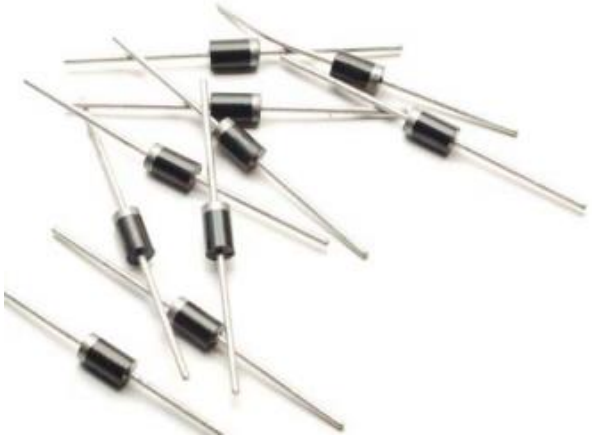
DÍODOS

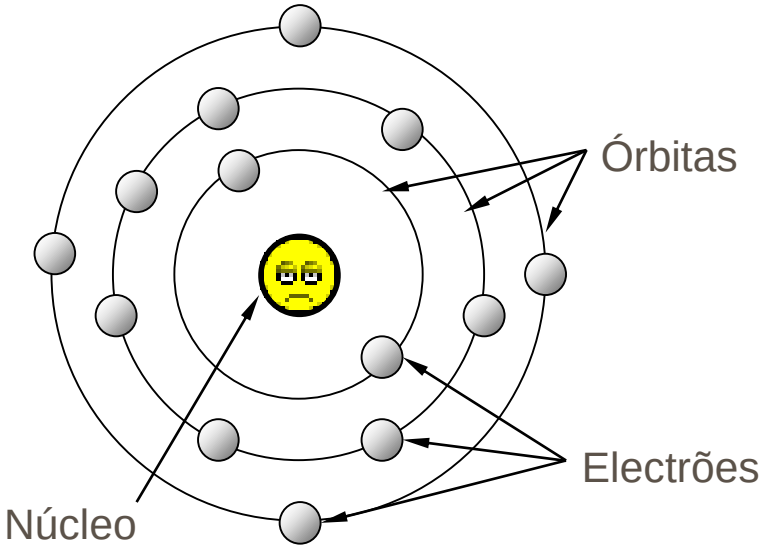


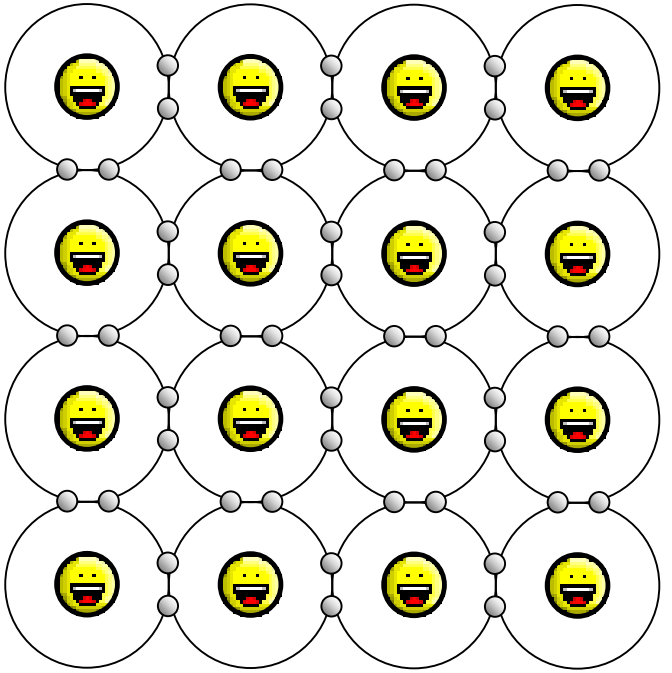
Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

- **Princípios de física dos semicondutores**
  - Funcionamento do díodo semicondutor – junção P-N

Átomo de silício





Cristal de silício (estrutura)

Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

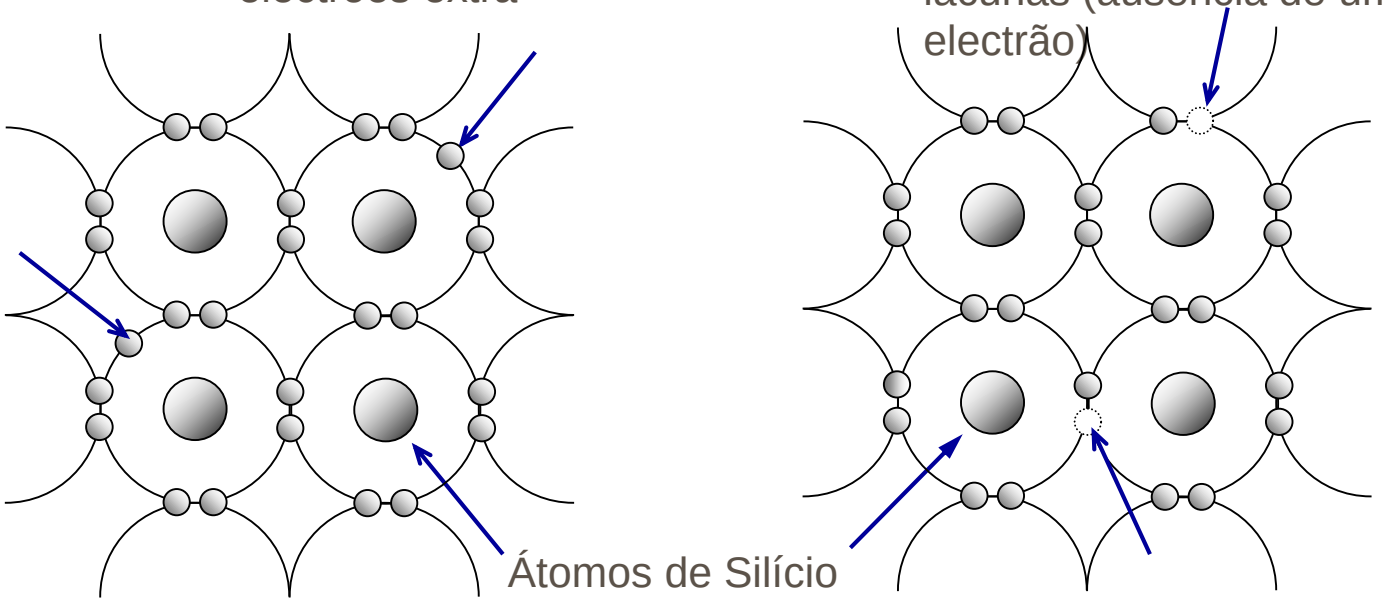
- **Princípios de Física dos Semicondutores**
  - Funcionamento do díodo semicondutor – junção P-N

Semicondutor tipo-N

Resultado da dopagem: electrões extra

Semicondutor tipo-P

Resultado da dopagem: lacunas (ausência de um electrão)



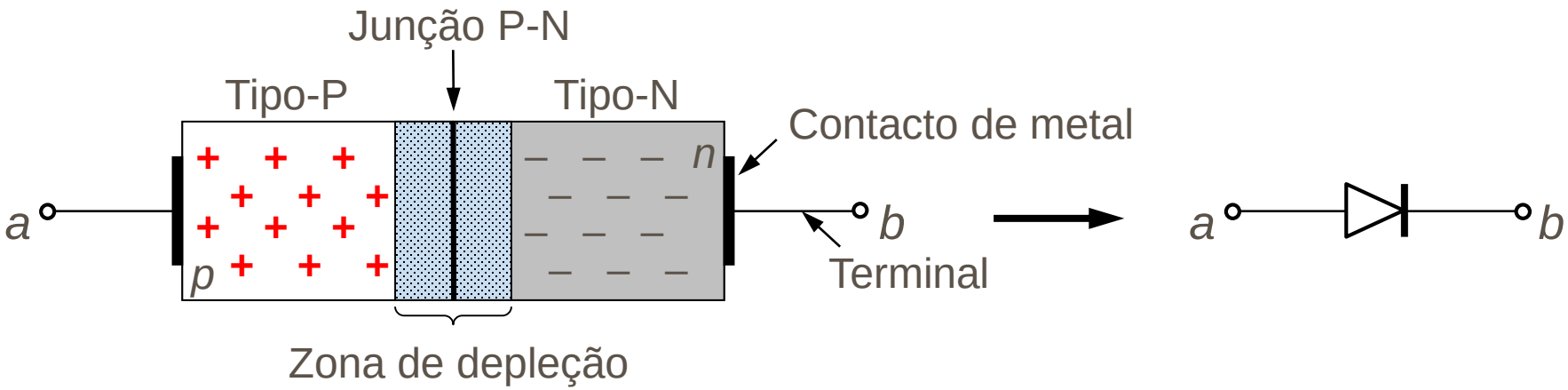
Fósforo

Boro

Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

- **Princípios de Física dos Semicondutores**
  - Funcionamento da junção P-N

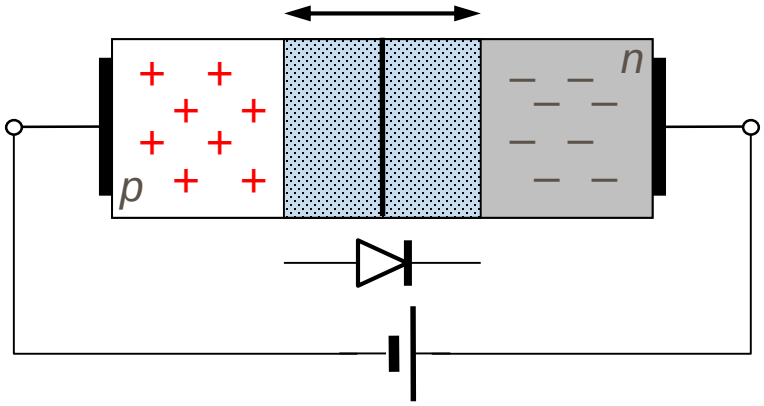


Díodo Semicondutor

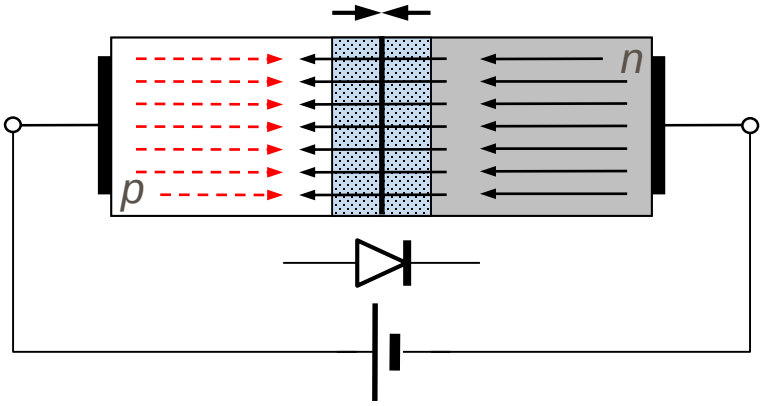
Universidade do Minho
Dep. de Electrónica Industrial

- **Princípios de Física dos Semicondutores**
  - Funcionamento da junção P-N

Junção inversamente polarizada



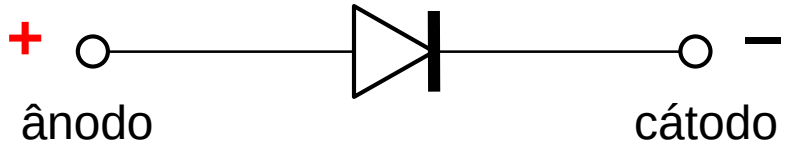
Junção directamente polarizada



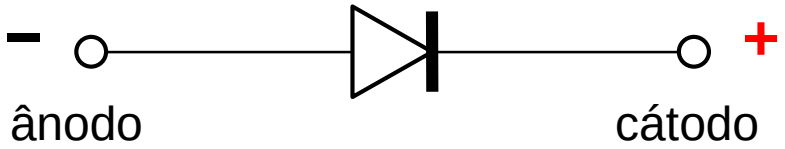
Comportamento do Díodo Ideal

- Característica *v-i* do díodo

Directamente polarizado



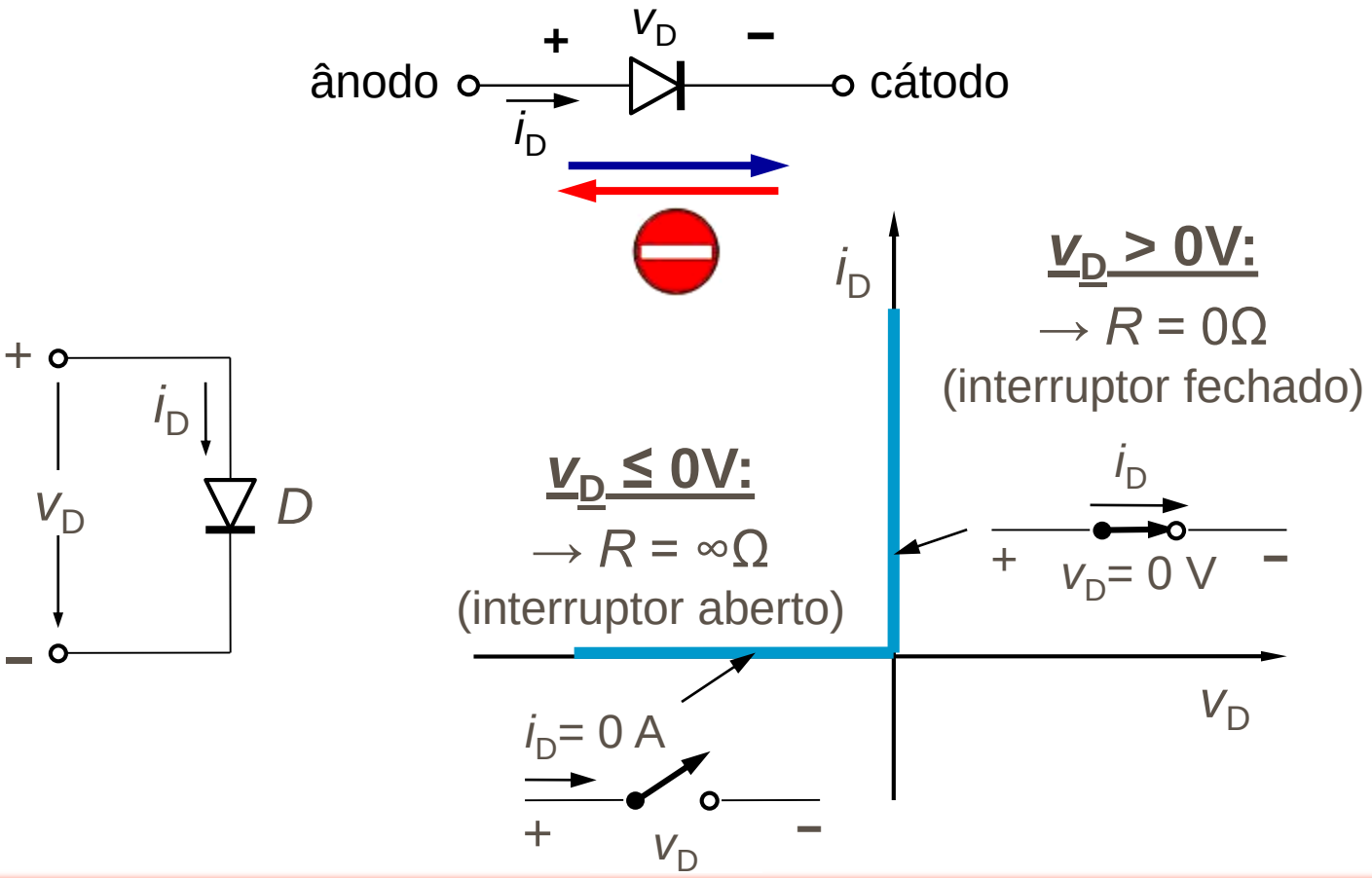
Inversamente polarizado



Díodo Semicondutor

Comportamento do Díodo Ideal

- Característica *v-i* do díodo



Universidade do Minho
Dep. de Electrónica Industrial

Comportamento do Díodo Ideal

- Análise de circuitos com díodos (exemplo)

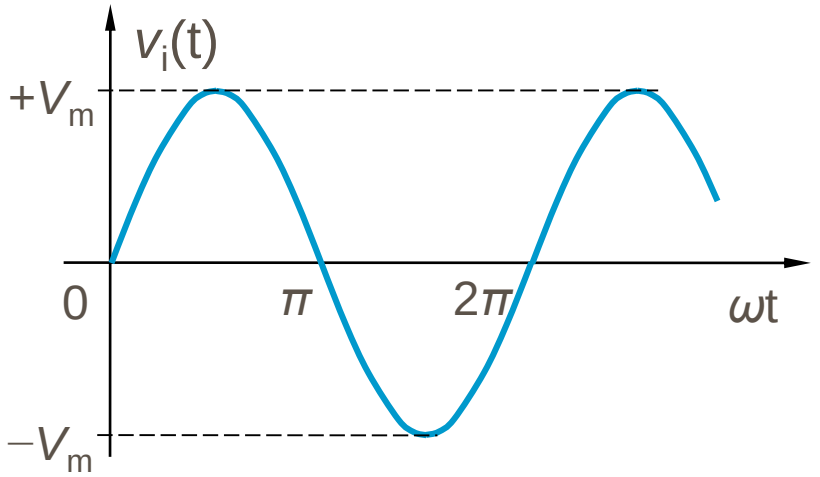
$$v_i = V_m \operatorname{sen}(\omega t)$$

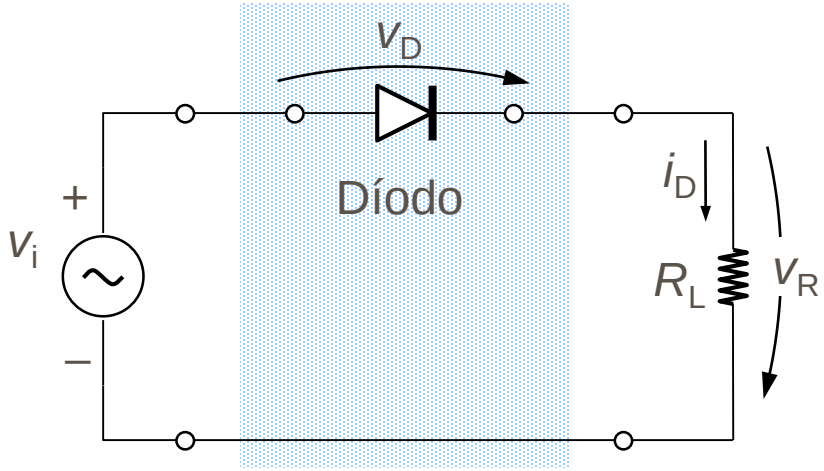
$$i_D = ?$$

$$v_i(t) = v_R + v_D$$

$$v_i(t) = R_L i_D + v_D \quad \text{?}$$

$$i_D = \frac{v_i - v_D}{R_L}$$

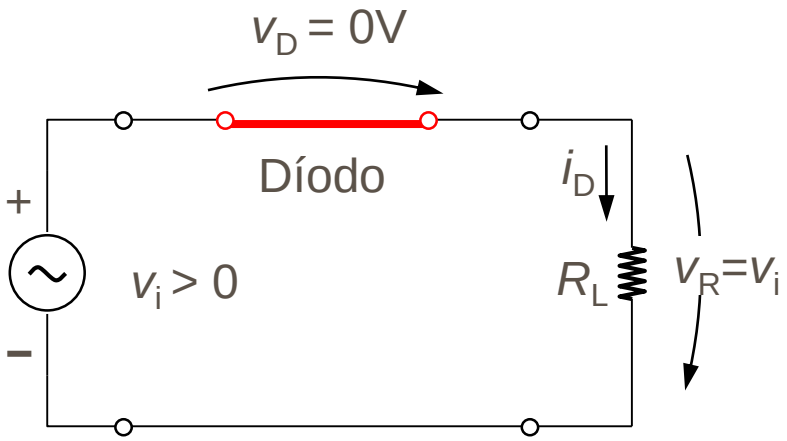


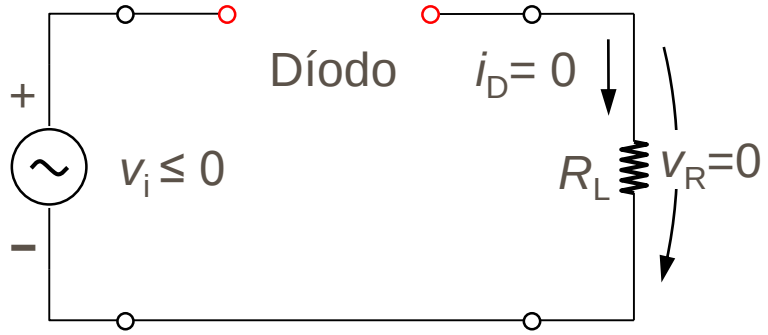


Díodo Semicondutor

Comportamento do Díodo Ideal

- Exemplo





Para $v_i > 0$:

$$i_D = \frac{v_i}{R_L} = \frac{V_m}{R_L} sen(\omega t)$$

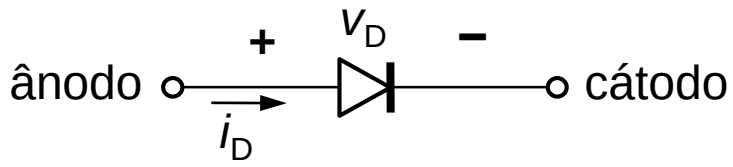
Para $v_i \leq 0$:

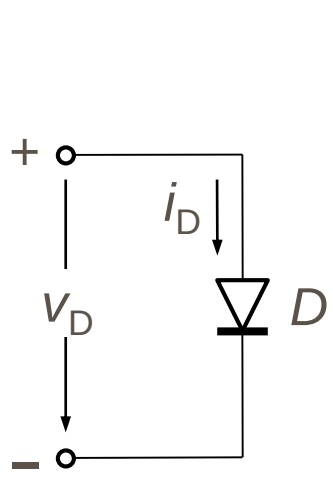
$$i_D = 0$$

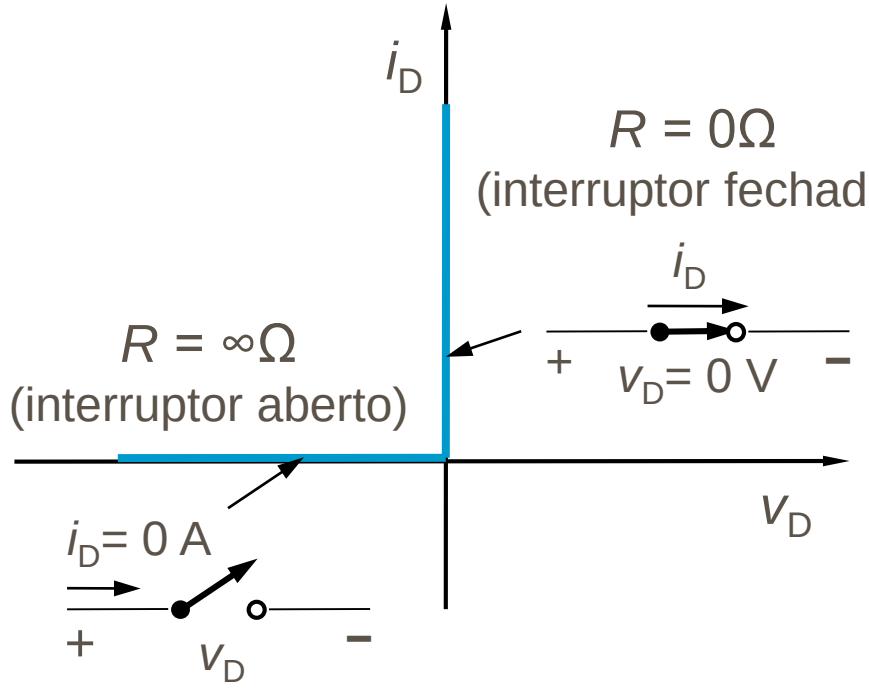
$$v_R = R_L i_D$$

Díodo Semicondutor

Característica *v-i* do Díodo Ideal



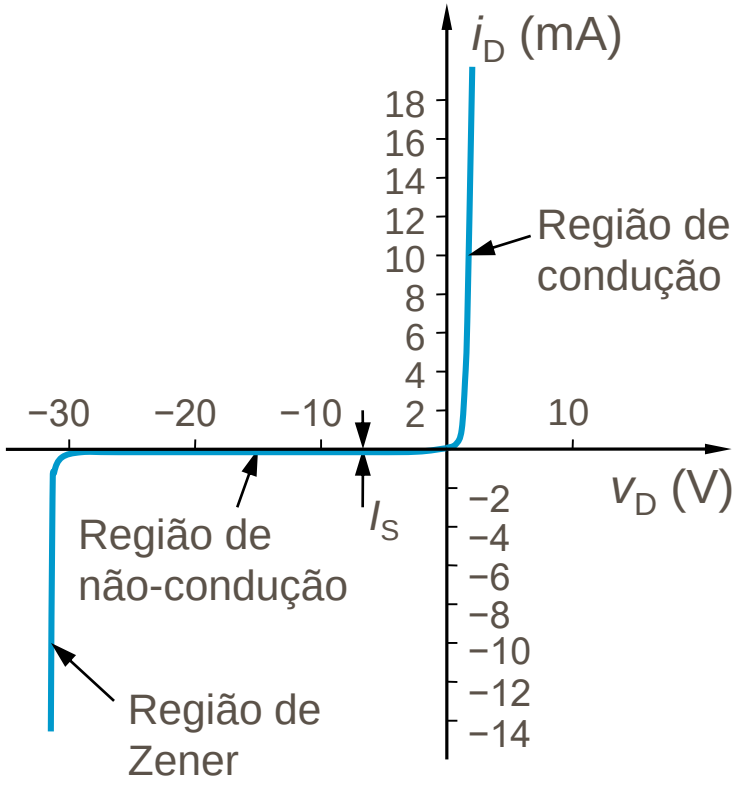


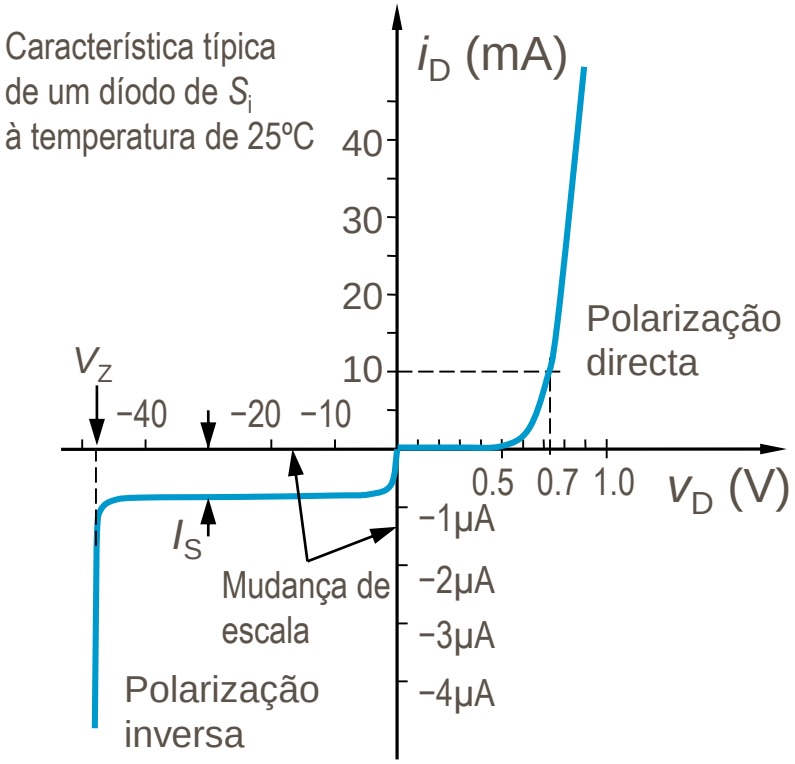


Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

Característica *V-I* do Díodo Semicondutor





Díodo Semicondutor

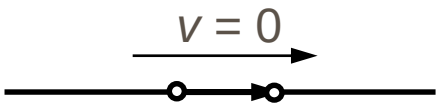
Característica *V-I* do Díodo Semicondutor

Desligado

Interruptor ideal

$$p = v \cdot i = v \cdot 0\text{A} = 0\ \text{W}$$

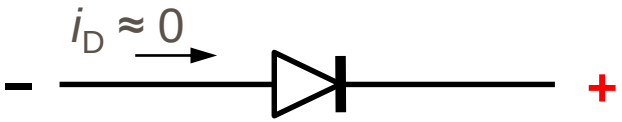
Ligado



Interruptor ideal

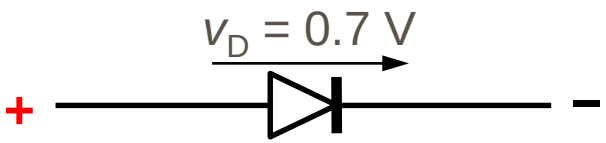
$$p = v \cdot i = 0\text{V} \cdot i = 0\ \text{W}$$

Inversamente polarizado



$$p_D = v_D \cdot i_D \approx v_D \cdot 0\text{A} = 0\ \text{W}$$

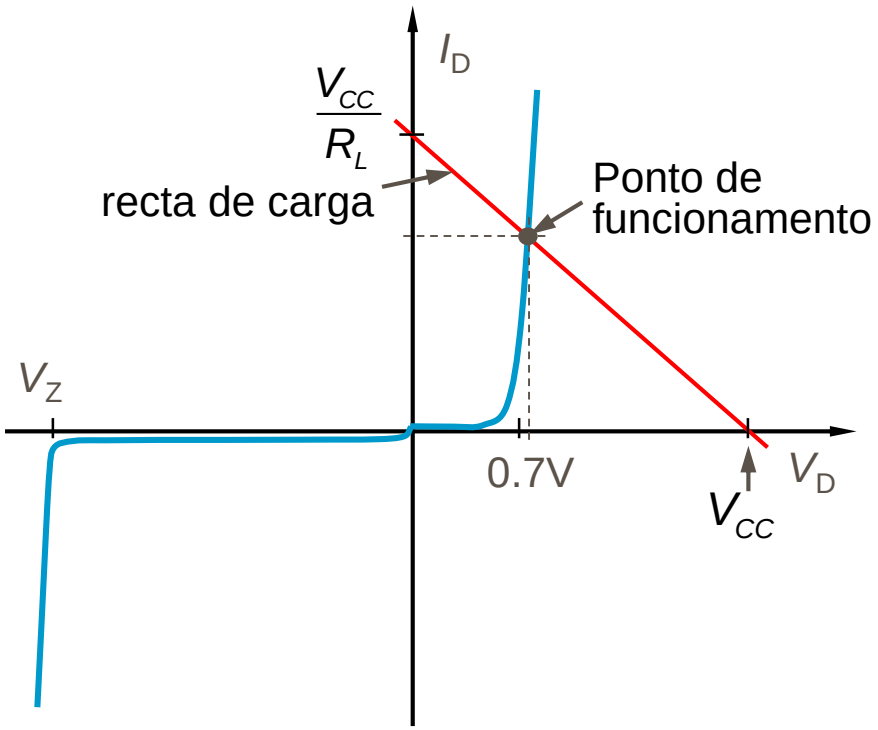
Directamente polarizado

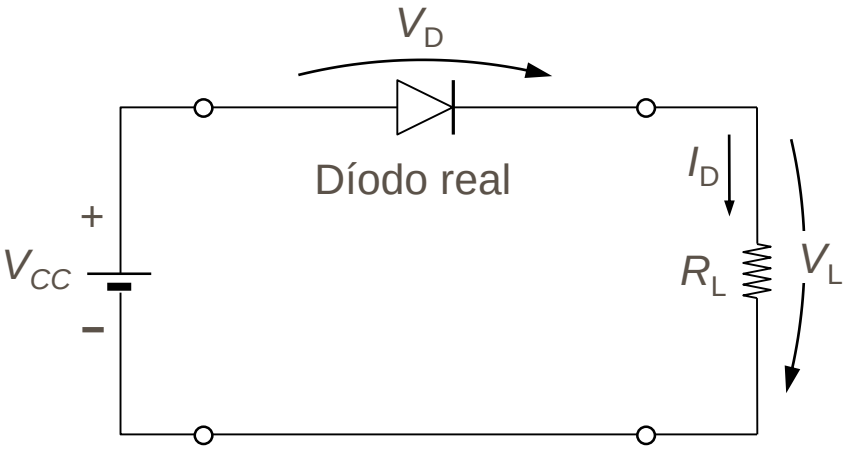


$$p_D = v_D \cdot i_D \approx 0.7V \cdot i_D$$

Díodo Semicondutor

Polarização do Díodo Semicondutor





$$V_{CC} = R_L I_D + V_D \quad \rightarrow \text{Recta de carga}$$

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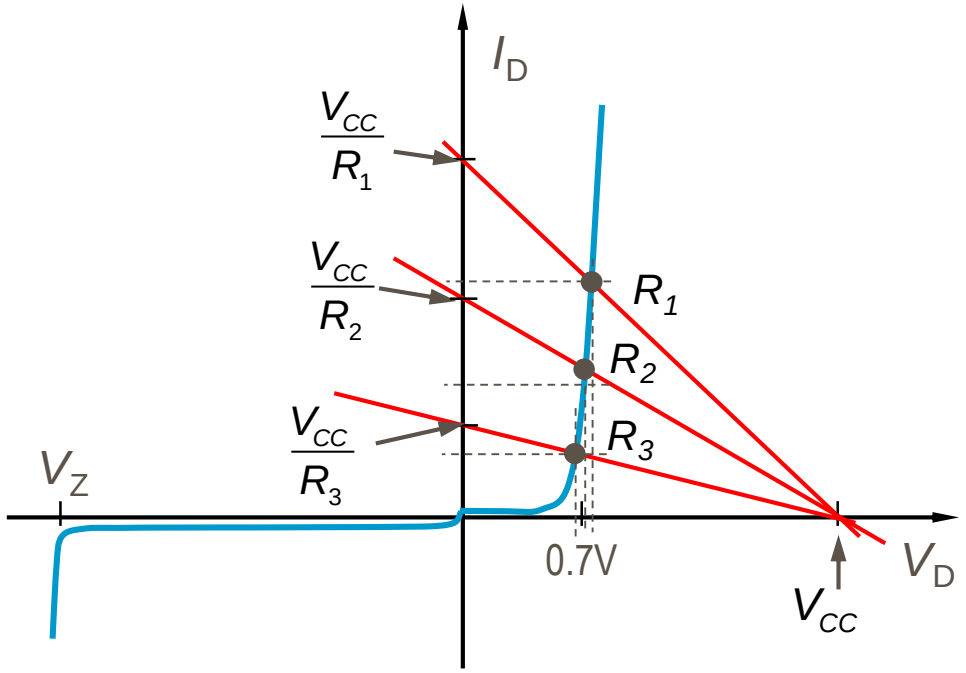
Polarização do Díodo Semicondutor

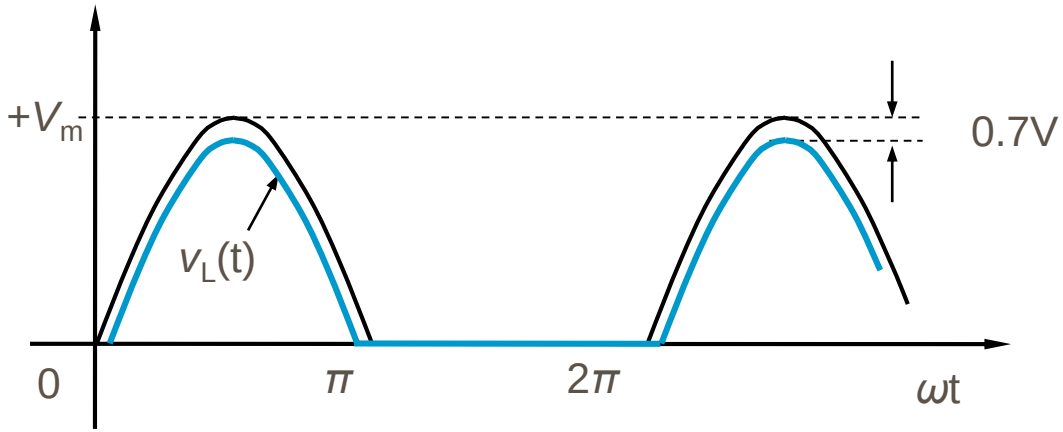


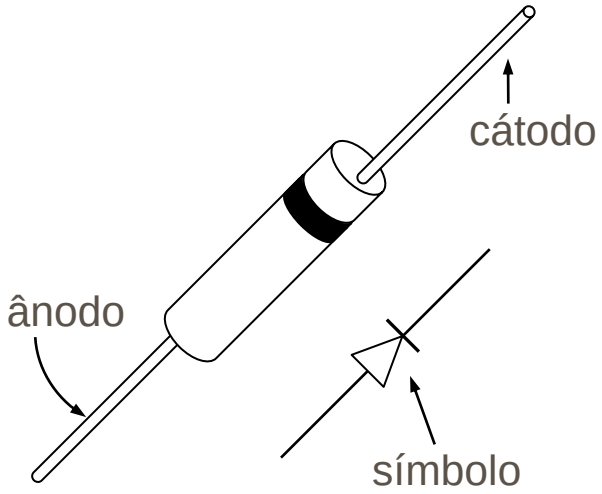
$$R_1 < R_2 < R_3$$

Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

Comportamento do Díodo Semicondutor



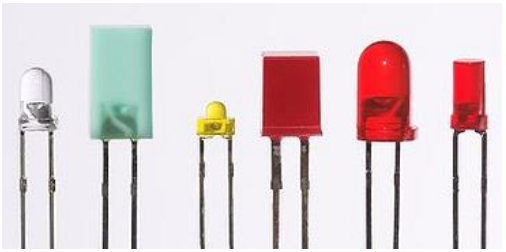


Díodo Semicondutor

- **Tipos de Díodos**

Pequenos Sinais

Emissor de Luz (LED)



Díodo de *Zener*

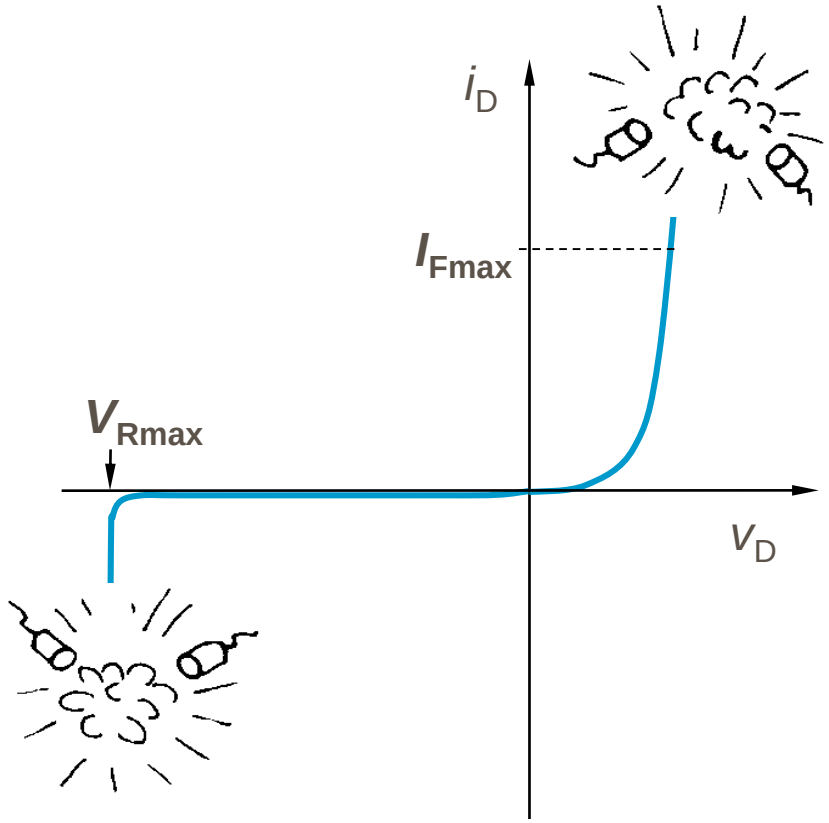
Díodo de Potência

Fotodíodo

Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

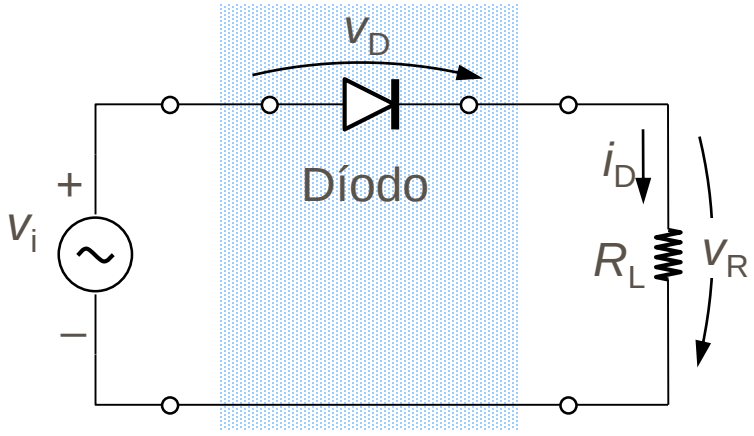
- **Limites de Operação dos Díodos**



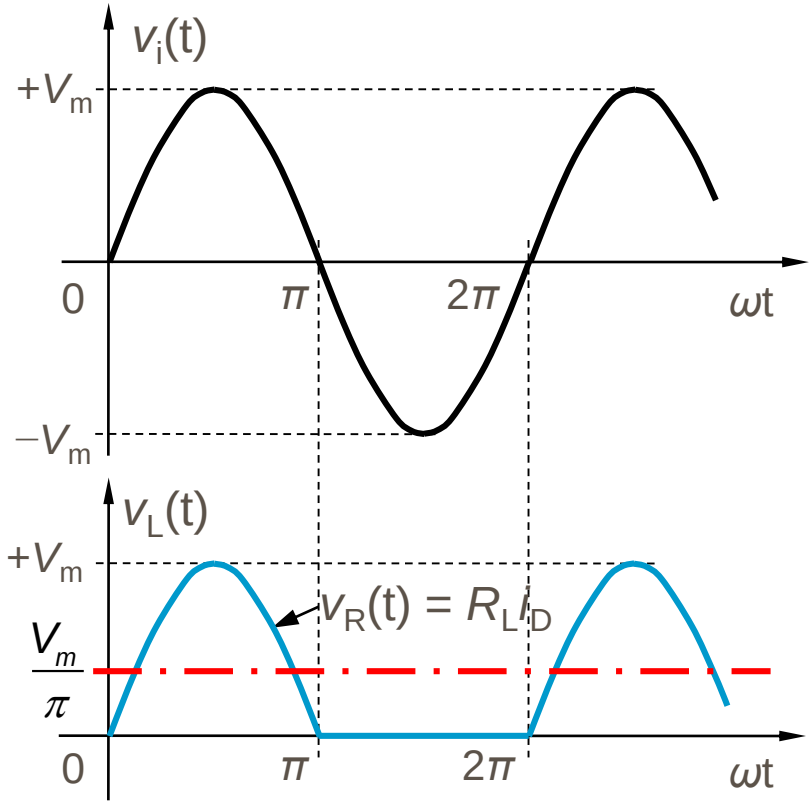
Díodo Semicondutor

Comportamento do Díodo Ideal

- Exemplo



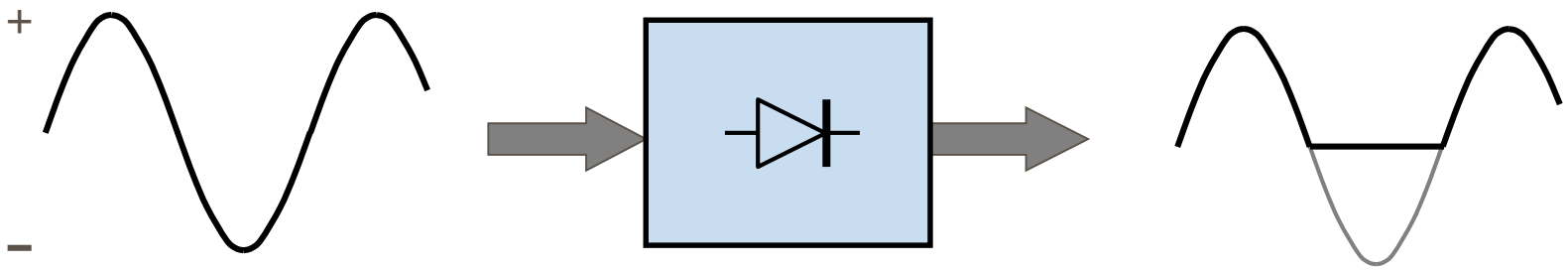
$$V_{Rmed} = \frac{1}{T}\int_0^T V_m sen(\omega t)\,dt = \frac{V_m}{\pi}$$



Díodo Semicondutor

Universidade do Minho
Dep. de Electrónica Industrial

- **Comportamento do Díodo Ideal**
  - Bloco Rectificador



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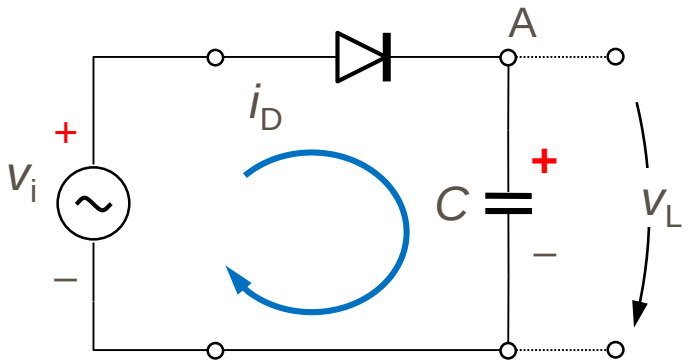
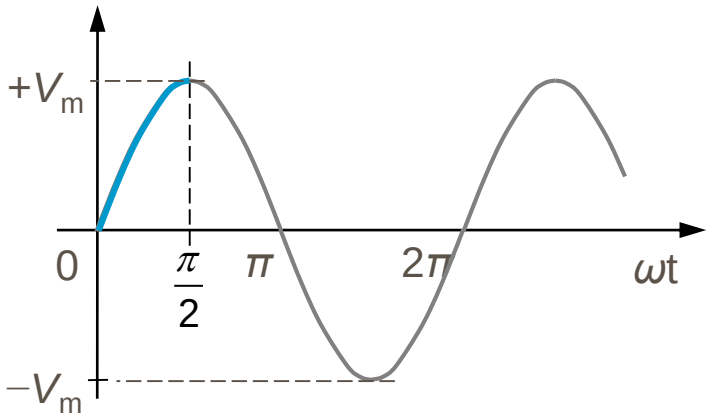
Dep. de Electrónica Industrial

Comportamento do Díodo Ideal

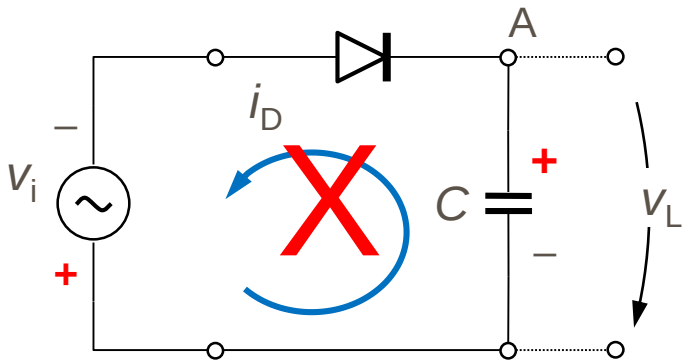
- Detector de Pico

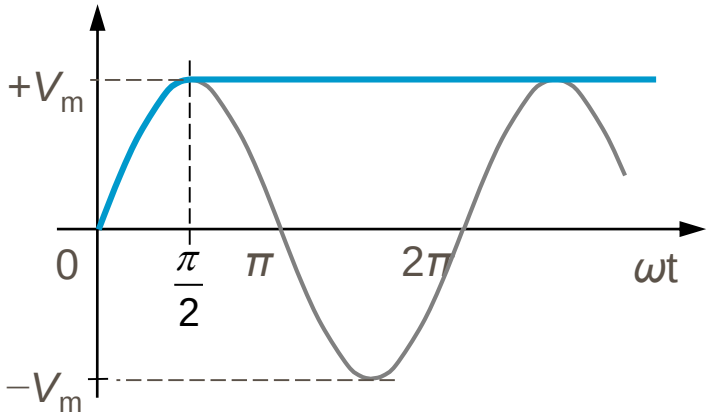




Comportamento do Díodo Ideal

- Detector de Pico

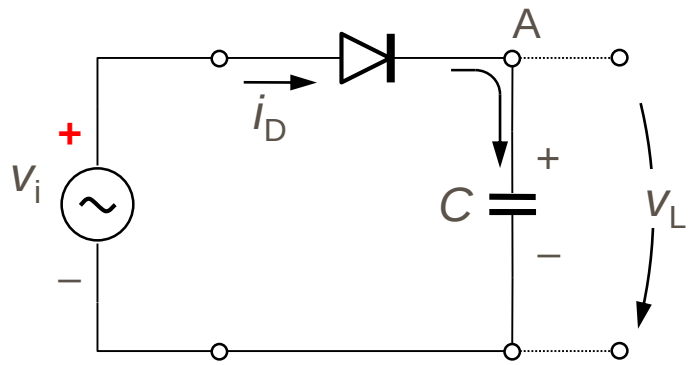


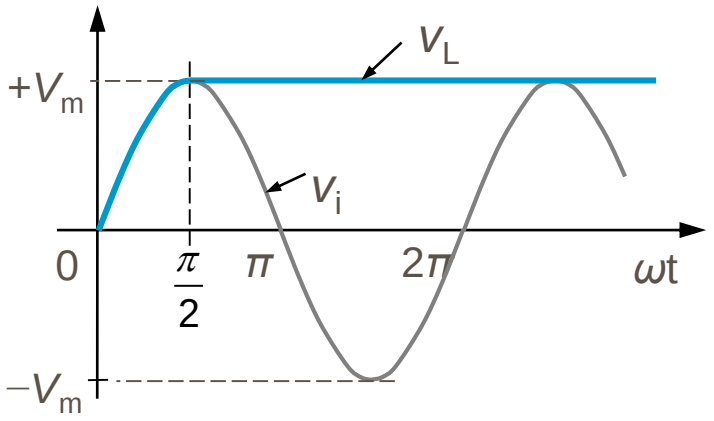


Universidade do Minho
Dep. de Electrónica Industrial

Comportamento do Díodo Ideal

- Detector de Pico

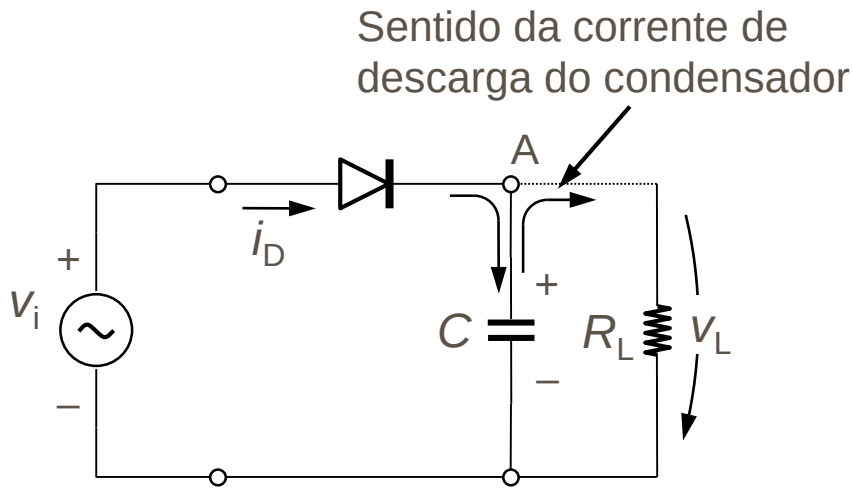


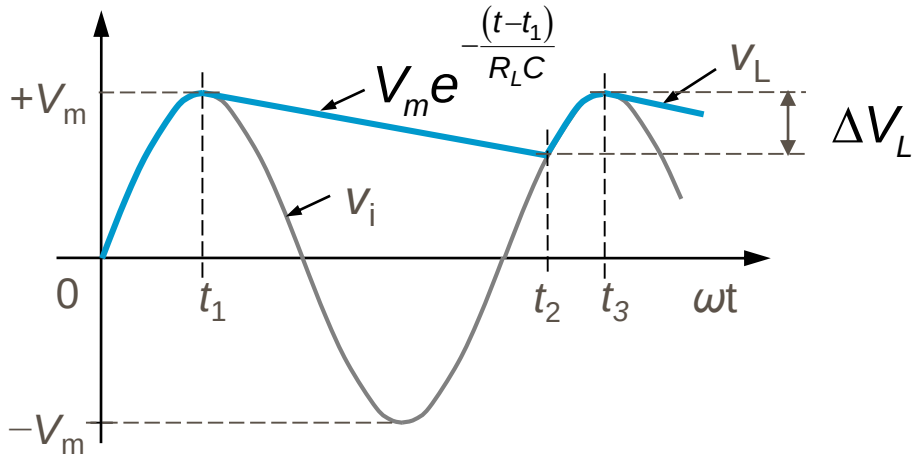


Díodo Semicondutor

Comportamento do Díodo Ideal

Detector de Pico (com carga)





Admitindo que $i_D \approx cte = \frac{V_m}{R_L}$

$$i_D \approx C\frac{\Delta V_L}{\Delta t} \quad \rightarrow \Delta V_L = \frac{i_D}{C}\Delta t \approx \frac{V_m}{f \cdot R_L C}$$

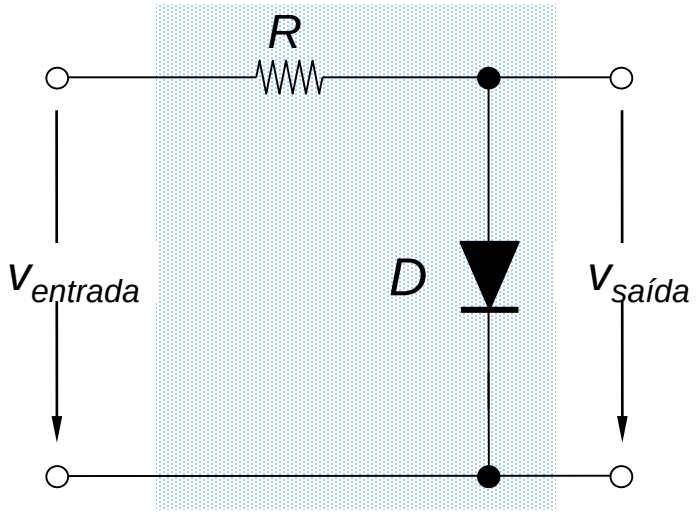
O valor médio da tensão de saída é:

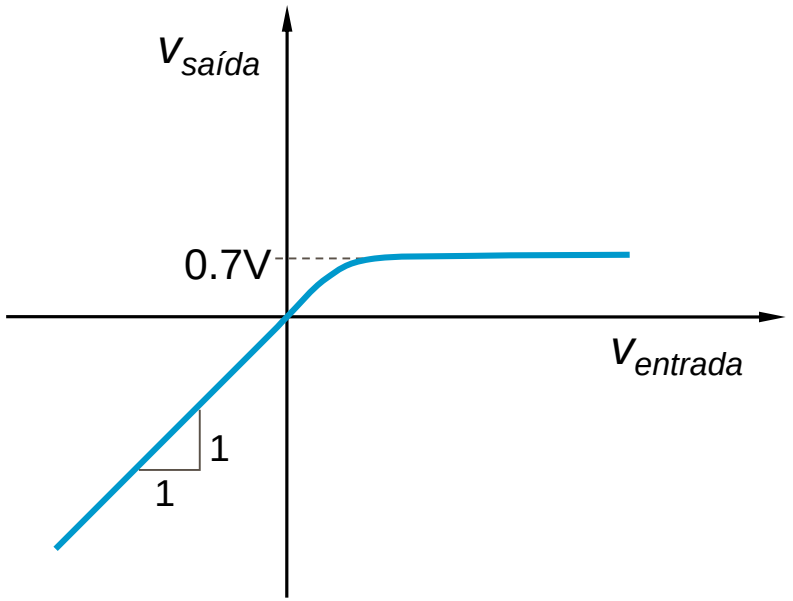
$$\rightarrow V_L \approx V_m - \frac{1}{2}\Delta V_L = V_m\left(1 - \frac{1}{2f \cdot R_L C}\right)$$

Díodos – Aplicações Básicas

Universidade do Minho
Dep. de Electrónica Industrial

- **Circuitos Limitadores**





Característica de transferência

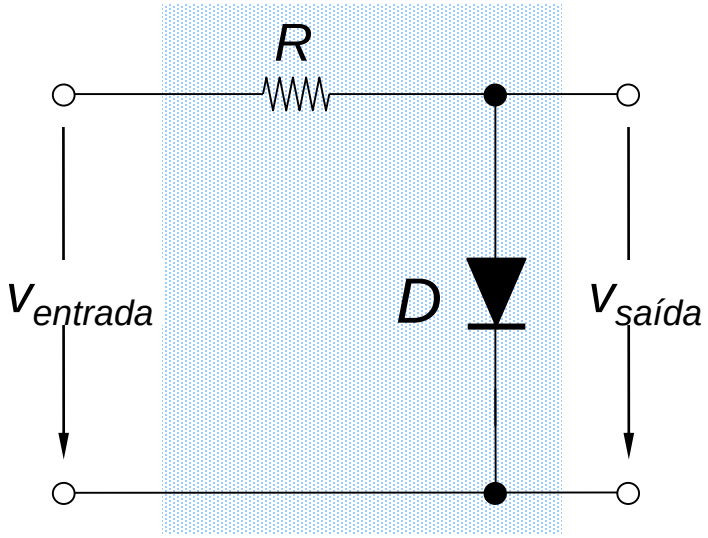
$$v_{entrada} < 0.7\ \text{V} \rightarrow \quad v_{saída} = v_{entrada}$$

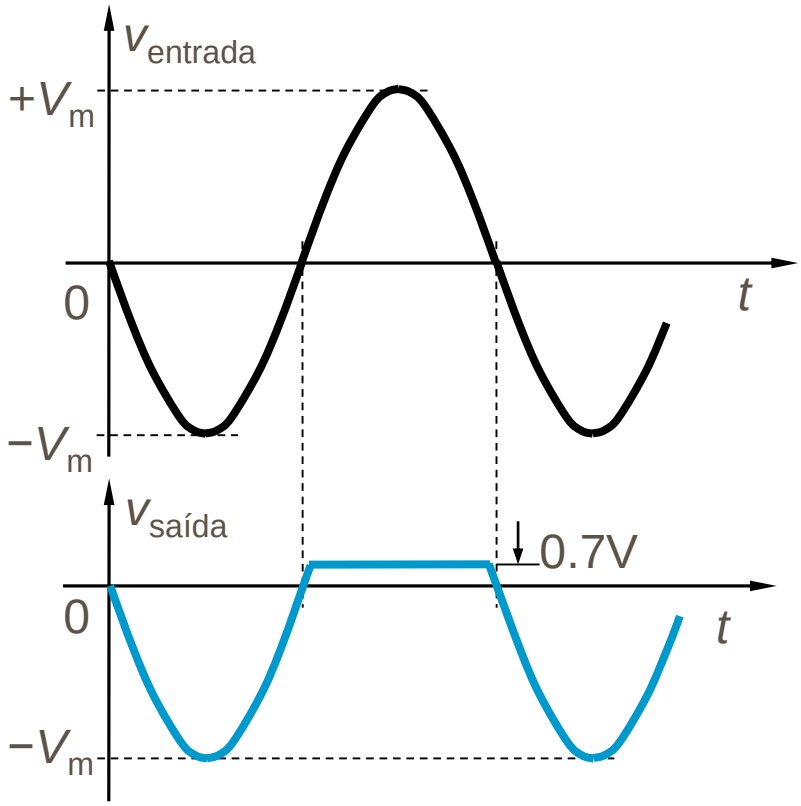
$$v_{entrada} \geq 0.7\ \text{V} \rightarrow \quad v_{saída} = 0.7\ \text{V}$$

Díodos – Aplicações Básicas

Universidade do Minho
Dep. de Electrónica Industrial

- **Circuitos Limitadores**



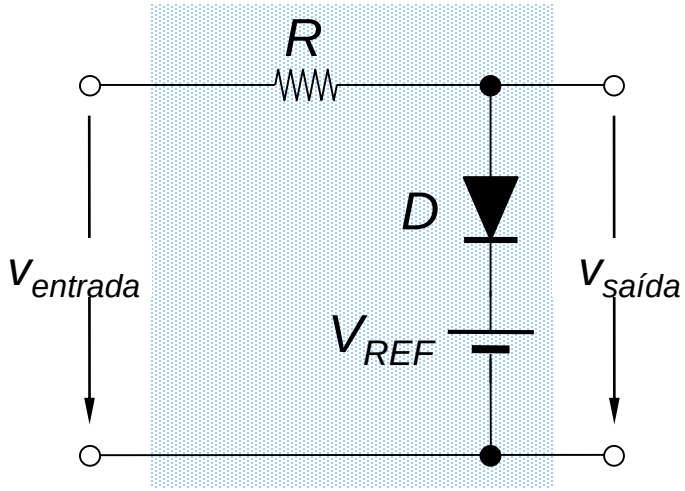


$$v_{entrada} < 0.7\ \text{V} \rightarrow \quad v_{saída} = v_{entrada}$$

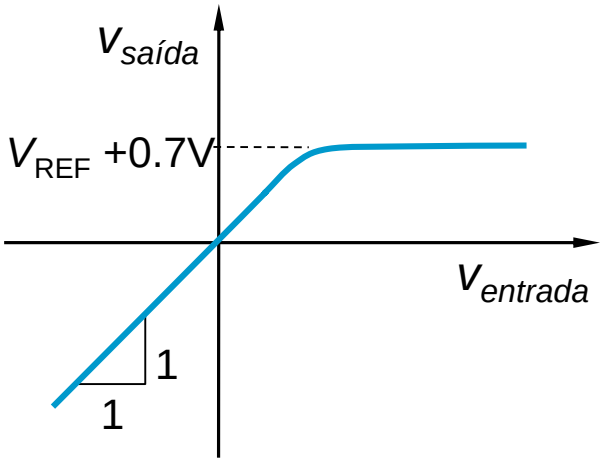
$$v_{entrada} \geq 0.7\ \text{V} \rightarrow \quad v_{saída} = 0.7\ \text{V}$$

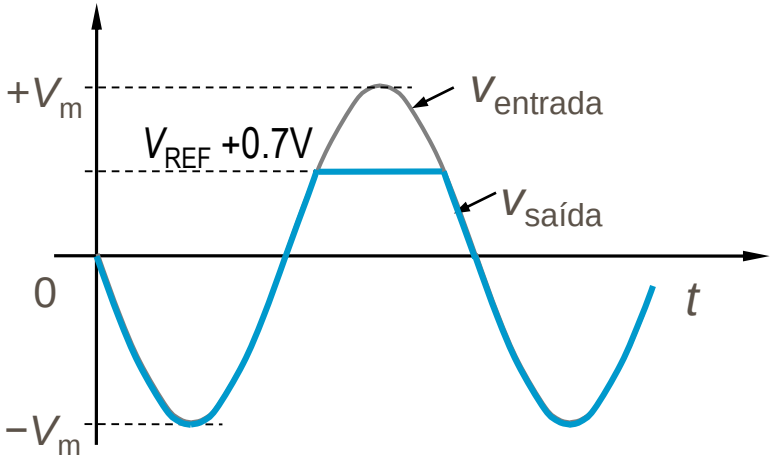
Díodos – Aplicações Básicas

Limitadores Polarizados



Característica de transferência



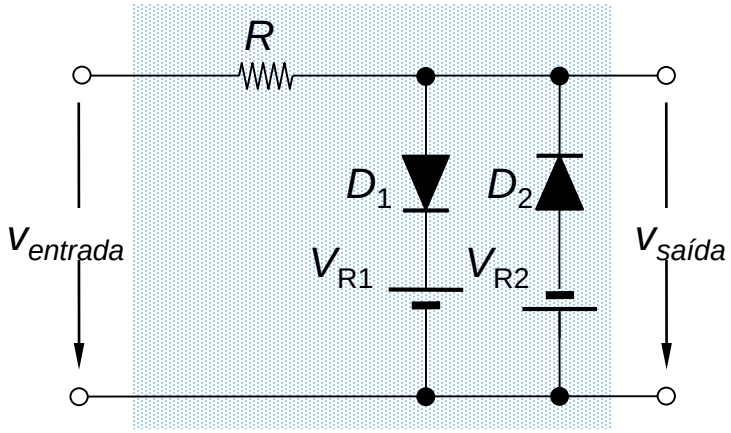


$$v_{entrada} < V_{REF} + 0.7\ \text{V} \rightarrow \quad v_{saída} = v_{entrada}$$

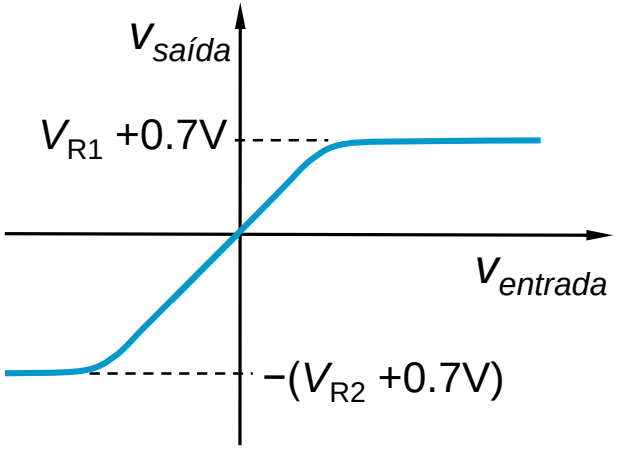
$$v_{entrada} \geq V_{REF} + 0.7\ \text{V} \rightarrow \quad v_{saída} = V_{REF} + 0.7\ \text{V}$$

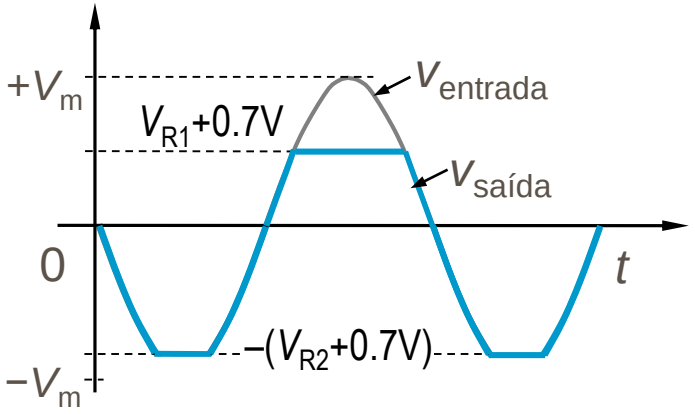
Díodos – Aplicações Básicas

- Limitação a 2 níveis



Característica de transferência





Exemplo

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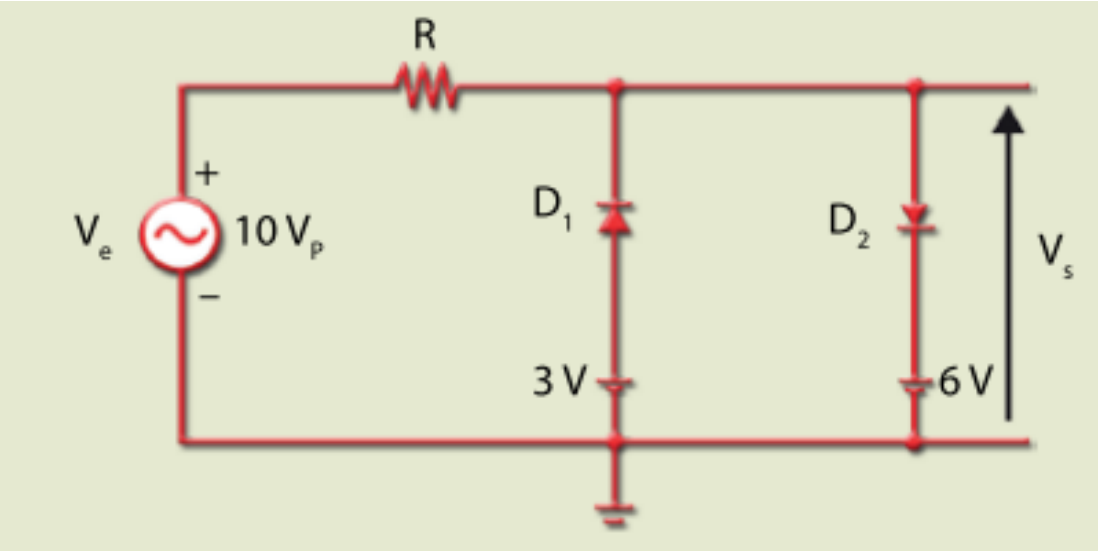
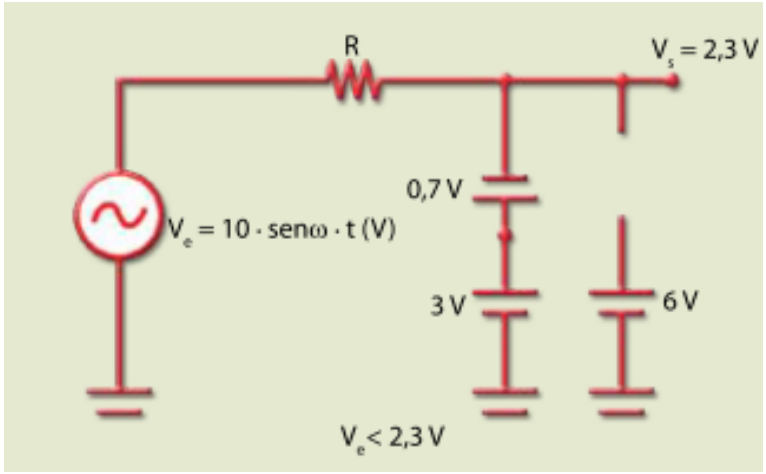
Dep. de Electrónica Industrial

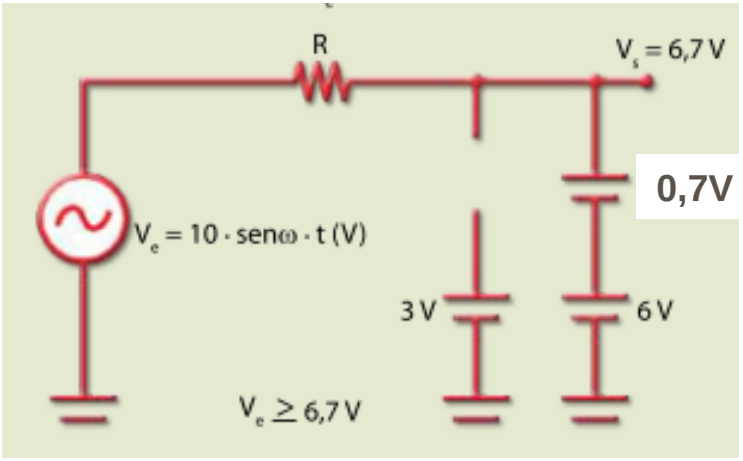
- **Considere o seguinte circuito:**

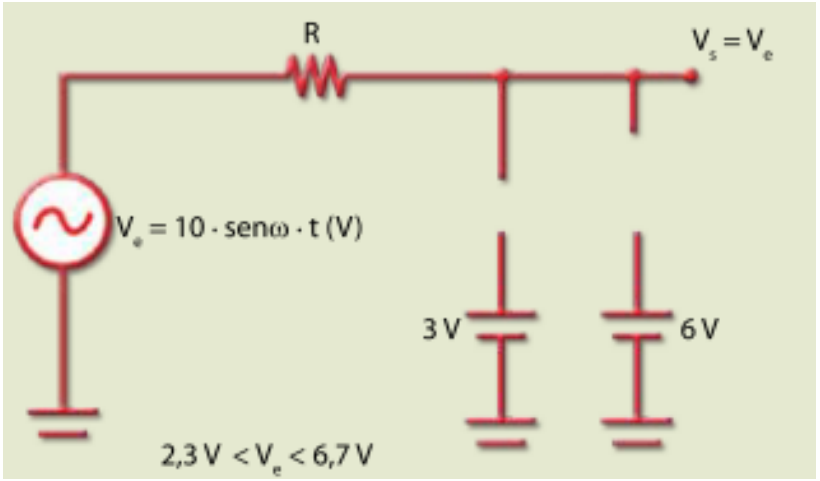


- Desenhe a curva caraterística (Vs x Ve)
- Desenhe a tensão de saída, considerando uma entrada sinusoidal, com $10V_p$.

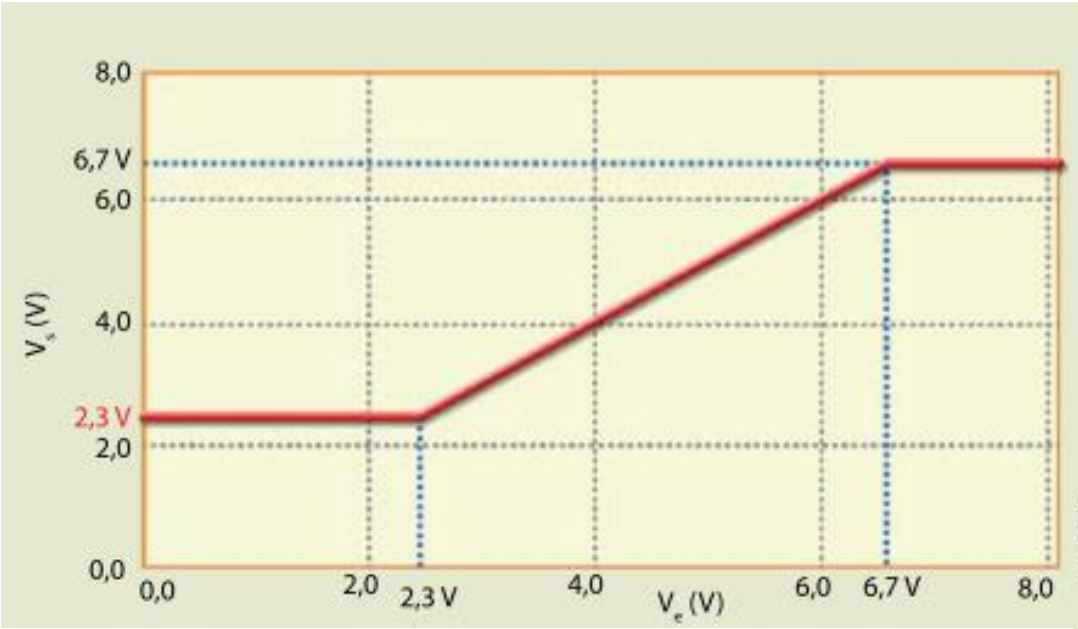
Solução

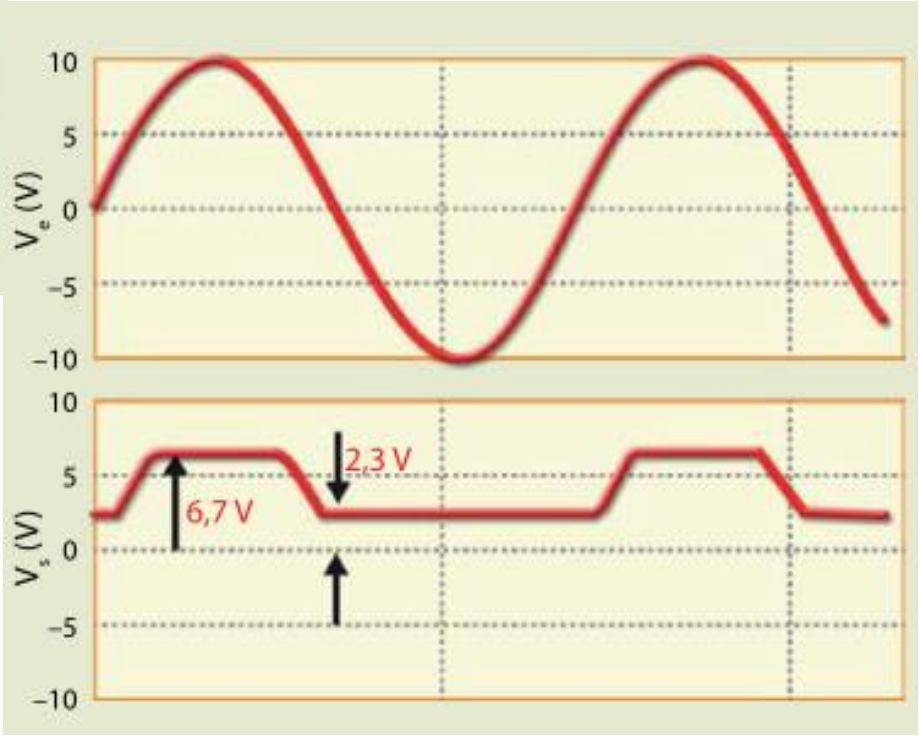

R
$V_s = 2{,}3\ V$
0,7 V
$V_e = 10 \cdot \text{sen}\omega \cdot t\ (V)$
3 V
6 V
$V_e < 2{,}3\ V$

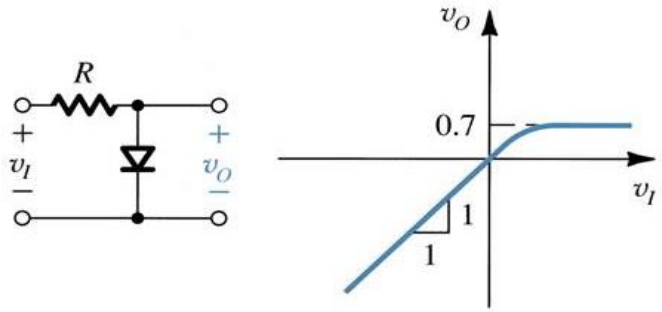

R
$V_s = 6{,}7\ V$
0,7V
$V_e = 10 \cdot \text{sen}\omega \cdot t\ (V)$
3 V
6 V
$V_e \geq 6{,}7\ V$


R
$V_s = V_e$
$V_e = 10 \cdot \text{sen}\omega \cdot t\ (V)$
3 V
6 V
$2{,}3\ V < V_e < 6{,}7\ V$

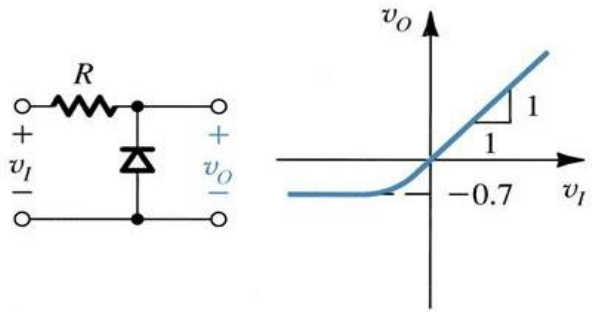
Solução


8,0
6,7 V
6,0
4,0
2,3 V
2,0
0,0
V_s (V)
0,0
2,0
2,3 V
4,0
V_e (V)
6,0
6,7 V
8,0

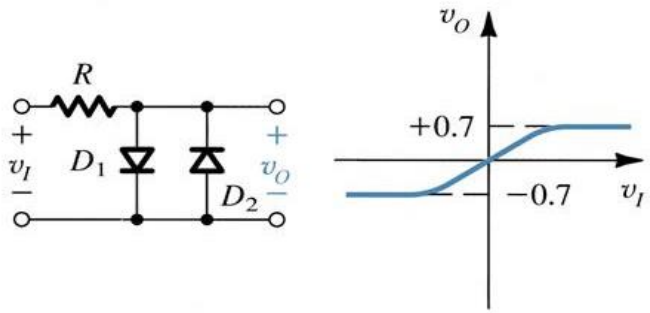

10
5
0
−5
−10
V_e (V)
10
5
0
−5
−10
V_s (V)
2,3 V
6,7 V


R
v_I
v_O
0.7
1
1
v_O
v_I

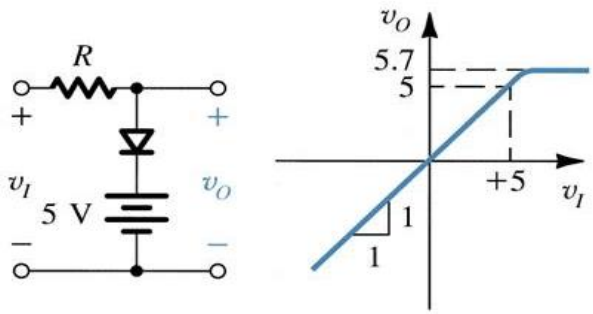
(a)


R
v_I
v_O
1
1
−0.7
v_O
v_I

(b)


R
D_1
D_2
v_I
v_O
+0.7
−0.7
v_O
v_I

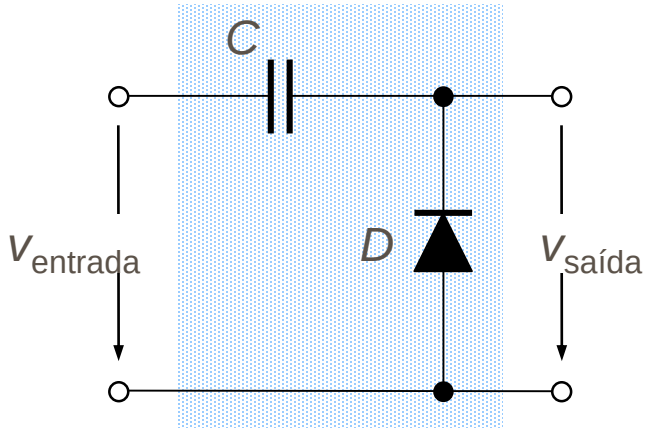
(c)

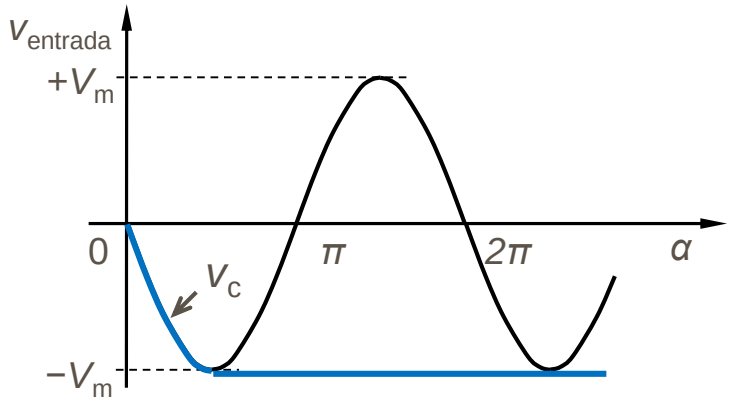

R
v_I
5 V
v_O
5.7
5
+5
1
1
v_O
v_I

(d)

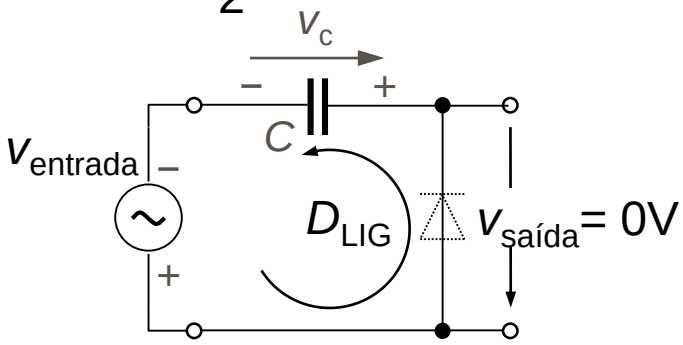
Díodos – Aplicações Básicas

- **Circuitos Fixadores (ou *Clamping*)**

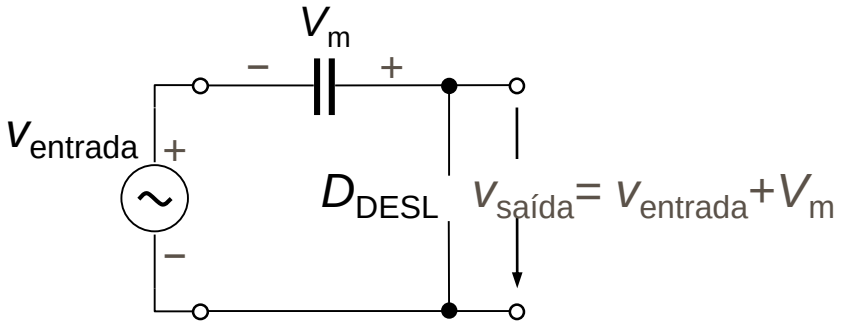




$v_{entrada} \leq \frac{\pi}{2}$ (díodo conduz)



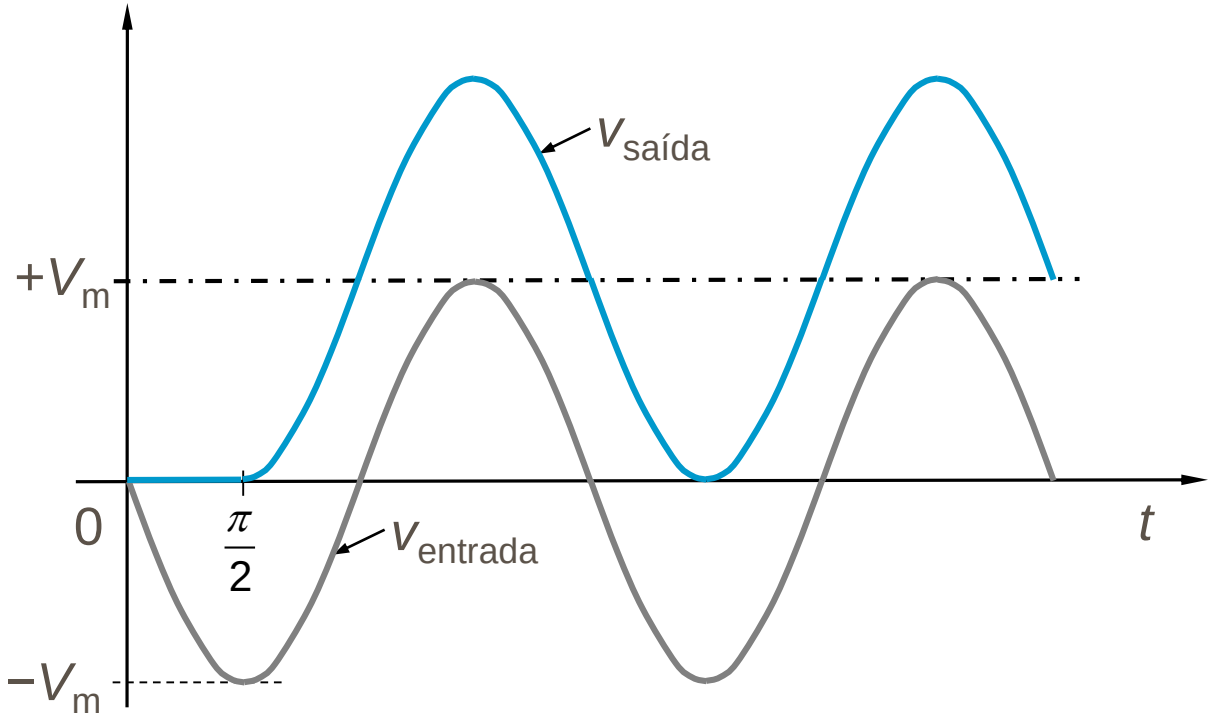
$v_{entrada} > \frac{\pi}{2}$ (díodo não conduz)



Díodos – Aplicações Básicas

Universidade do Minho
Dep. de Electrónica Industrial

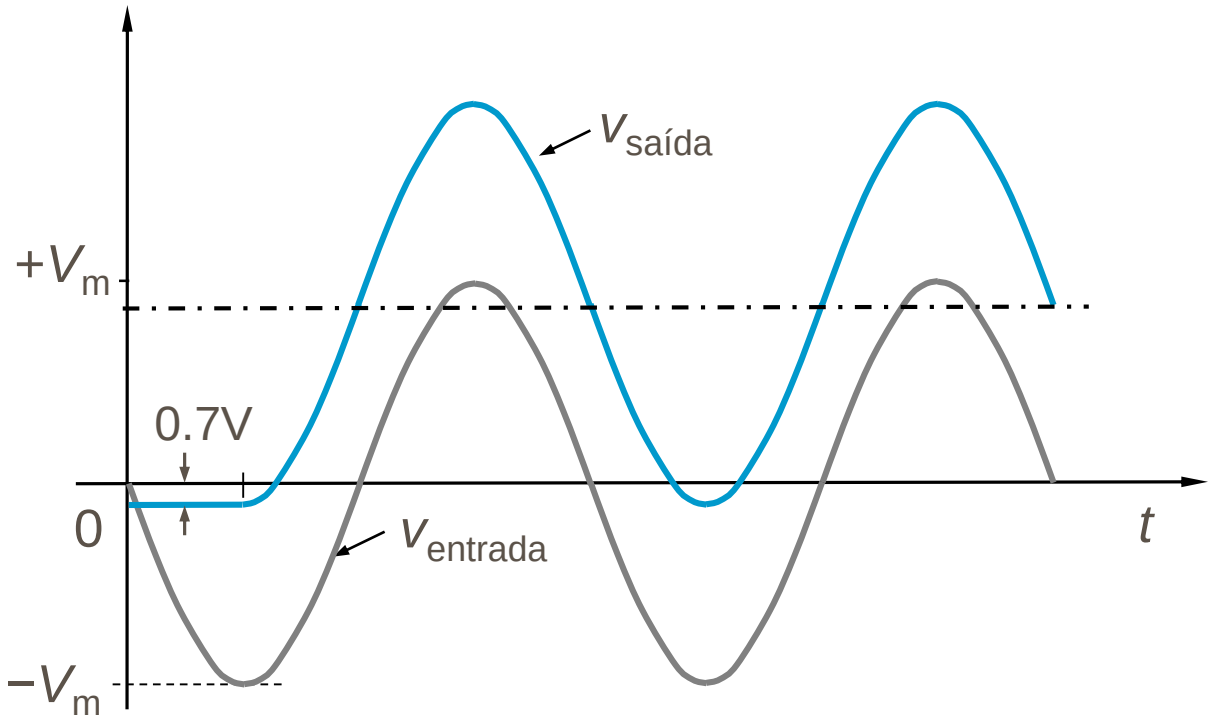
- **Circuitos Fixadores**



Fixador – formas de onda admitindo díodo ideal

Díodos – Aplicações Básicas

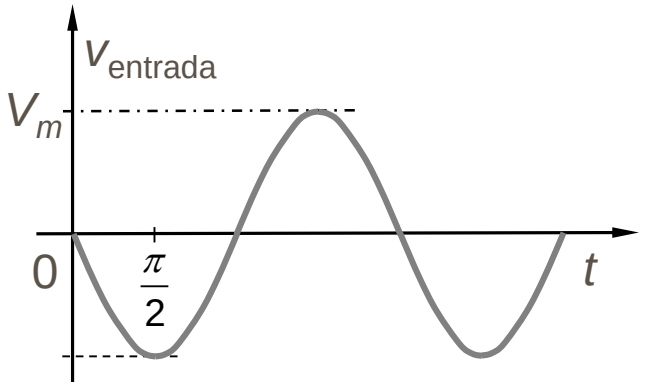
- **Circuitos Fixadores**

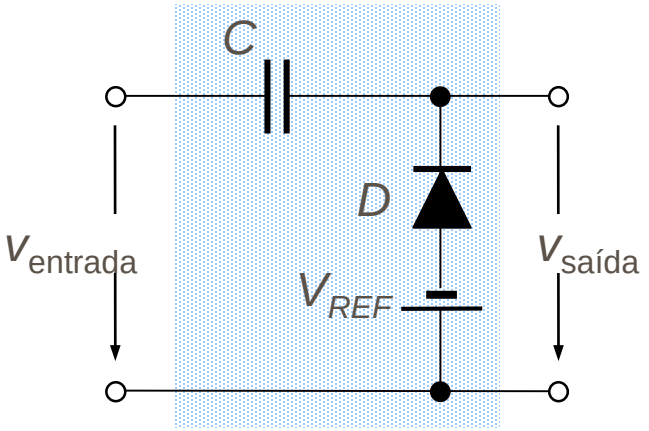


Fixador – formas de onda no caso do díodo real

Díodos – Aplicações Básicas

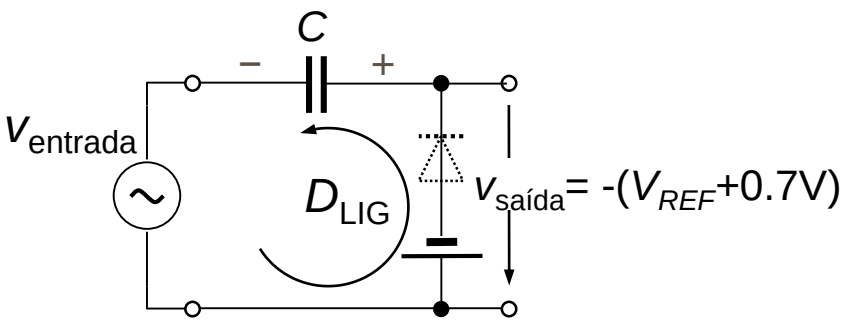
- **Circuitos Fixadores (caso geral)**

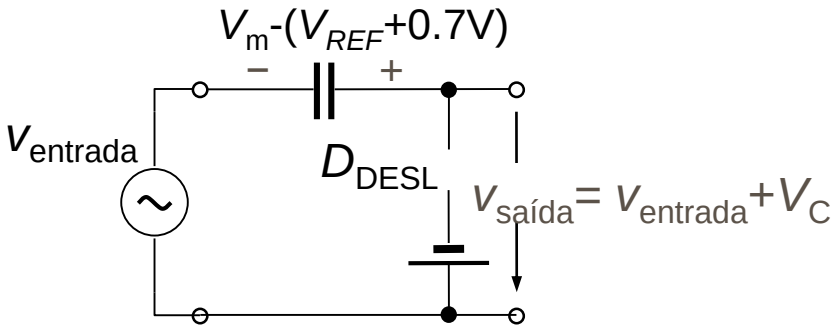




$v_{entrada} \leq \frac{\pi}{2}$ (díodo conduz)

$v_{entrada} > \frac{\pi}{2}$ (díodo não conduz)

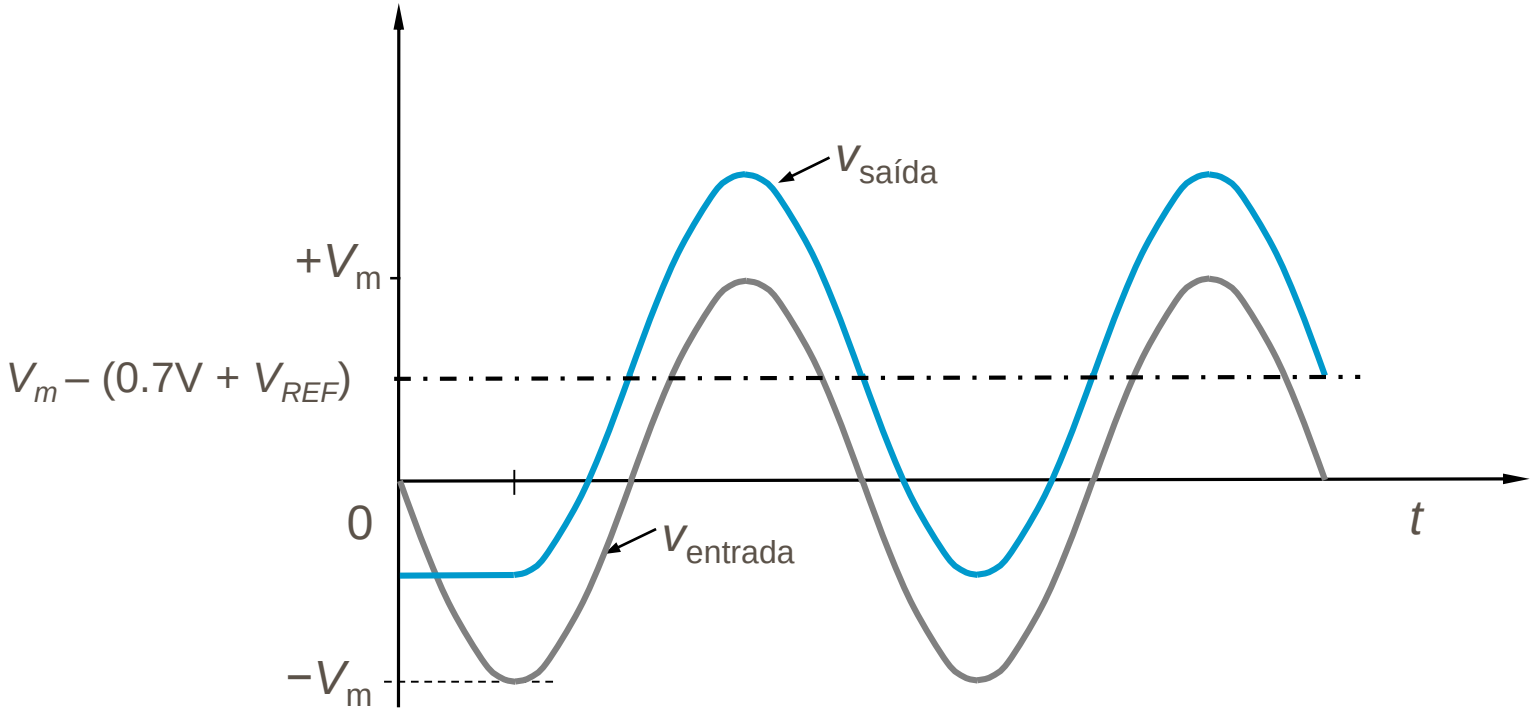




Díodos – Aplicações Básicas

Universidade do Minho
Dep. de Electrónica Industrial

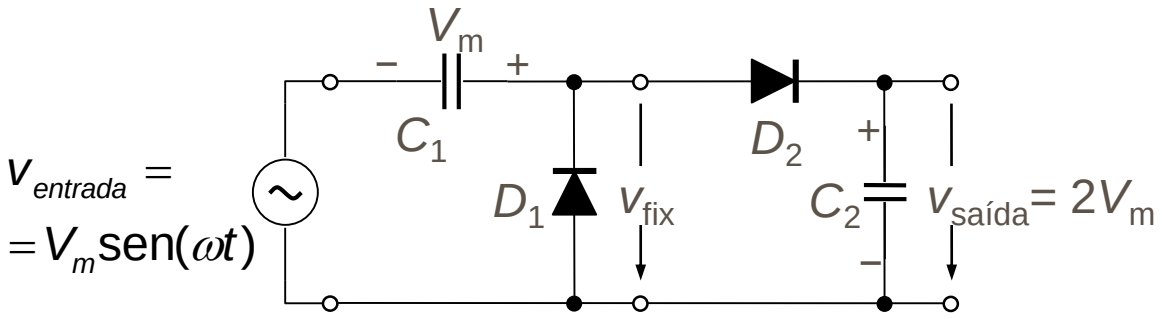
- **Circuitos Fixadores (caso geral)**



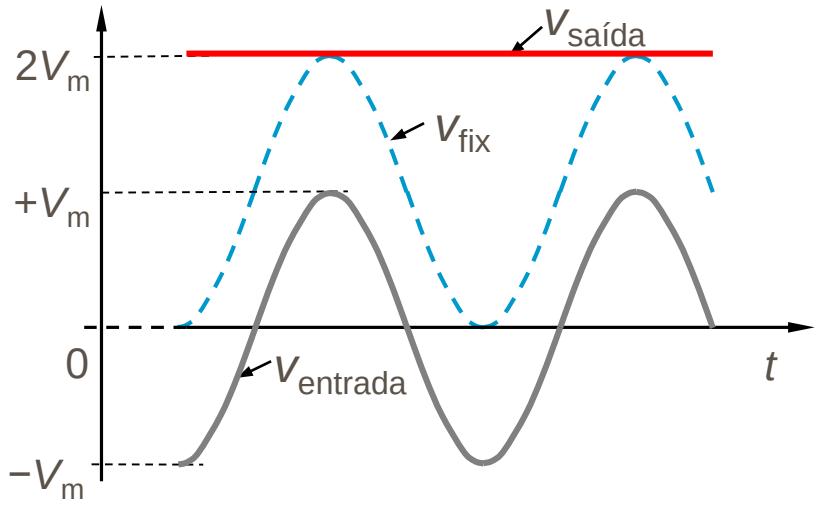
Fixador – formas de onda no caso do díodo real

Díodos – Aplicações Básicas

- **Detector Pico-a-Pico (ou duplicador de tensão)**



Duplicador – formas de onda admitindo díodo ideal (reg. permanente)



Díodos – Aplicações Básicas

- **Multiplicador de tensão**