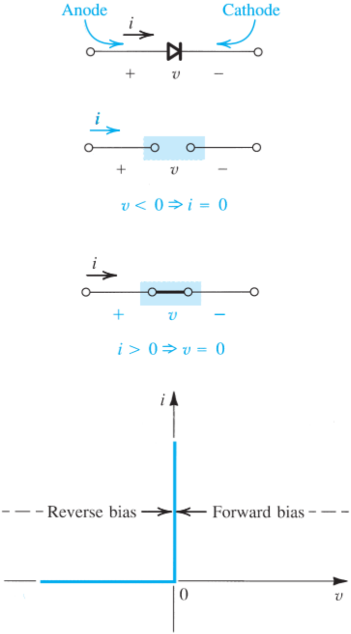
- **Zener Breakdown:** occurs when the electric field in the depletion region increases to the point of breaking covalent bonds and generating electron-hole pairs
- **Avalanche Breakdown:** occurs when minority carriers that cross the depletion region under the influence of the electric field gain sufficient kinetic energy to be able to break covalent bonds in atoms with which they collide



- **Breakdown Region:** V reaches V_Z, reverse current increases dramatically and reverse voltage remains almost constant
- It is not a destructive phenomenon as long as the power dissipated in the junction is acceptable

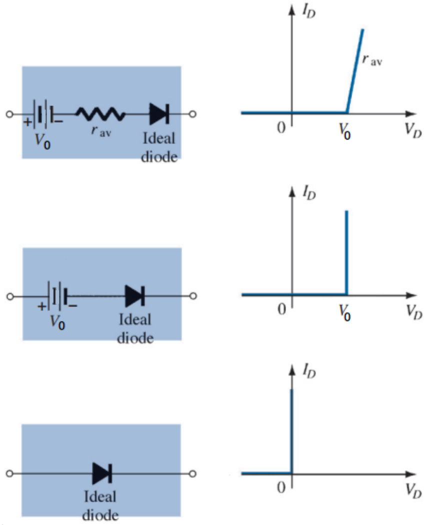
Ideal Rectifier Diode

- Two-terminal device having two states: <u>cut off</u> or <u>off</u>, and <u>turned on</u> or <u>on</u>
- **Cut off state**
  - If negative voltage is applied, no current flows through the diode
  - Diode behaves as an open circuit
  - Diode is said to be reverse biased
- **Turned on state**
  - If positive voltage is applied, zero voltage drop appears across the diode
  - Diode behaves as a short circuit
  - Diode is said to be forward biased

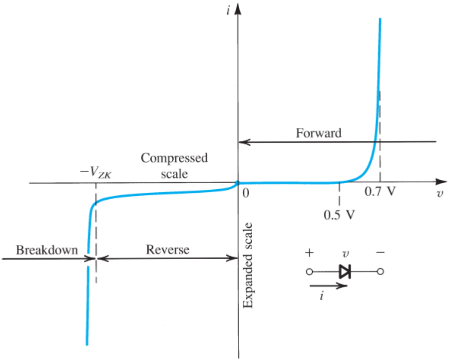


Rectifier Diode

- Approximation Models

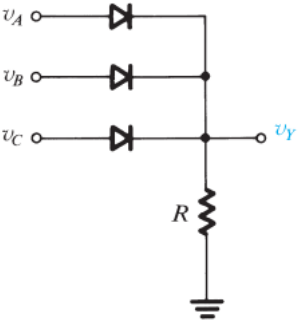


- Actual: i-v relationship (silicon)

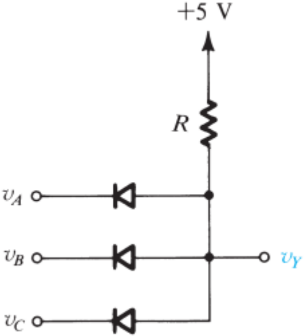


Circuit Example: Simple Diode Logic Gates

- OR gate: $Y = A + B + C$

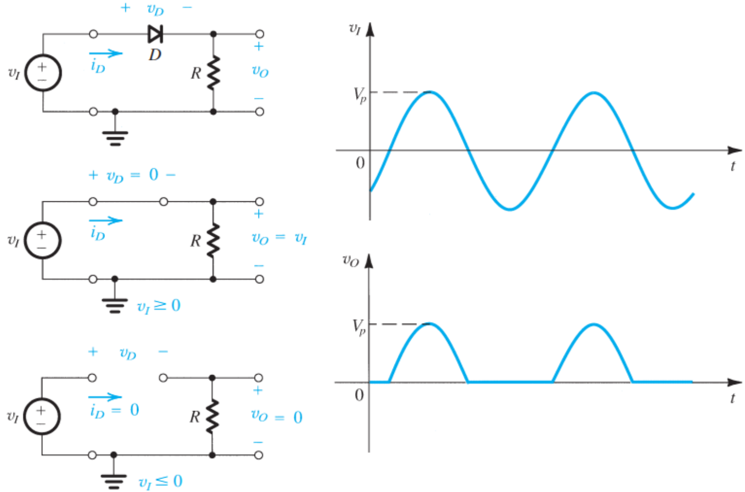


- AND gate: $Y = A \cdot B \cdot C$



Circuit Example: Half-Wave Rectifier Circuit

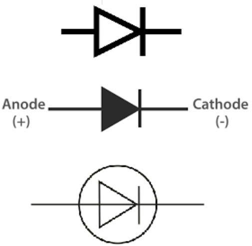
- Output RMS value for ideal diode: $\hat{v}_I/2$
- Output average (DC) value for ideal diode: $\hat{v}_I/\pi$



Commercial Rectifier Diode

Aula do dia 22/05
↳ Até circuito retificador de meia onda

- Used in power supplies and optimized for use at 50-60 Hz (power-line frequencies)
  - Power supplies convert alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction
- They have power ratings greater than 0.5 W
- Symbols & photos



Power diode

Regular

Diode bridge

High power diodes

Limits of Operation

- Maximum forward current (depends on the ambient temperature)
  - Continuous forward current
  - Peak repetitive forward current
- Maximum reverse-voltage rating: peak inverse voltage, peak reverse voltage or breakdown voltage
- Maximum total power dissipation (depends on the ambient temperature)
- Maximum junction operation temperature
- Other information:
  - Forward voltage (at a specified current and temperature)
  - Reverse current (at a specified voltage and temperature)
  - Capacitance
  - Reverse recovery time
  - Operating temperature

Analysis of Circuits with Diodes

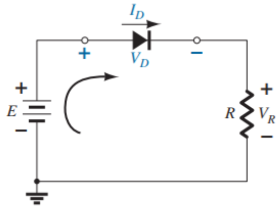
26/05/25

- Calculate current and voltage values that satisfy both the characteristics of the diode and the chosen circuit at the same time:
  - Analytical: use **diode approximation models** given earlier
  - Graphical: use **load-line analysis**

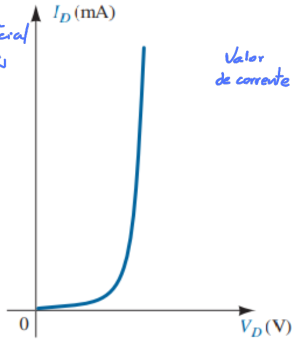
Ponto quiescente → ponto de operação do diodo.

- **Quiescent point** (abbreviated **Q-point**): the operating point (i.e., current and voltage values) of the device (in this case, the diode)
- Calculate V_D and I_D in the circuit below, with the given diode characteristics

Diodo polarizado diretamente



curva exponencial



Valor de corrente ∈ função

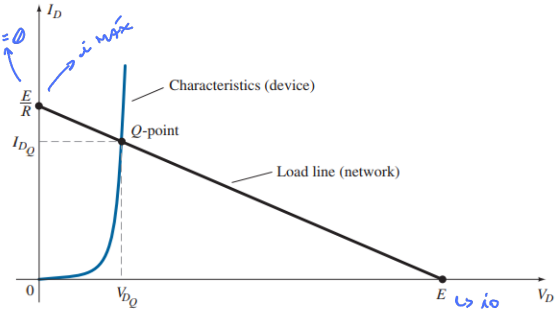
Load-line Analysis

RETA DE CARGA

$i = 0$
$V = E$

$i_{MAX} = \frac{E}{R}$

Valores possíveis no circuito

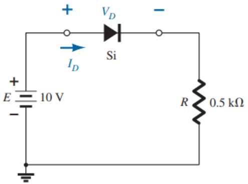


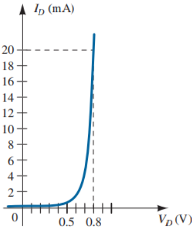
- The figure above shows both diode characteristics and circuit load-line
- Load-line determined by Kirchhoff's voltage law

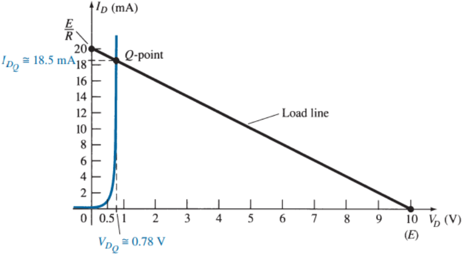
$$E = V_D + I_D R \text{ with } I_D = \left.\frac{E}{R}\right|_{V_D=0} \text{ and } V_D = E|_{I_D=0}$$

- Intersection of the load-line on the characteristics is the Q-point

Load-line Analysis Example







- Load-line (given by Kirchhoff's voltage law): $E = V_D + I_D R$

for $V_D = 0 \rightarrow I_D = \dfrac{E}{R} = \dfrac{10}{0.5\text{k}} = 20$ mA

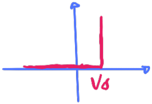
for $I_D = 0 \rightarrow V_D = E = 10$ V

from the graph $I_{D_Q} \approx 18.5$ mA, $V_{D_Q} \approx 0.78$ V

Q-point $\equiv (0.78$ V, 18.5 mA$)$

Load-line Analysis Example

Diodo com V_δ



$V_D = V_\delta = 0{,}7V$

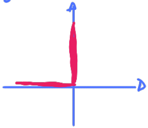
$I = \frac{E - V_\delta}{R} = \frac{10-0{,}7}{500} = 18{,}6mA$

- Analytical results:

Diodo ideal

$V_D = 0$

$i = \frac{10}{500} = 20mA$



- - Using ideal diode

$V_D = 0$ V

$$I_D = \frac{E - V_D}{R} = 20 \text{ mA}$$

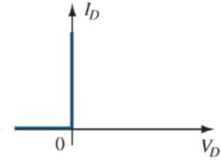
Q-point $\equiv (0 \text{ V}, 20 \text{ mA})$

- - Using ideal diode and $V_0 = 0.7$ V

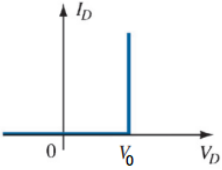
$V_D = 0.7$ V

$$I_D = \frac{E - V_D}{R} = 18.6 \text{ mA}$$

Q-point $\equiv (0.7 \text{ V}, 18.6 \text{ mA})$



Ideal Diode Characteristics



Ideal Diode and V_0 Characteristics

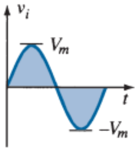
Clipping and Limiting Circuits

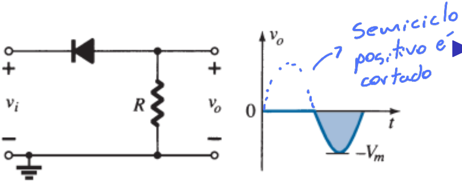
- Except for power supplies, circuits inside electronics equipment run at frequencies much higher than the power-line frequency
- For such applications, small-signal diodes are used
- They are optimized for use at high frequencies and have power ratings less than 0.5 W (current rating in mA)

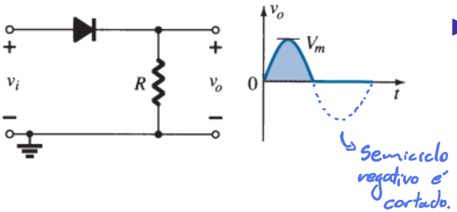
- **Clipper Circuit:** removes (clips) either positive or negative parts of a waveform
  - Useful for signal shaping, circuit protection, and communications
- **Limiter Circuit:** limits the output voltage of a waveform
  - Useful to eliminate amplitude noise and voltage spikes

Circuit Example: Series Clippers

- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$
- Equivalent to a half-wave rectifier



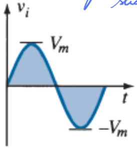




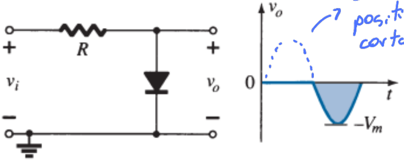
- Upper circuit: $v_o = v_R = v_i + v_D$
  - If $v_i > 0$: diode is reverse-biased ($i_D = 0$) and $v_o = 0$
  - If $v_i < 0$: diode is forward-biased ($v_D = 0$) and $v_o = v_i$
- Lower circuit: $v_o = v_R = v_i - v_D$
  - If $v_i > 0$: diode is forward-biased ($v_D = 0$) and $v_o = v_i$
  - If $v_i < 0$: diode is reverse-biased ($i_D = 0$) and $v_o = 0$

Circuit Example: Parallel Clippers

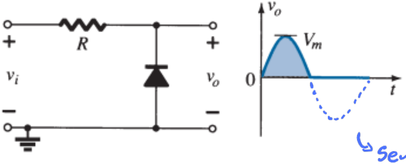
Na aula, o professor inverteu os polos positivo e negativo da fonte de alimentação. Aqui nos slides, é o diodo que é invertido.



- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$



Semiciclo positivo é cortado

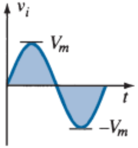


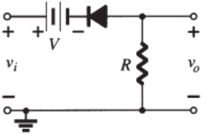
Semiciclo negativo é cortado.

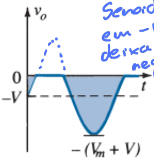
- Upper circuit: $v_o = v_D$
  - If $v_i > 0$: diode is forward-biased ($v_D = 0$) and $v_o = 0$
  - If $v_i < 0$: diode is reverse-biased ($i_D = 0$) and $v_o = v_i$
- Lower circuit: $v_o = -v_D$
  - If $v_i > 0$: diode is reverse-biased ($i_D = 0$) and $v_o = v_i$
  - If $v_i < 0$: diode is forward-biased ($v_D = 0$) and $v_o = 0$

Circuit Example: Biased Series Clippers (1)

- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$



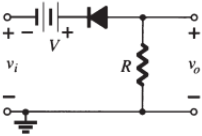


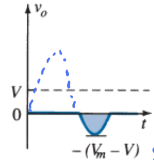


Senoide deslocada em −V e o diodo deixa só a tensão negativa

measures tension on the resistor

- Upper circuit: $v_o = v_R = v_i + v_D - V$
  - If $v_i > V$: diode is reverse-biased, $v_o = 0$
  - If $v_i < V$: diode is forward-biased, $v_o = v_i - V$





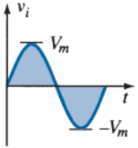
- Lower circuit: $v_o = v_R = v_i + v_D + V$
  - If $v_i > -V$: diode is reverse-biased, $v_o = 0$
  - If $v_i < -V$: diode is forward-biased, $v_o = v_i + V$

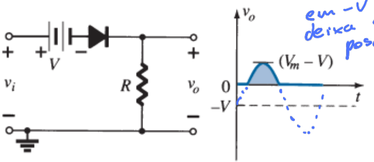
Based on Kirchhoff laws, when we analyse sources, if the "cycle" enters the source's negative side, the tension measured in it is negative.

Senoide deslocada em V e o diodo deixa só a tensão negativa

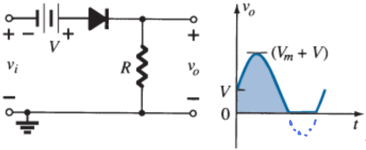
Circuit Example: Biased Series Clippers (2)

- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$





Senoide deslocada em −V e o diodo deixa só a tensão positiva

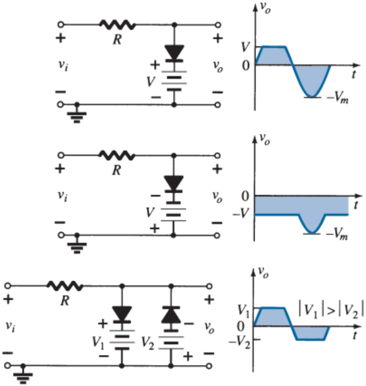


Senoide deslocada em V e o diodo deixa só a tensão positiva

- Upper circuit: $v_o = v_R = v_i - v_D - V$
  - If $v_i > V$: diode is forward-biased, $v_o = v_i - V$
  - If $v_i < V$: diode is reverse-biased, $v_o = 0$
- Lower circuit: $v_o = v_R = v_i - v_D + V$
  - If $v_i > -V$: diode is forward-biased, $v_o = v_i + V$
  - If $v_i < -V$: diode is reverse-biased, $v_o = 0$

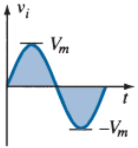
Circuit Example: Biased Parallel Clippers (1)

- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$



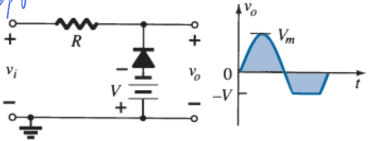
- Upper circuit: $v_o = v_D + V$
  - If $v_i > V$: diode is forward-biased, $v_o = V$
  - If $v_i < V$: diode is reverse-biased, $v_o = v_i$
- Middle circuit: $v_o = v_D - V$
  - If $v_i > -V$: diode is reverse-biased, $v_o = v_i$
  - If $v_i < -V$: diode is forward-biased, $v_o = -V$
- Lower circuit: $v_o = v_{D1} + V_1 = -v_{D2} - V_2$
  - If $v_i > V_1$: D_1 is forward-biased, D_2 is reverse-biased, $v_o = V_1$
  - If $V_1 > v_i > -V_2$: D_1 and D_2 are reverse-biased, $v_o = v_i$
  - If $v_i < -V_2$: D_1 is reverse-biased, D_2 is forward-biased, $v_o = -V_2$

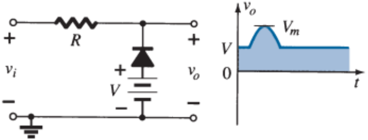
Circuit Example: Biased Parallel Clippers (2)



- Assuming ideal diodes and $v_i = V_M \sin(\omega t)$

Passado em aula pelo professor

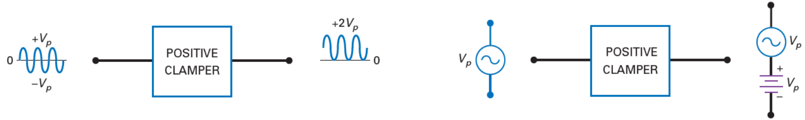




- Upper circuit: $v_o = -v_D - V$
  - If $v_i > -V$: diode is reverse-biased, $v_o = v_i$
  - If $v_i < -V$: diode is forward-biased, $v_o = -V$
- Lower circuit: $v_o = -v_D + V$
  - If $v_i > V$: diode is reverse-biased, $v_o = v_i$
  - If $v_i < V$: diode is forward-biased, $v_o = V$

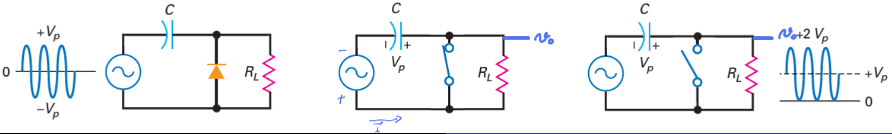
Clamping Circuits

- Adds a DC voltage to the signal, i.e., shifts the AC reference level (normally zero) up or down to a DC level

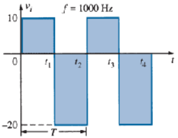


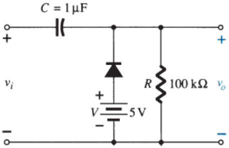
- Circuit Example
  - Capacitor is initially uncharged; on the first negative half-cycle, diode turns on and capacitor is charged with peak voltage V_p
  - Slightly beyond the negative peak, diode shuts off
  - If time constant $R_L C$ is much larger than period T of signal (e.g., $R_L C > 100T$), capacitor remains almost fully charged during off time of diode
  - Capacitor acts like a battery of V_p volts

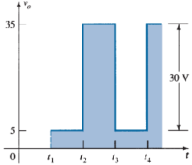
Desloca a tensão pra cima ou pra baixo dependendo da polaridade do capacitor

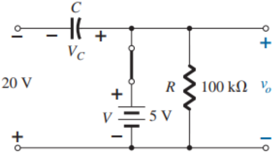


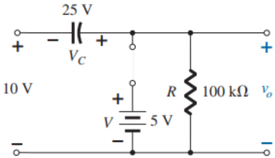
Circuit Example: Clamping Circuit







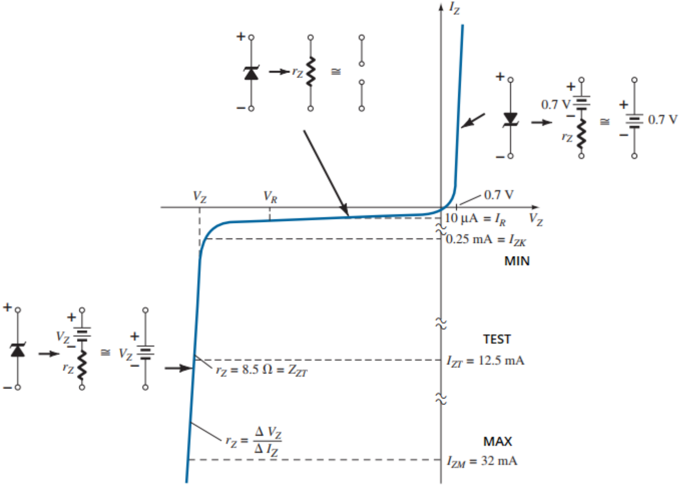




- Input signal frequency: $f = 1$ kHz, period $T = 1$ ms
- RC circuit time constant: $1\ \mu\text{F} \times 1\ \text{k}\Omega = 0.1$ s
- $t_1 < t < t_2$: diode is forward-biased
  - $V_C - v_i - V = 0 \rightarrow V_C = v_i + V = 25$ V
  - Capacitor charges up to 25 V
  - $v_o = V = 5$ V
- $t_2 < t < t_3$: diode is reverse-biased
  - $V_C + v_i - v_o = 0 \rightarrow v_o = v_i + V_C = 35$ V

Zener Diode → Quando eu quero uma tensão constante que não muda nunca.

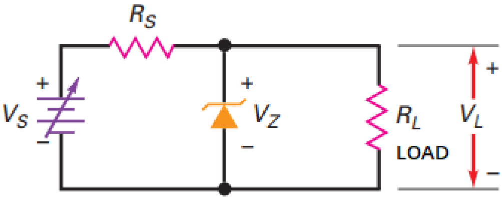
- Silicon diode optimized for operation in the breakdown (zener) region
- Used in voltage regulators, i.e., circuits that hold the load voltage almost constant despite changes in line (input) voltage and load resistance



Zener Diode

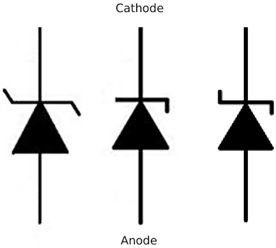
- Opera na região Zener (tensão constante)
- Opera com tensão contrária à fonte.

- Basic regulator circuit

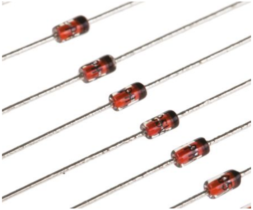


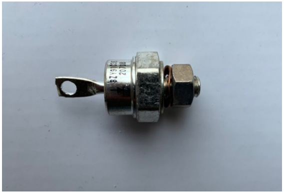
- Also used in clipping and limiting circuits
- Available in potentials of 1.8 V to 200 V, with power ratings from 1/4 W to 50 W

- Symbols



- Photos



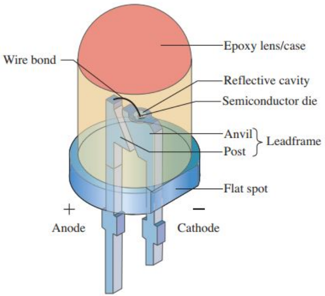


Light-Emitting Diode (LED)

Every diode has extra energy being liberated. LED have it in form of photons (colors).

- LEDs explore a situation in which minority carriers recombine with majority carriers and give rise to light emission
- The color of the light corresponds to the wavelength energy of the photons and is primarily determined by the energy band gap of the semiconductor materials used
- Can be designed to produce coherent light with a very narrow bandwidth (laser diode), used in optical communication systems and DVD players

Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1



Light-Emitting Diode (LED)

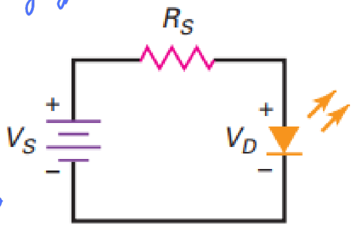
- The light emitted is proportional to the forward current in the diode
- Basic circuit

Color of LED
Batery Type

V_D

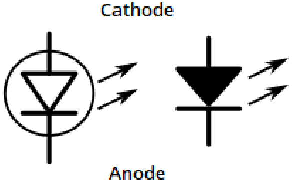
Amarelo - 2,1V
Vermelho - 1,8V
Laranja - 2,0V
Verde - 2,2V
Azul - 5V

$$R = \frac{V_E - V_D}{I}$$

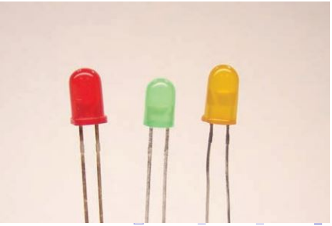


$i\uparrow$ maior o brilho da luz do LED

- Symbols

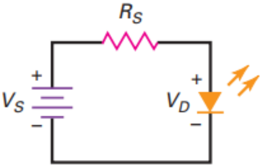


- Photos



Circuit Example: LED Circuit

- Typical voltage drop for most commercial low-power LED is from 1.5 to 2.5 V for currents between 10 and 50 mA
- Voltage drop depends on the LED current, color, tolerance, along with other factors



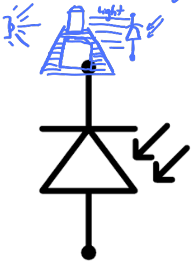
- Assume LED voltage drop $V_D = 2$ V, LED current $I_D = 15$ mA, and battery voltage $V_S = 5$ V
- Therefore

$$R_S = \frac{V_S - V_D}{I_D} = \frac{5-2}{15\text{m}} = 200\ \Omega$$

- Closest commercially available resistors are 180 Ω and 220 Ω
- For $R_S = 180\ \Omega$, $I_S = \frac{V_S - V_D}{R_S} = 16.7$ mA
- For $R_S = 220\ \Omega$, $I_S = \frac{V_S - V_D}{R_S} = 13.6$ mA

Photo-Diode

→ On the other hand of LEDs, this one is activated by light. } Useful for counting



- Photo-diode can be used to convert light into electrical signals
- If a reverse-biased PN junction is illuminated, photons cause covalent bonds to break, and generate electron-hole pairs
- A reverse current across the junction is produced, which is proportional to the intensity of the incident light
- **Opto-isolator:** combination of a photo-diode and an LED in the same package
  - LED converts an electrical signal applied to the opto-isolator into light, which the photo-diode detects and converts back to an electrical signal at the output of the opto-isolator
  - Opto-isolator provides complete electrical isolation between the input and output circuits
  - This isolation can be useful in reducing electrical interference on signal transmission within a system
  - It can also be used in medical instruments to reduce the risk of electrical shock to patients

Other Special Diodes

- **Schottky Diode:** formed by bringing metal into contact with a moderately doped N-type semiconductor material
  - Behaves like a diode, although without the PN junction
  - Can be switched from on to off, and vice versa, much faster than PN-junction diodes
  - Forward voltage drop of a conducting Schottky Diode is lower than that of a PN-junction diode (0.3 V to 0.5 V compared to 0.6 V to 0.8 V of silicon PN-junction diodes)

- **Varactor** or **Varicap Diode:** uses the reversed-biased PN junction as a capacitor Usado em circuitos de sintonia
  - Regions P and N are like plates of a capacitor, and the depletion layer is like the dielectric
  - If diode is reverse biased, the width of the depletion layer depends on the reverse voltage
  - The capacitance is inversely proportional to the reverse voltage
  - Mainly used in radio frequency (RF) circuits to provide voltage controlled variable capacitance

-> Igual ao capacitor variável, dá pra alterar o valor dele