Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina
Departamento Acadêmico de Eletrônica
Eletrônica de Potência

Conversores cc-ca

Prof. Clovis Antonio Petry.

Florianópolis, setembro de 2020.

Curso Básico de Eletrônica de Potência

O material do curso está disponível em:

1. Moodle para os alunos matriculados na disciplina.
2. Página do professor.
3. Canal no youtube do professor.

https://moodle.ifsc.edu.br

www.ProfessorPetry.com.br

https://www.youtube.com

INSTITUTO FEDERAL
SANTA CATARINA

Agenda

Esta aula está organizada em:

1. Introdução aos conversores cc-ca:
   - Quadrantes de operação;
   - Modulação PWM senoidal;
   - Princípio de funcionamento.
2. Conversor meia ponte:
   - Onda quadrada;
   - PWM senoidal.
3. Conversor ponte completa:
   - Onda quadrada;
   - PWM senoidal.

Motivação

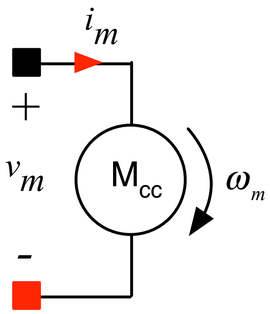
Os conversores cc-ca tem ampla utilização na indústria, por exemplo no acionamento de motores.

https://www.weg.net/

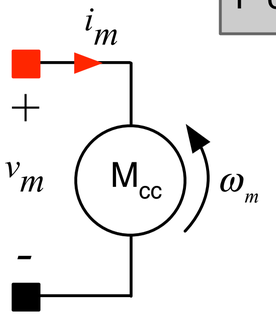
Quadrantes de Operação

2º quadrante

$$\begin{cases} v_m < 0 \\ i_m > 0 \end{cases} \rightarrow P_m < 0 \rightarrow \text{Modo gerador}$$



1º quadrante



$$\begin{cases} v_m > 0 \\ i_m > 0 \end{cases} \rightarrow P_m > 0 \rightarrow \text{Modo motor}$$

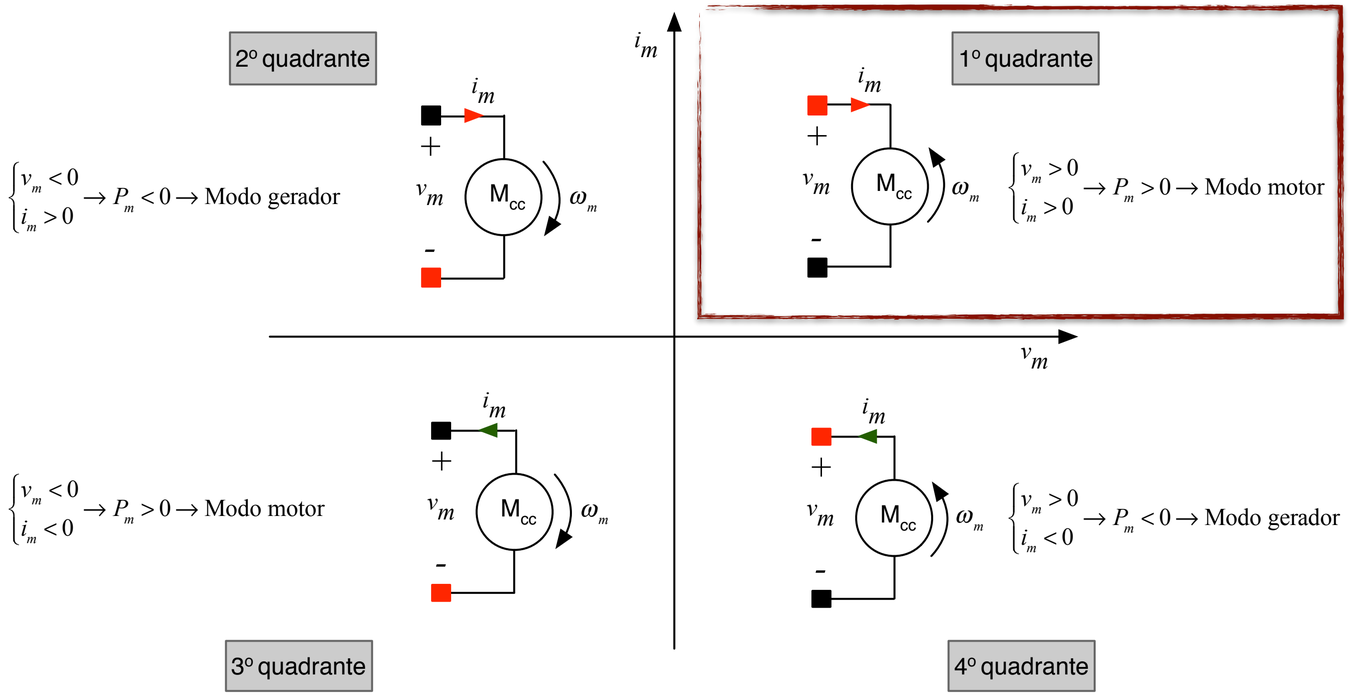
$$\begin{cases} v_m < 0 \\ i_m < 0 \end{cases} \rightarrow P_m > 0 \rightarrow \text{Modo motor}$$

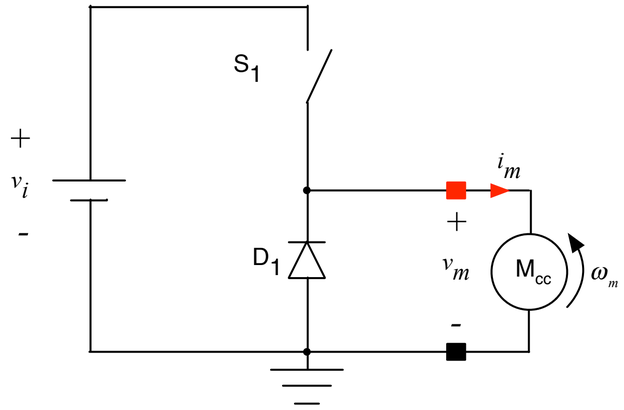
3º quadrante

$$\begin{cases} v_m > 0 \\ i_m < 0 \end{cases} \rightarrow P_m < 0 \rightarrow \text{Modo gerador}$$

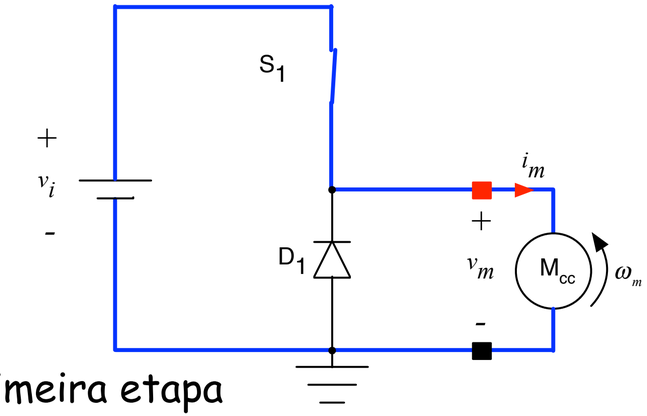
4º quadrante

Quadrantes de Operação

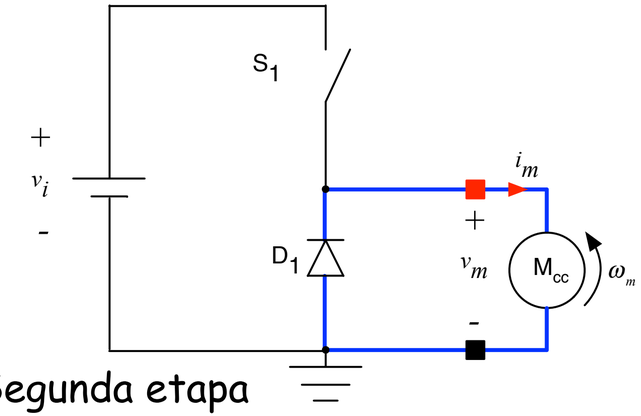




Conversor simples com chave

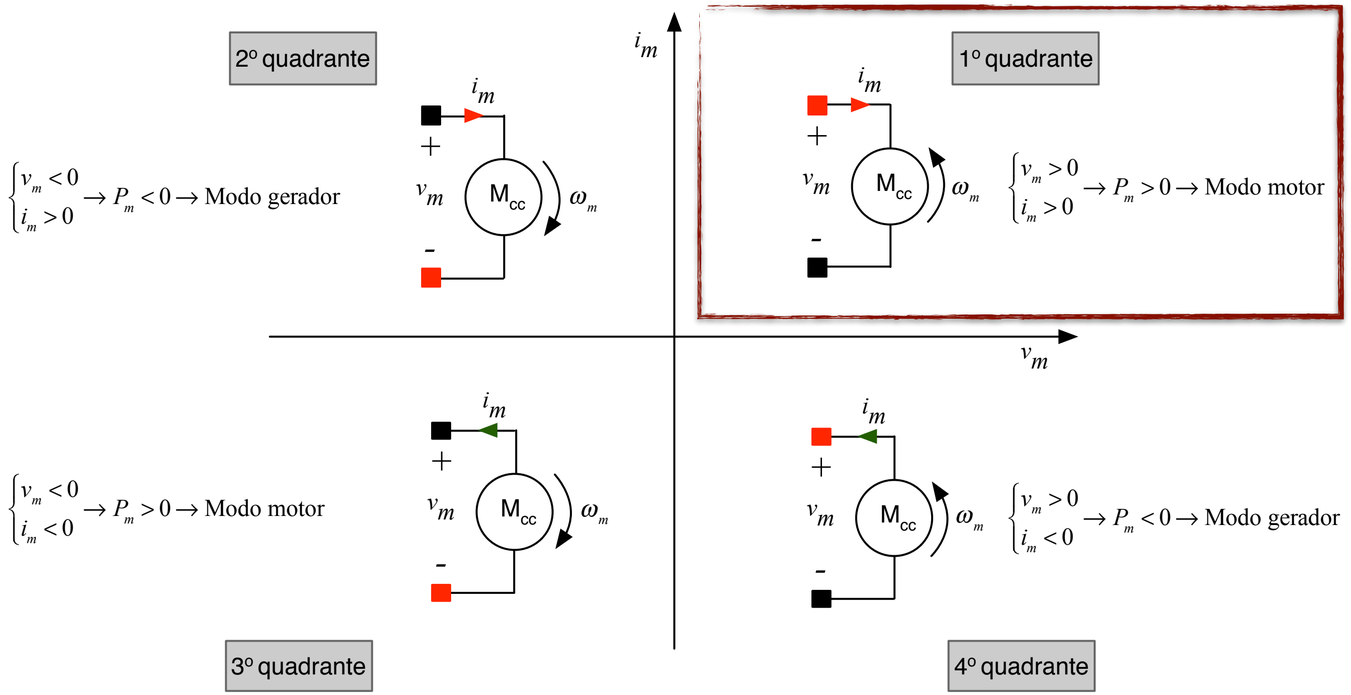


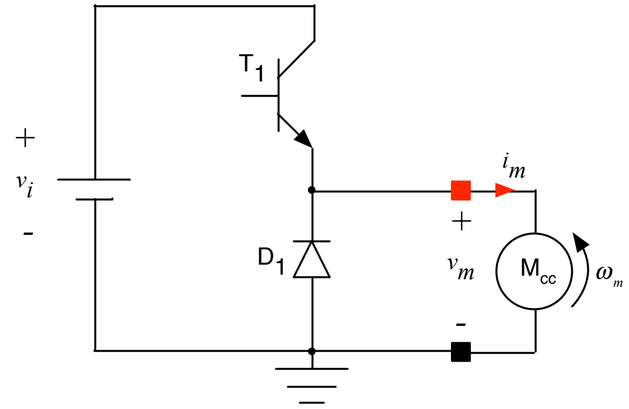
Primeira etapa



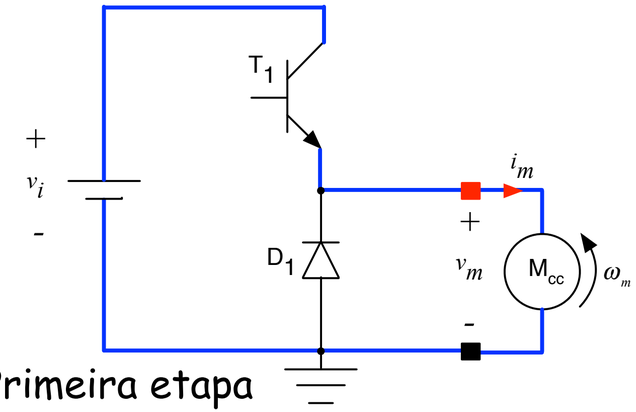
Segunda etapa

Quadrantes de Operação

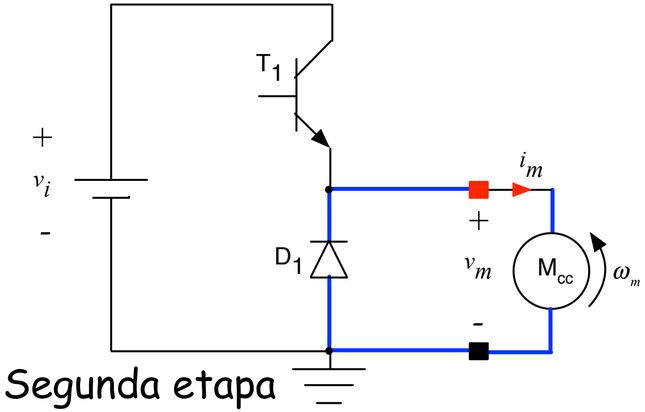




Conversor simples com transistor

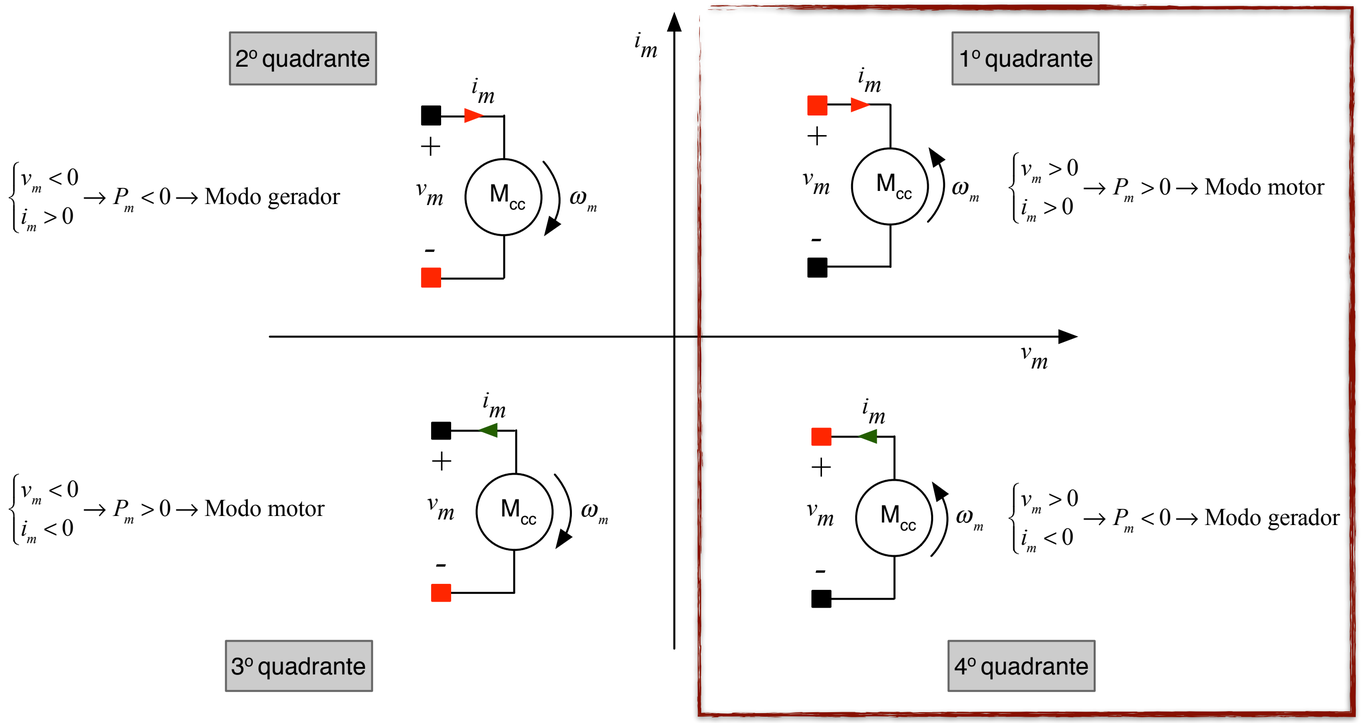


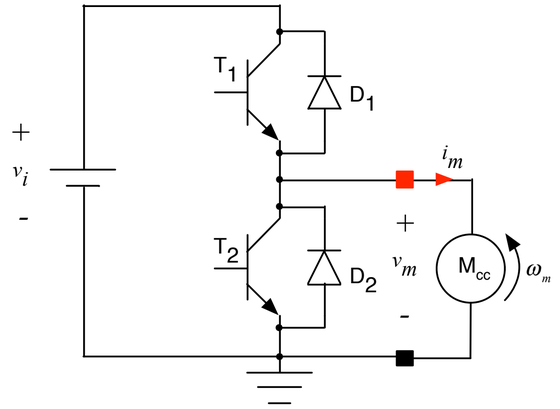
Primeira etapa



Segunda etapa

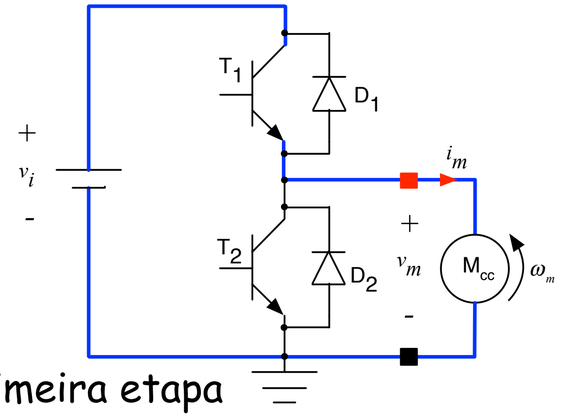
Quadrantes de Operação





Conversor meia ponte

Modo motor



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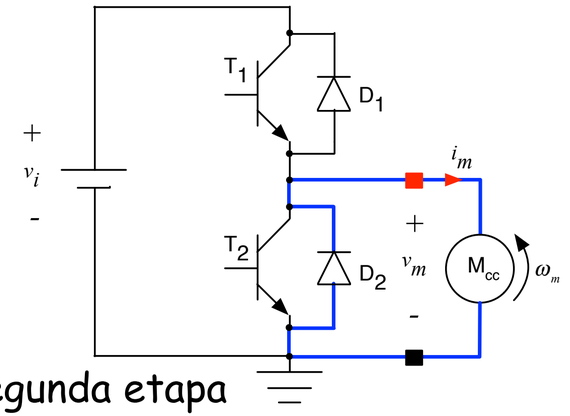
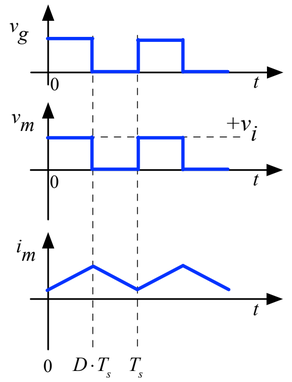
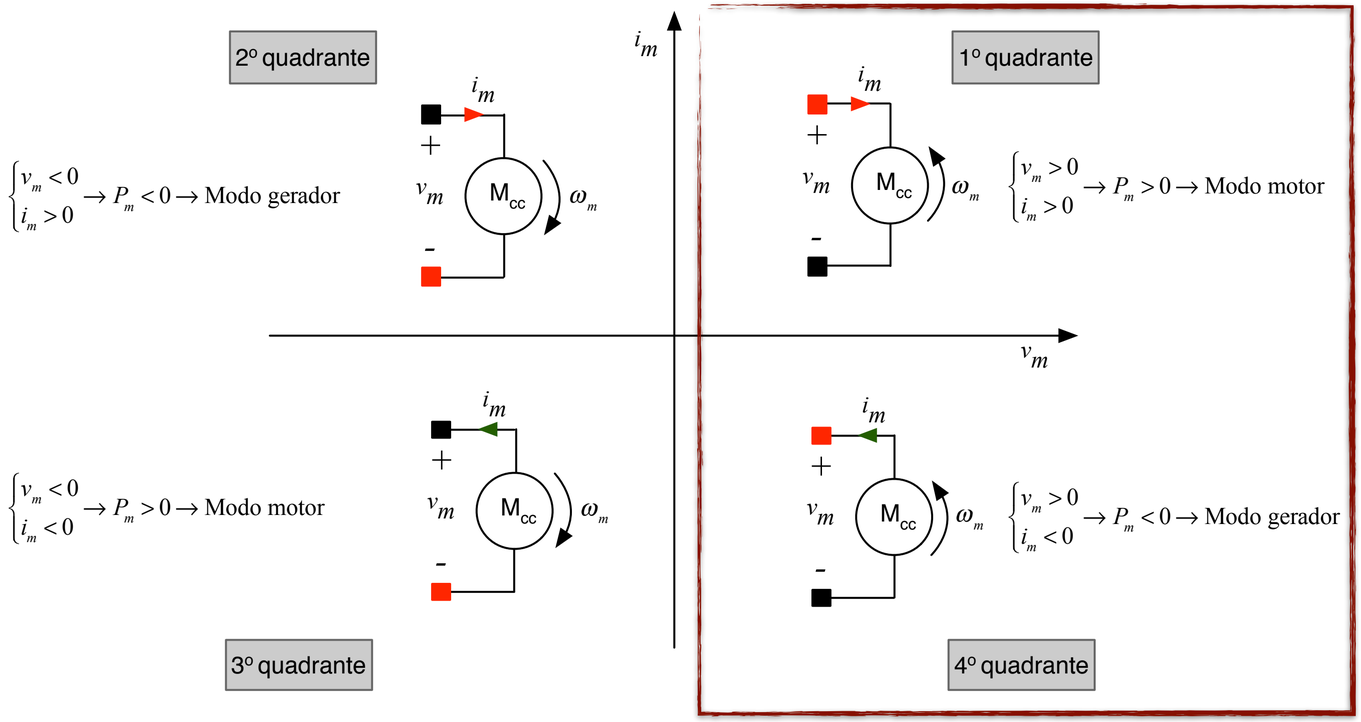
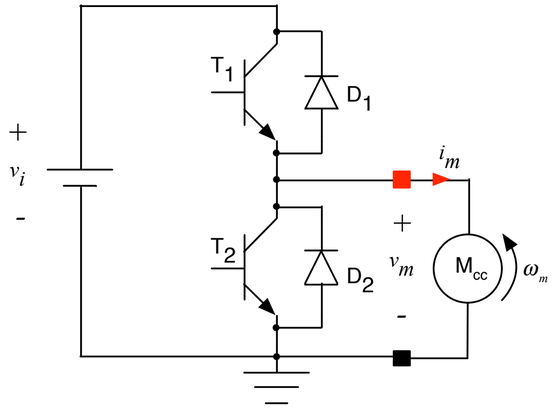


Segunda etapa



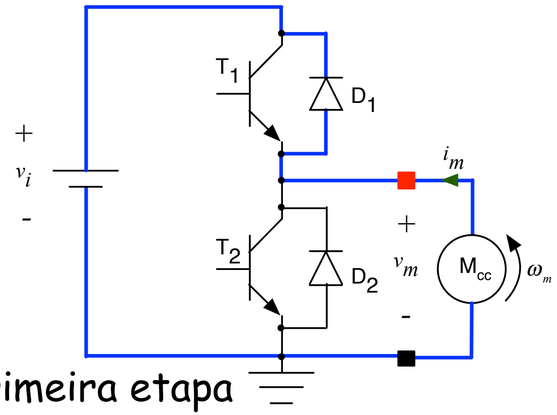
Quadrantes de Operação



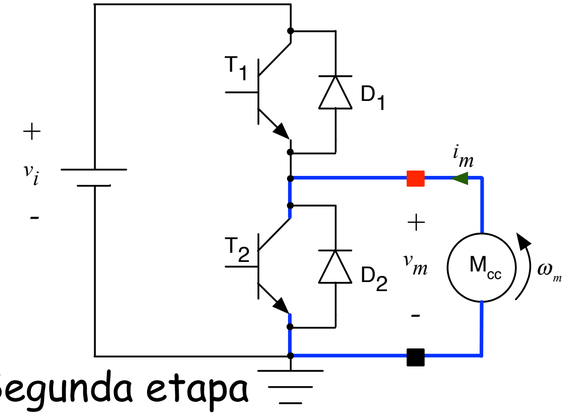


Conversor meia ponte

Modo gerador



Primeira etapa



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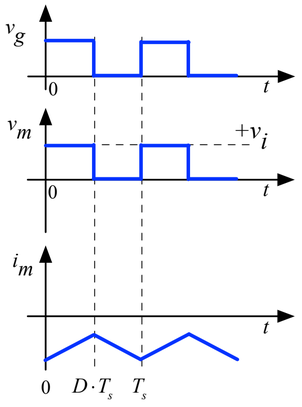
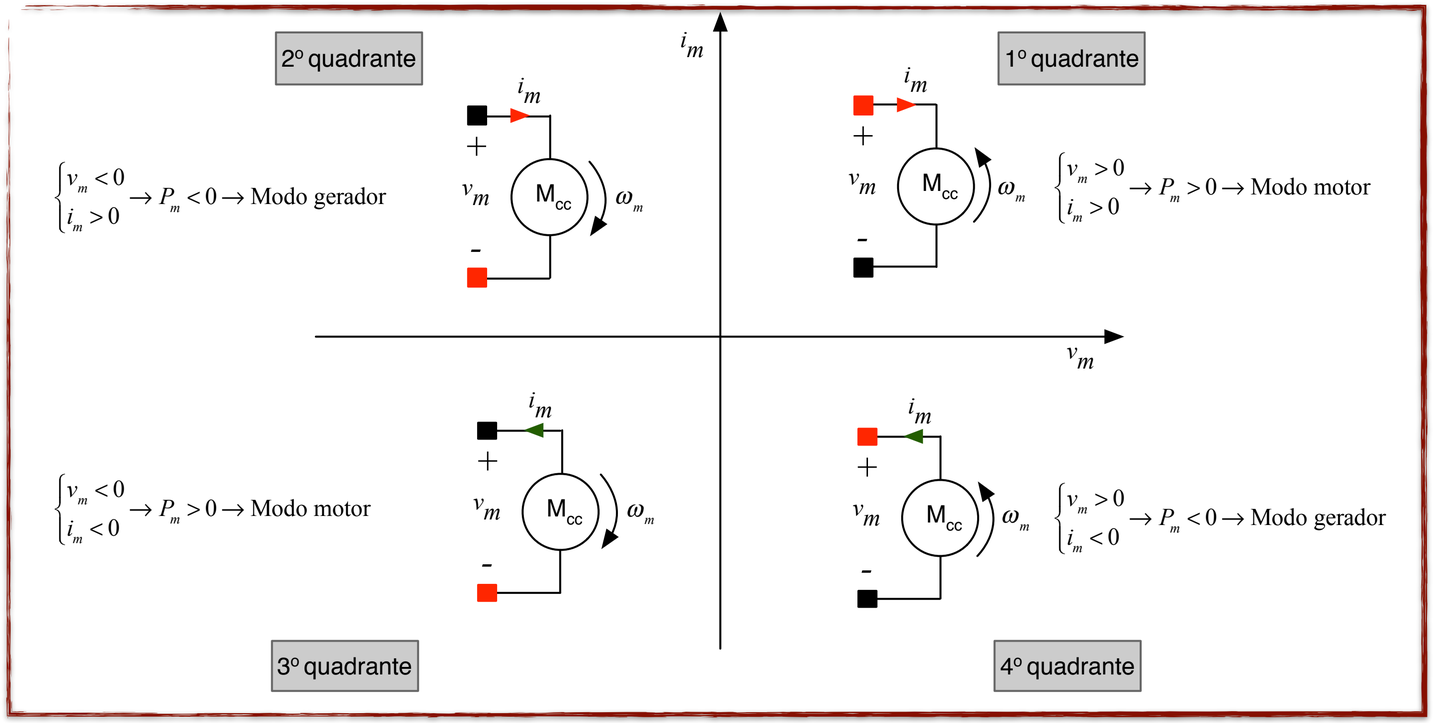
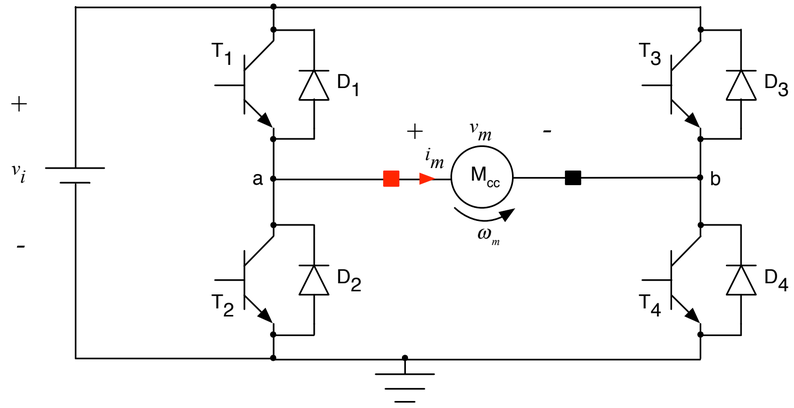


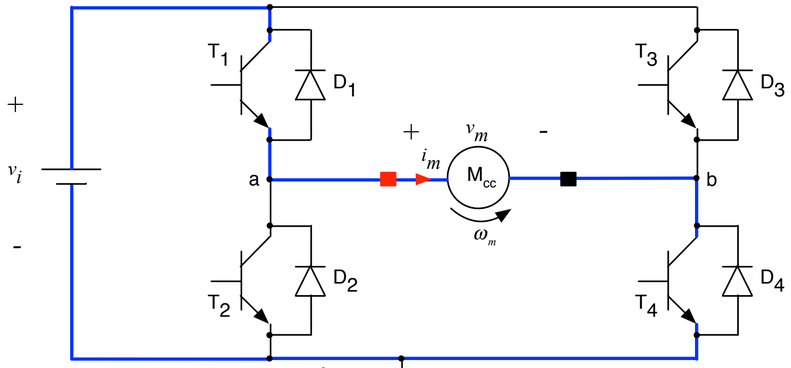
Quadrantes de Operação



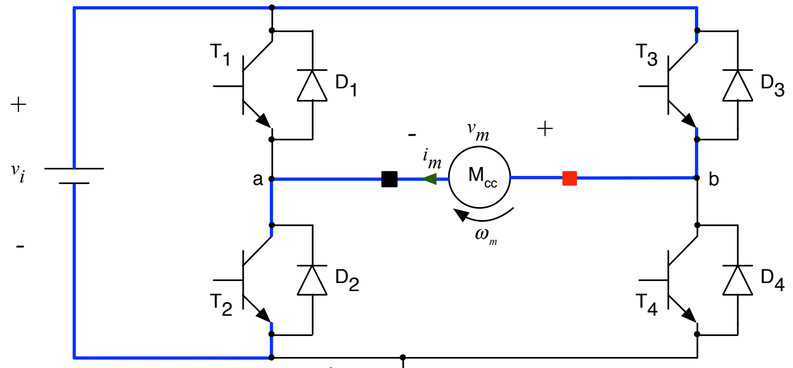


Conversor ponte completa

Modo motor

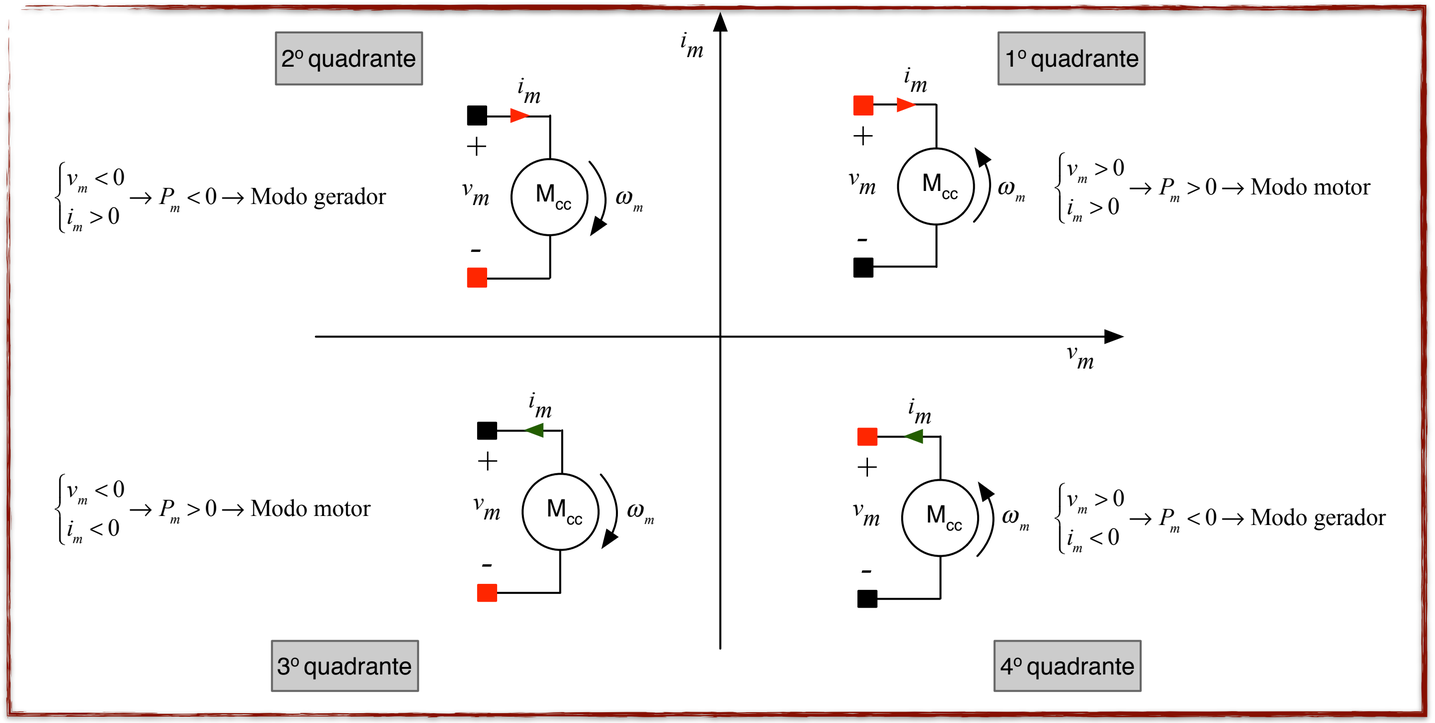


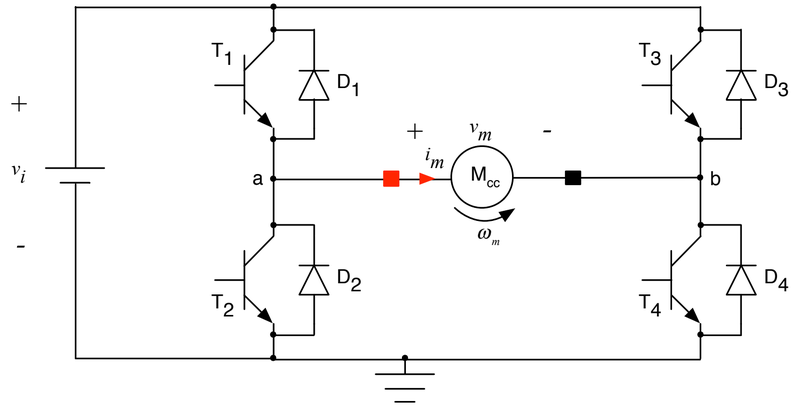
Rotação um sentido



Rotação em outro sentido

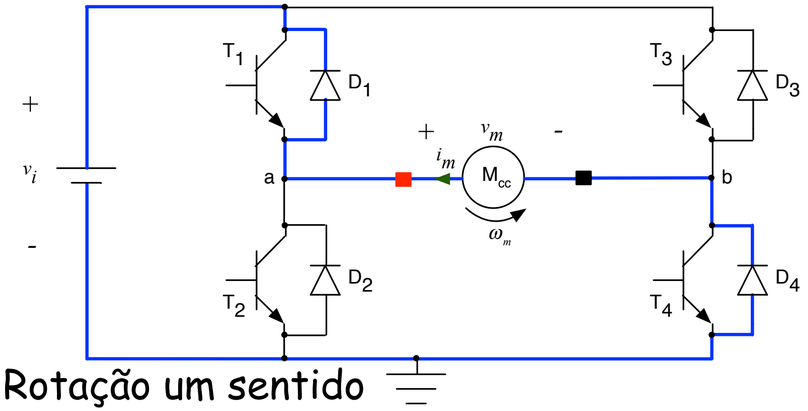
Quadrantes de Operação



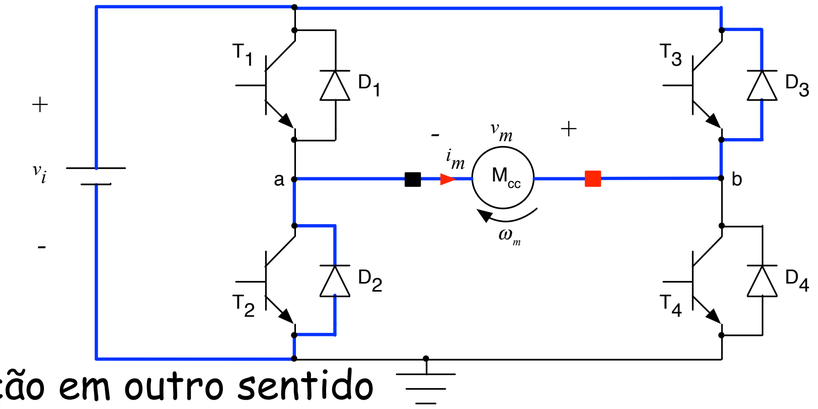


Conversor ponte completa

Modo gerador

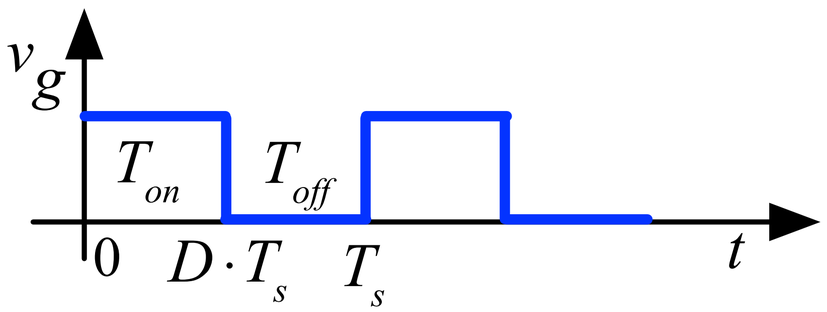


Rotação um sentido



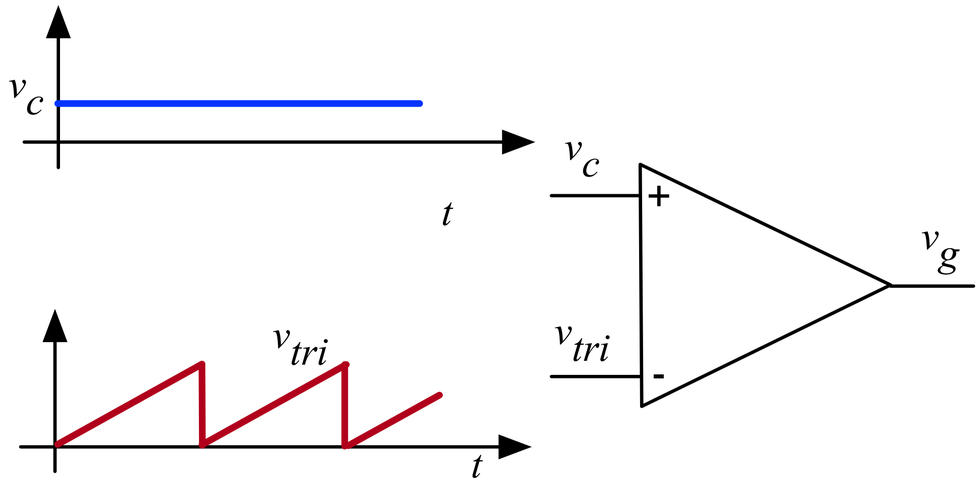
Rotação em outro sentido

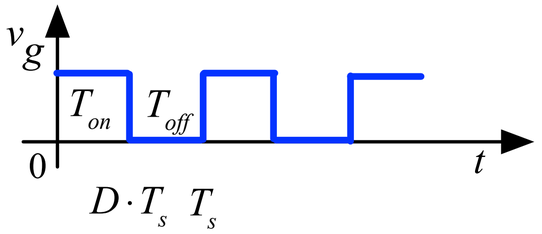
Modulação PWM



$$T_s = \frac{1}{F_s} \qquad T_{on} = D \cdot T_s$$

$$T_{of} = T_s - T_{on} = T_s - D \cdot T_s = \left(1 - D\right) \cdot T_s$$





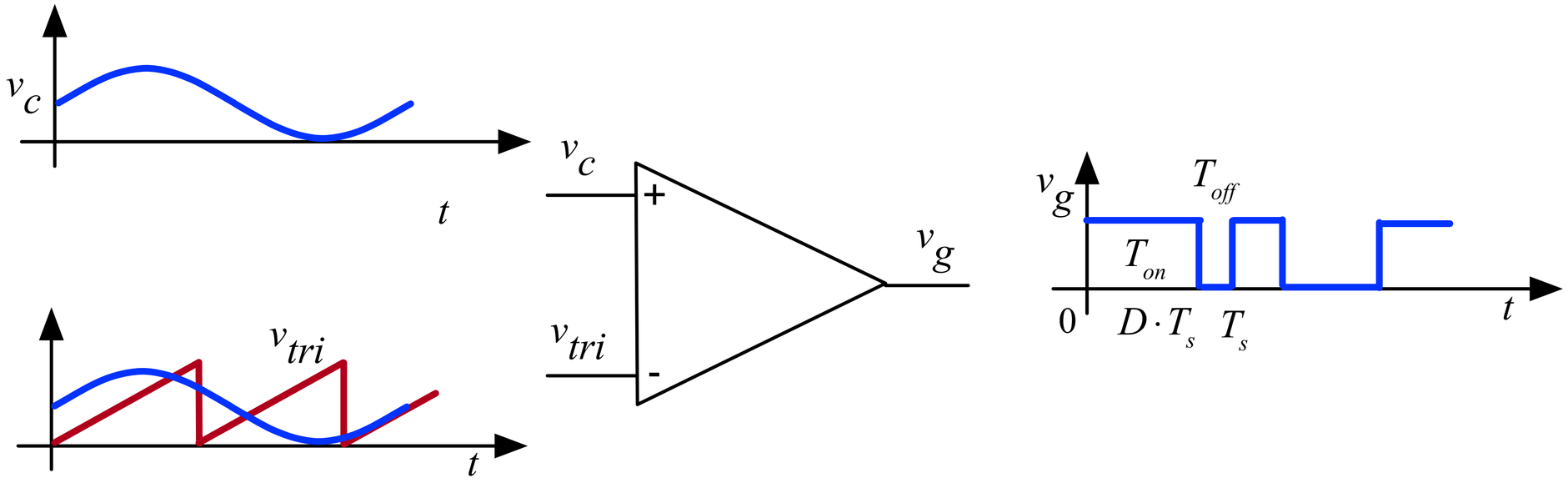
$$D = \frac{T_{on}}{T_s}$$

$$D = \frac{V_c}{V_{tri}}$$

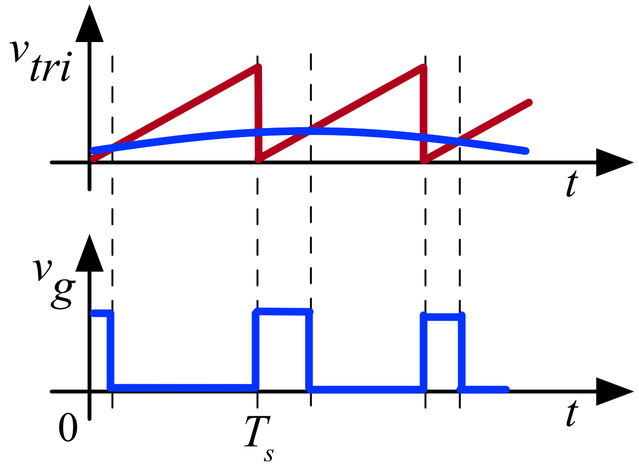
Modulação PWM Senoidal

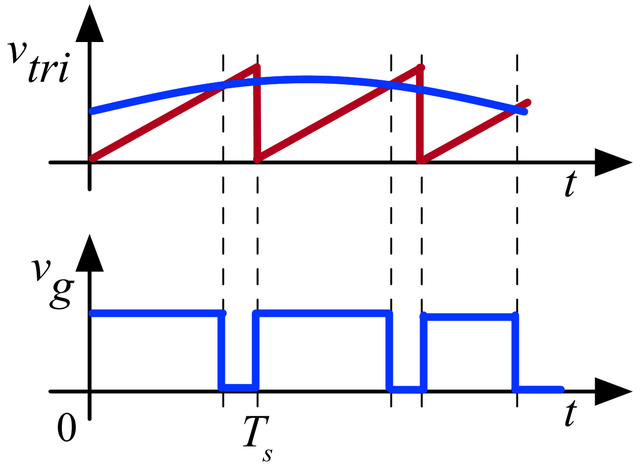
$$d(t) = \frac{v_c(t)}{v_{tri}(t)} = \frac{V_c \cdot seno(t)}{V_{tri}} = \frac{V_c}{V_{tri}} \cdot seno(t)$$

$$IM = \frac{V_c}{V_{tri}} \rightarrow d(t) = IM \cdot seno(t)$$

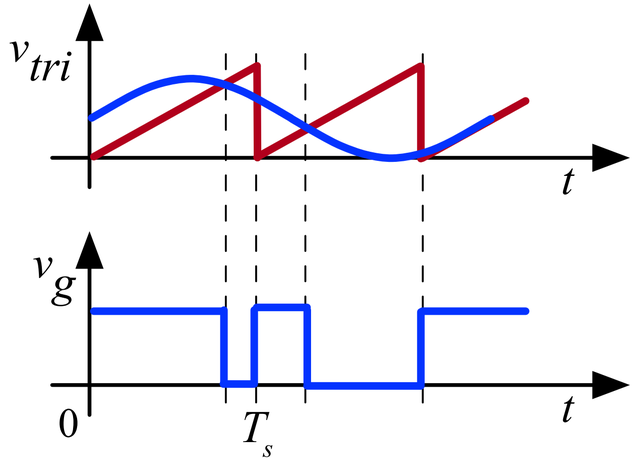


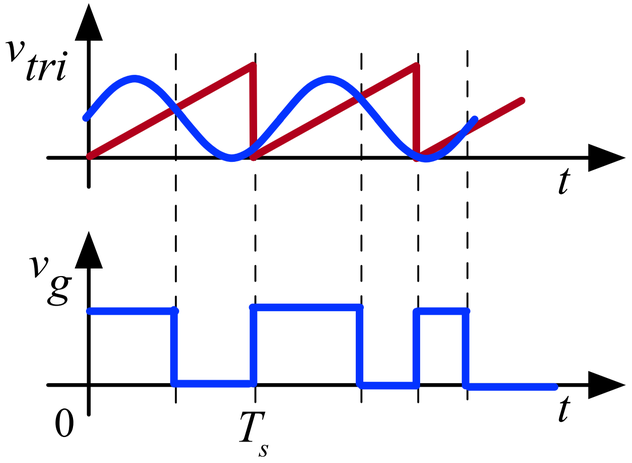
Modulação PWM Senoidal





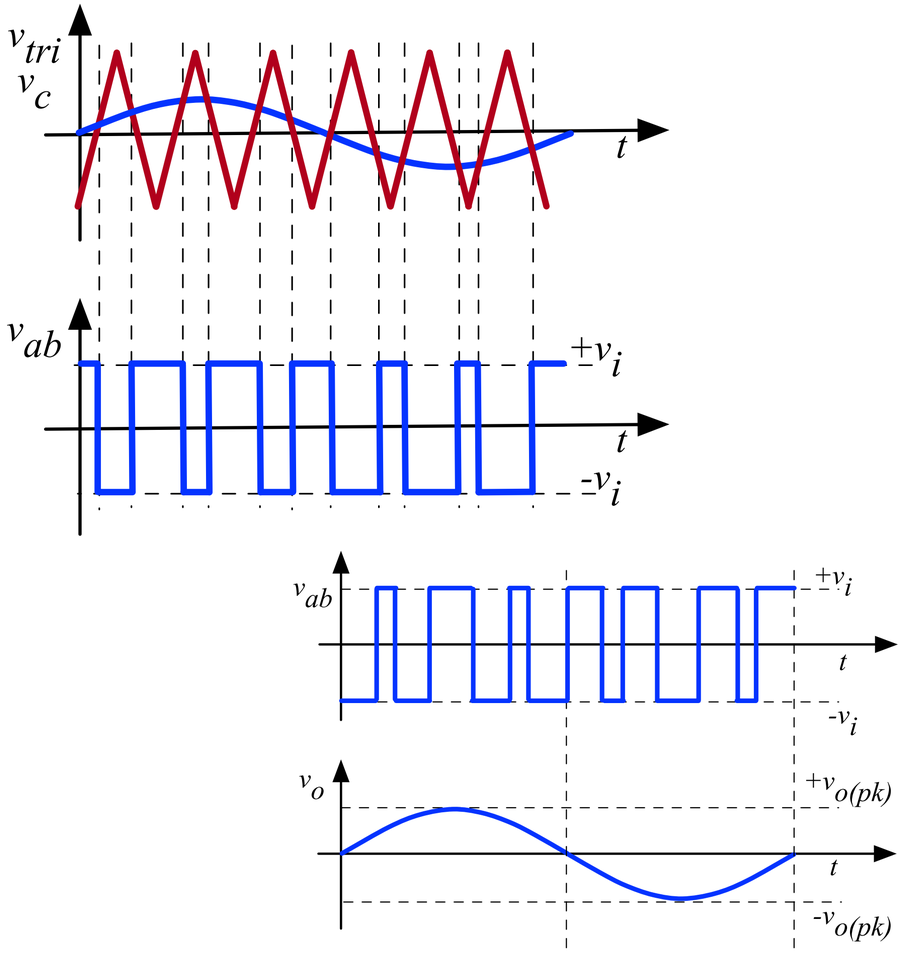
Modificação na amplitude da modulante



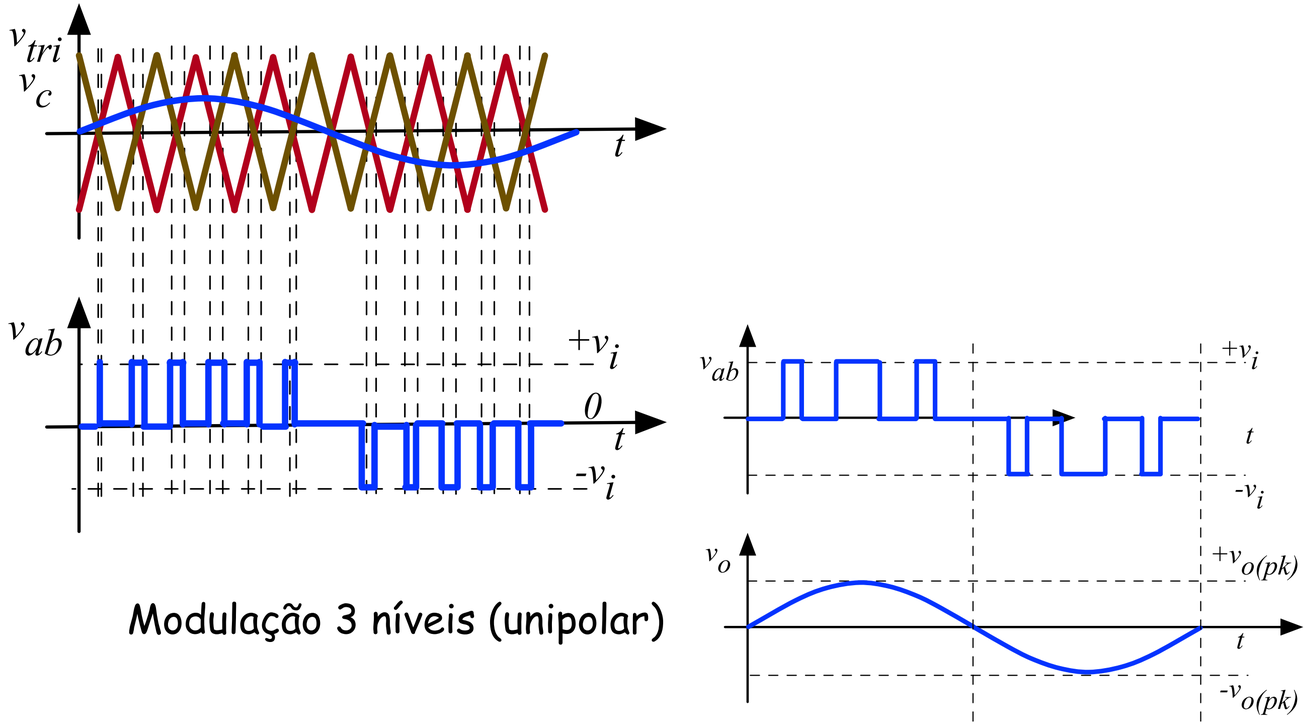


Modificação na frequência da modulante

Modulação PWM Senoidal

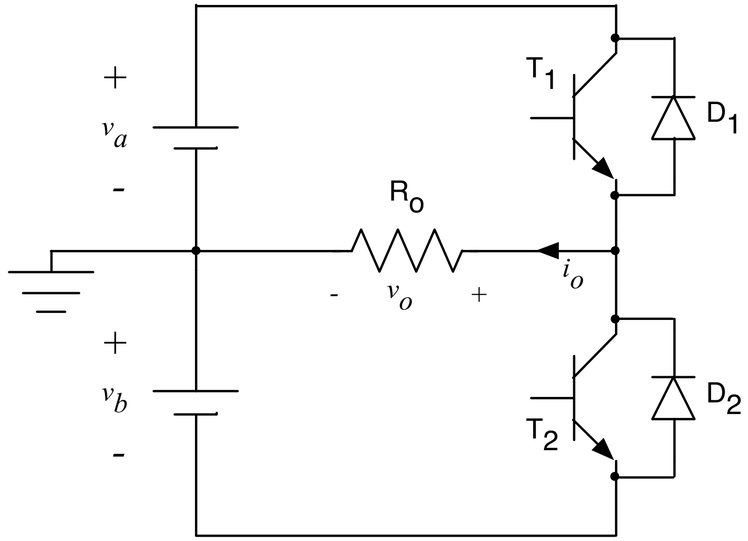


Modulação 2 níveis (bipolar)



Modulação 3 níveis (unipolar)

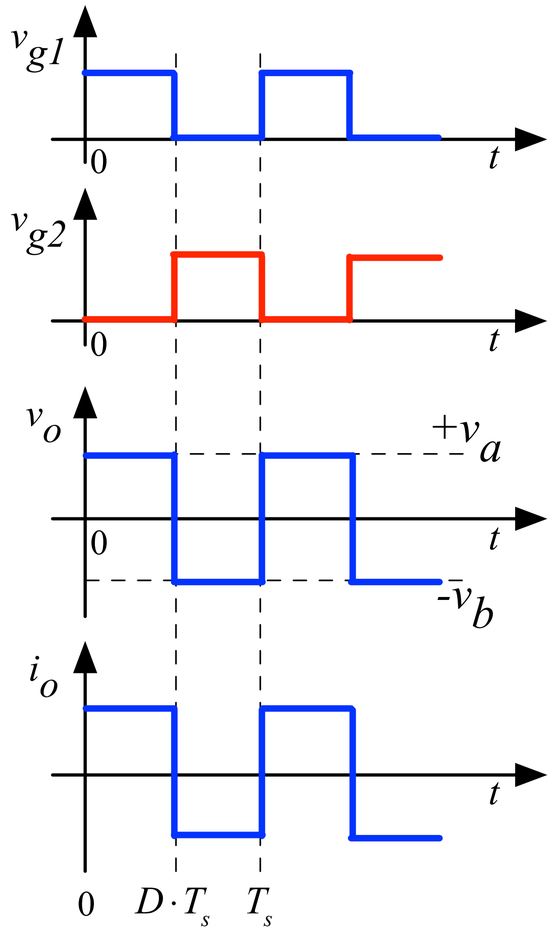
Princípio de funcionamento



$$\begin{cases} v_a = V_a \\ v_b = V_b \end{cases} \rightarrow \text{definidas} \qquad \begin{aligned} +V_{o(\max)} &= V_{a(\max)} \\ -V_{o(\max)} &= V_{b(\max)} \end{aligned}$$

$$V_a = V_b = \frac{V_i}{2} \qquad V_o = \frac{1}{T_s} \cdot V_a \cdot D \cdot T_s + \frac{1}{T_s} \cdot \left(-V_b\right) \cdot \left(1 - D\right) \cdot T_s$$

$$V_o = V_a \cdot D - V_b \cdot \left(1 - D\right)$$

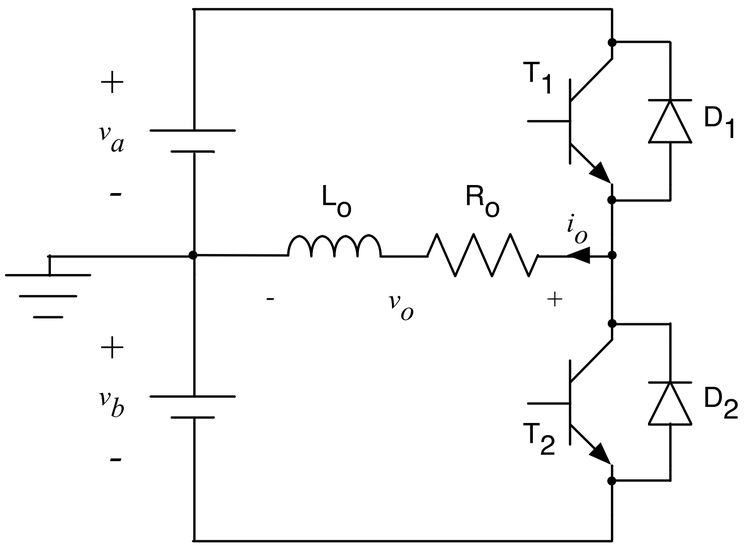


$$V_o = \frac{V_i}{2} \cdot \left(2 \cdot D - 1\right)$$

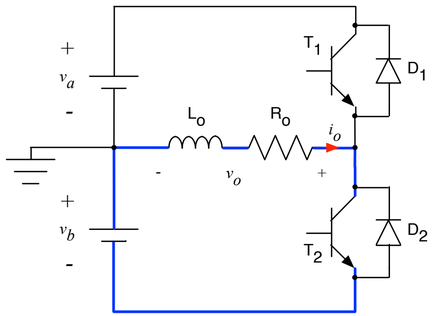
$$V_o = \begin{cases} D = 0 \rightarrow -\frac{V_i}{2} \\ D = 0{,}5 \rightarrow 0 \\ D = 1 \rightarrow +\frac{V_i}{2} \end{cases}$$

$$D = \frac{1}{2} + \frac{V_o}{V_i}$$

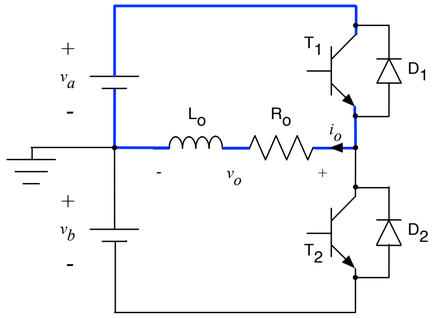
Princípio de funcionamento



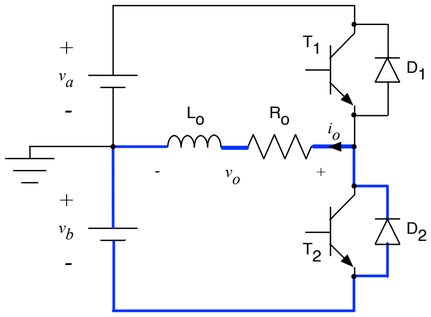
Tempo morto



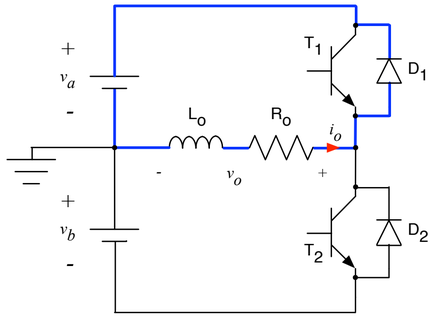
Terceira etapa



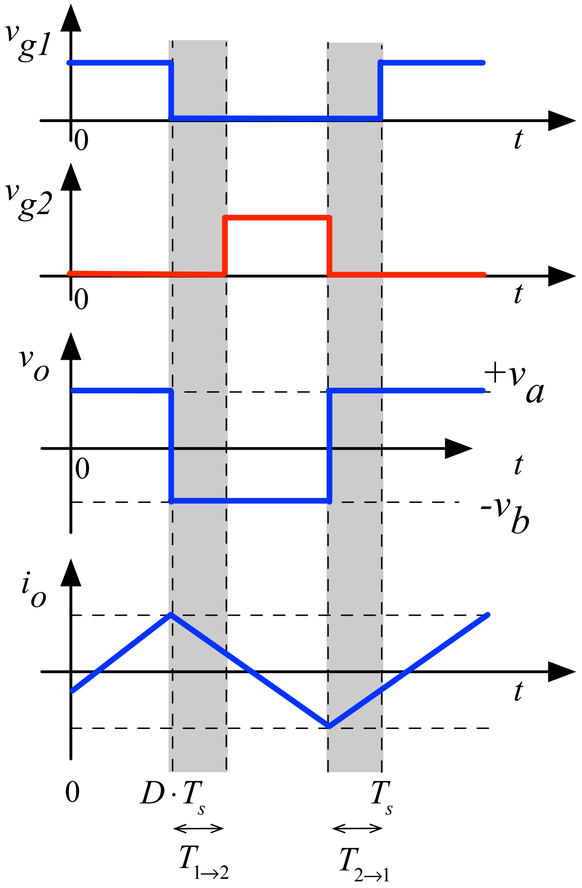
Primeira etapa



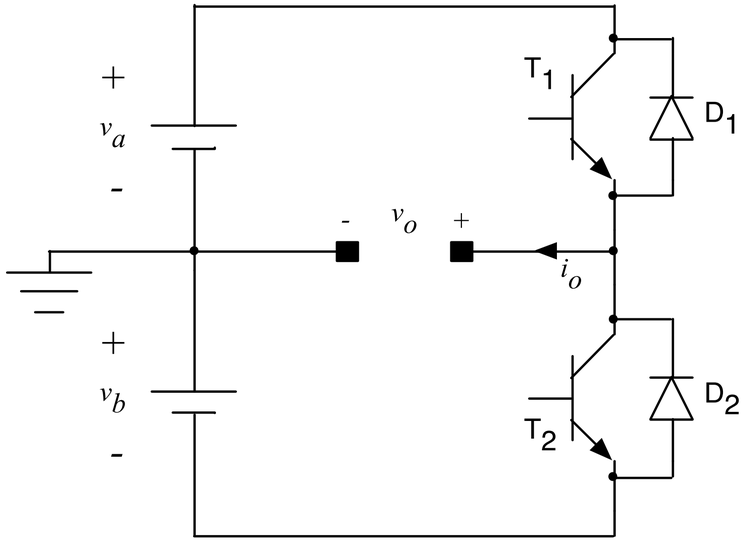
Segunda etapa



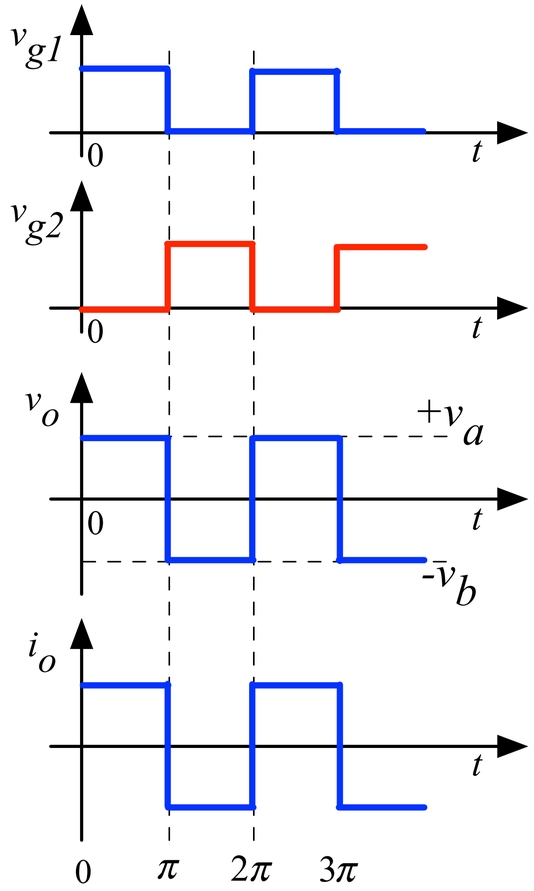
Quarta etapa



Conversor Meia Ponte

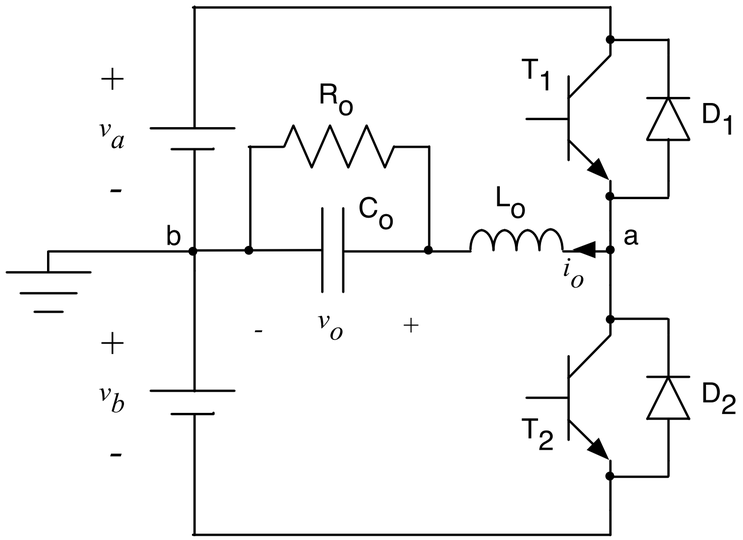


Onda Quadrada

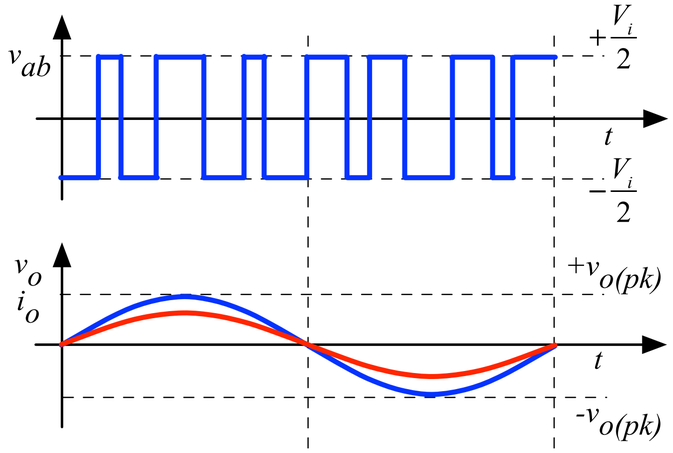


$$V_{o(ef)} = \frac{V_i}{2} \rightarrow V_a = V_b = \frac{V_i}{2}$$

Conversor Meia Ponte



PWM Senoidal



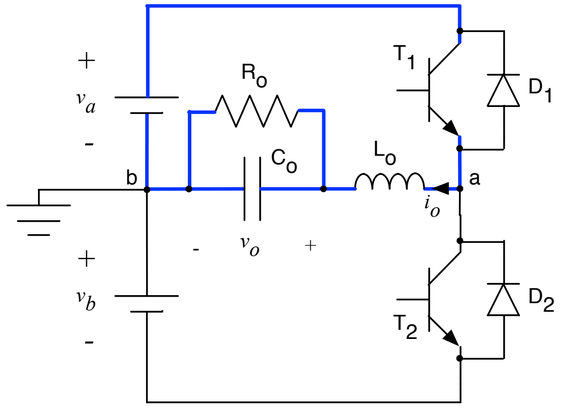
$$V_a = V_b = \frac{V_i}{2}$$

$$V_{Lo} = 0 \rightarrow V_o = V_{ab} \rightarrow V_o = \frac{V_i}{2} \cdot \left(2 \cdot D - 1\right)$$

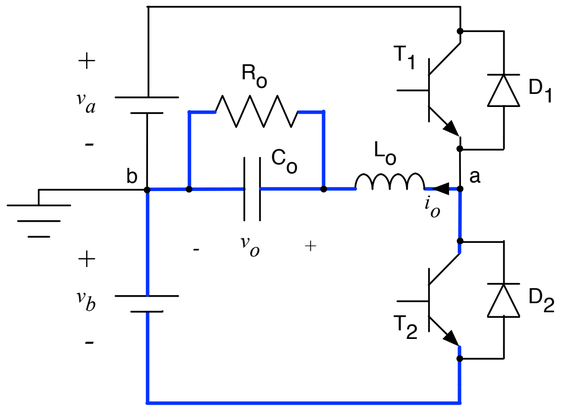
$$v_o\left(t\right) = V_{o(pk)} \cdot seno(t)$$

$$d\left(t\right) = \frac{1}{2} + \frac{V_{o(pk)} \cdot seno\left(t\right)}{V_i} \rightarrow d\left(t\right) = \frac{1}{2} + \frac{V_{o(pk)}}{V_i} \cdot seno\left(t\right)$$

$$IM = \frac{V_{o(pk)}}{V_i} \rightarrow d\left(t\right) = \frac{1}{2} + IM \cdot seno\left(t\right)$$

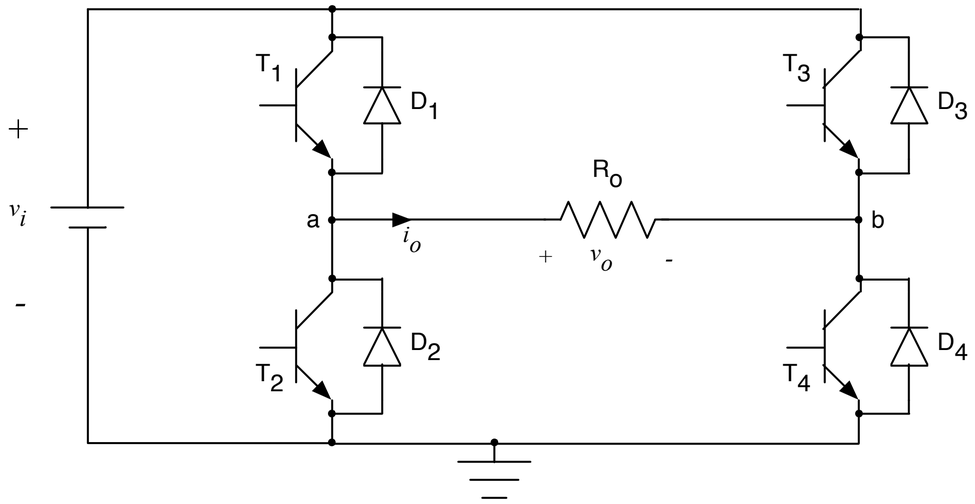


Primeira etapa



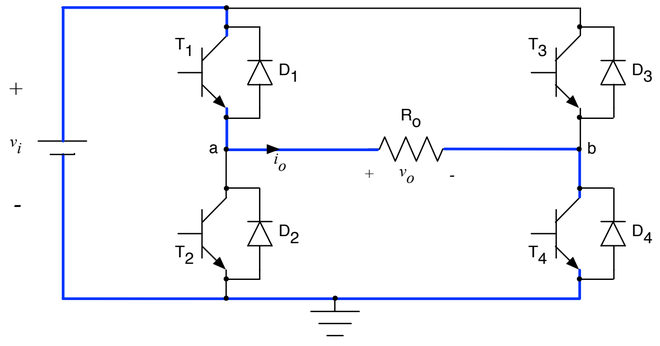
Segunda etapa

Conversor Ponte Completa

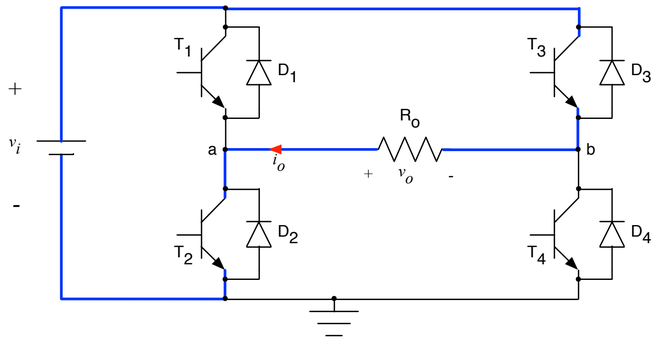


Onda Quadrada

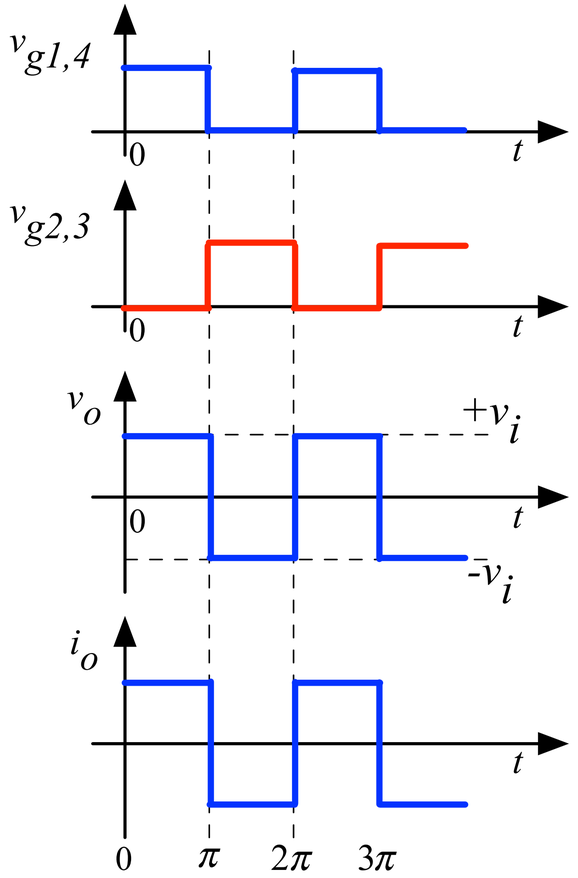
$$V_{o(ef)} = V_i$$



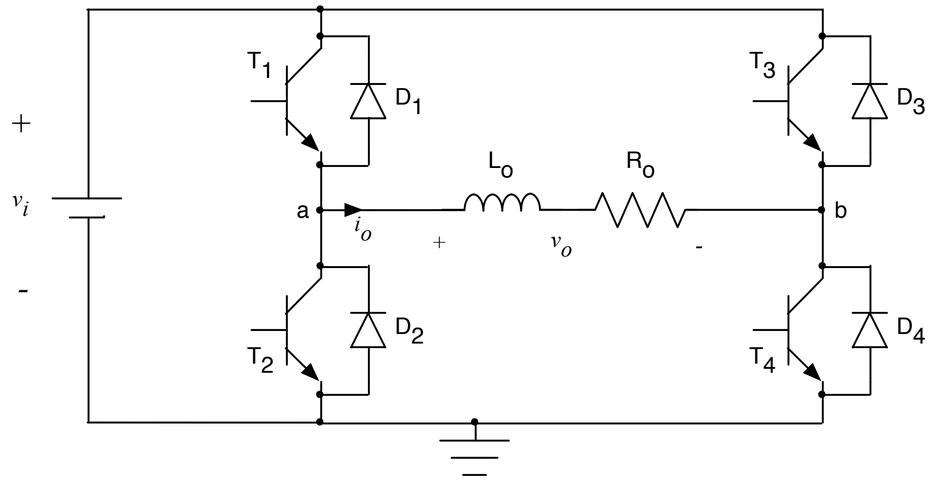
Primeira etapa



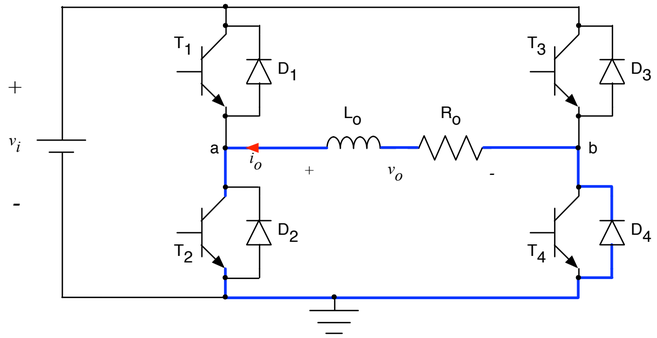
Segunda etapa

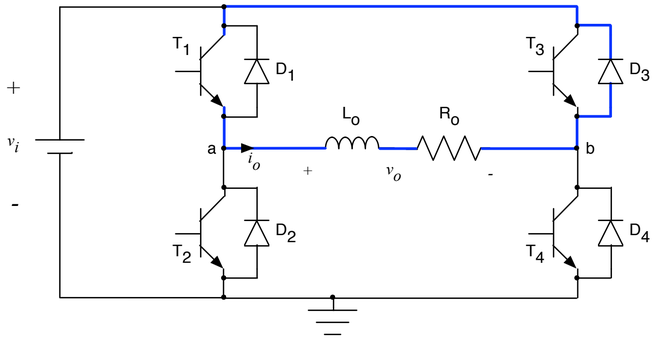


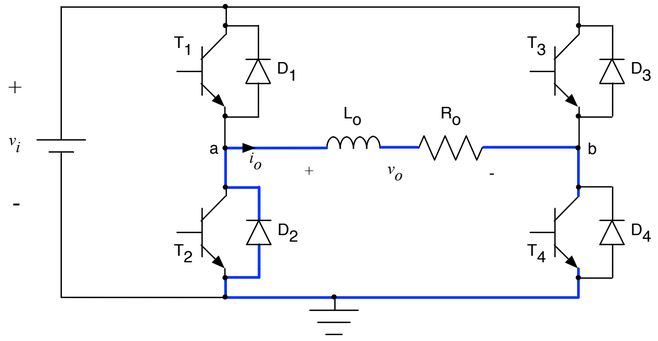
Conversor Ponte Completa



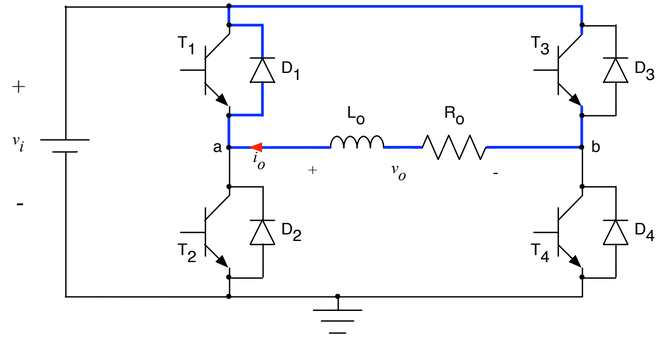
Três níveis







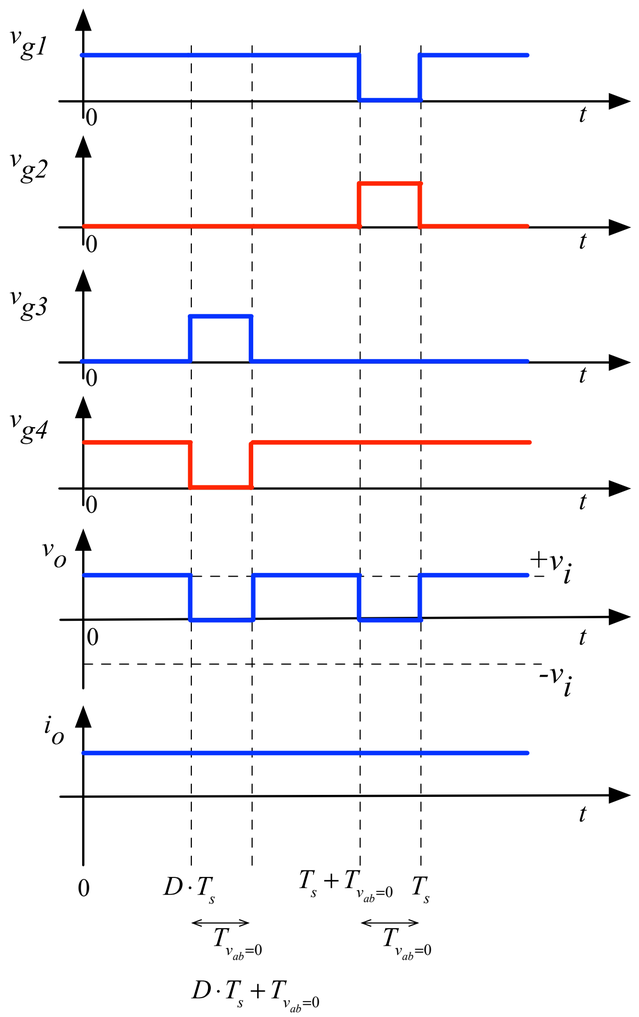
Semiciclo positivo



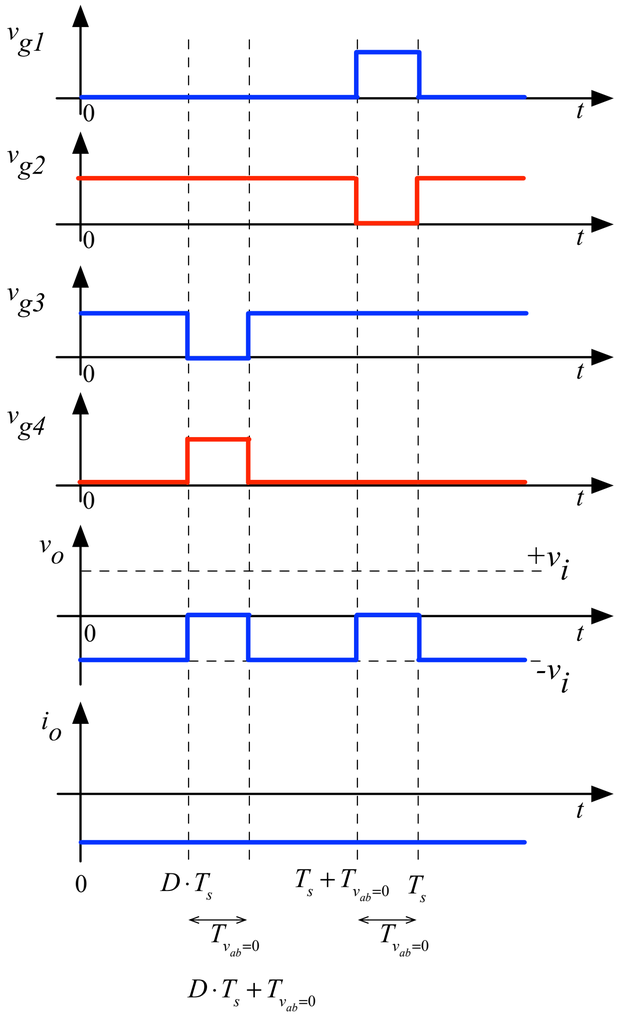
Semiciclo negativo

Conversor Ponte Completa

Três níveis

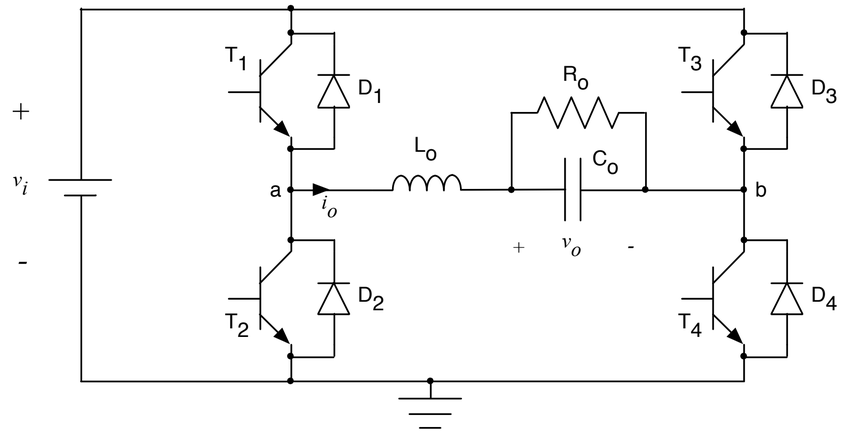


Semiciclo positivo

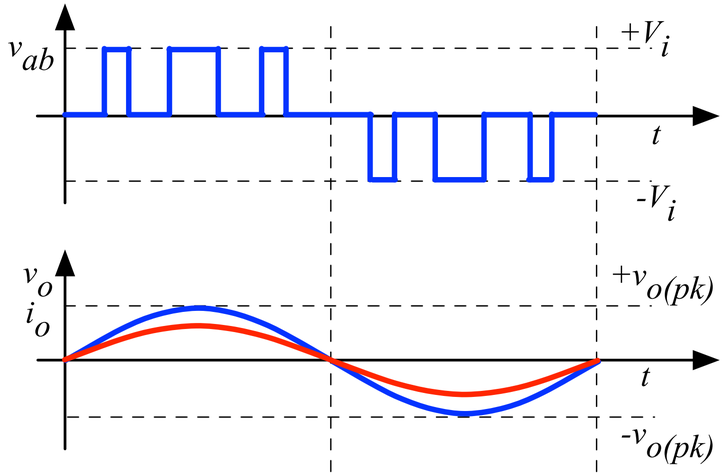


Semiciclo negativo

Conversor Ponte Completa



PWM Senoidal



$$V_i = \text{definida}$$

$$V_{ab} = \frac{1}{T_s} \cdot V_i \cdot D \cdot T_s$$

$$V_{ab} = V_i \cdot D$$

$$V_{Lo} = 0 \rightarrow V_o = V_{ab} \rightarrow V_o = V_i \cdot D$$

$$V_{o(ef)} = \frac{V_{o(pk)}}{\sqrt{2}}$$

$$v_o(t) = V_{o(pk)} \cdot seno(t)$$

$$V_{o(pk)} \cdot seno(t) = V_i \cdot d(t)$$

$$d(t) = \frac{V_{o(pk)} \cdot seno(t)}{V_i} \rightarrow d(t) = \frac{V_{o(pk)}}{V_i} \cdot seno(t)$$

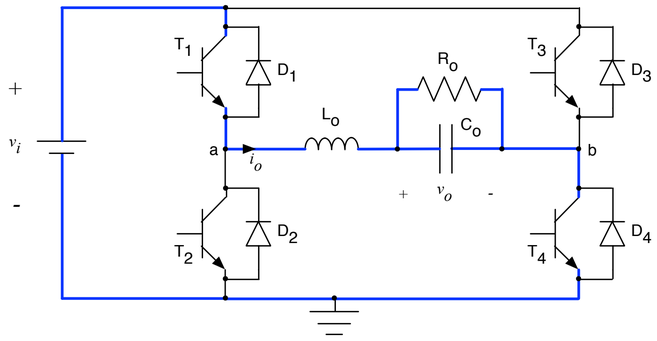
$$IM = \frac{V_{o(pk)}}{V_i} \rightarrow d(t) = IM \cdot seno(t)$$

$$\Delta i = \% \cdot I_o[A] \qquad \Delta v = \% \cdot V_o[V]$$

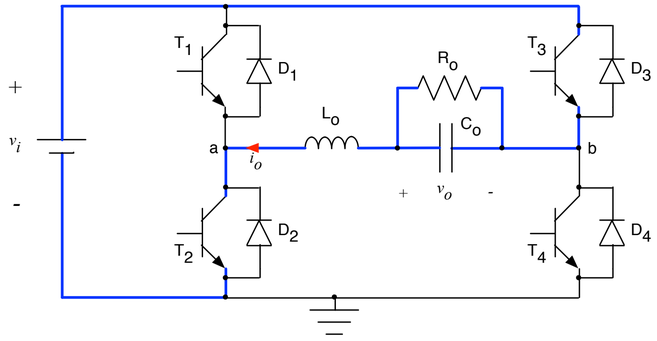
$$L_o = \frac{V_i}{2 \cdot \Delta_i \cdot F_s} \cdot D \cdot (1 - D) \qquad C_o = \frac{V_i}{4 \cdot \pi^3 \cdot \Delta v \cdot L_o \cdot F_s^2}$$

Conversor Ponte Completa

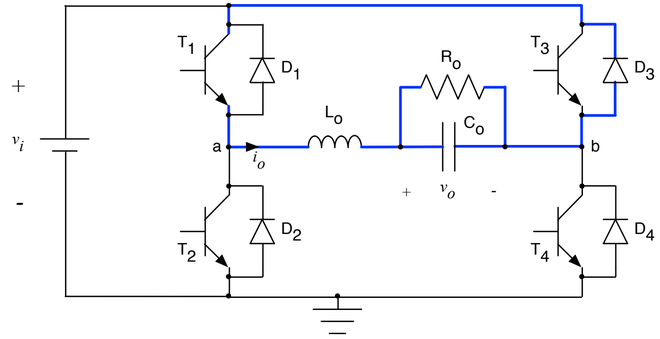
PWM Senoidal



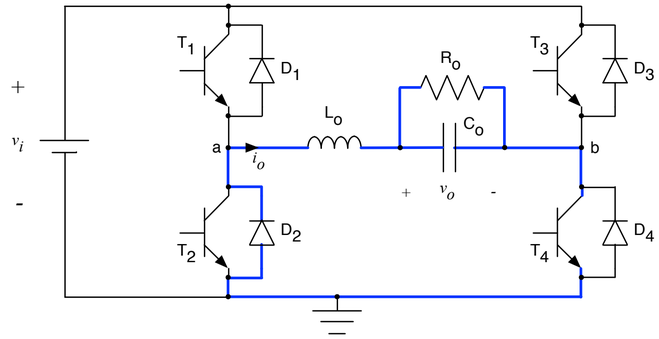
$v_{ab} = +V_i$ e $i_o > 0$



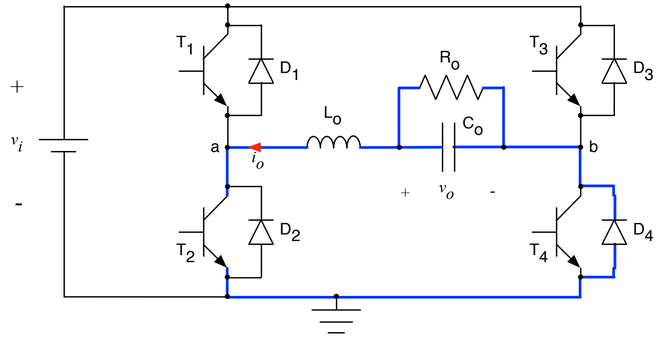
$v_{ab} = -V_i$ e $i_o < 0$



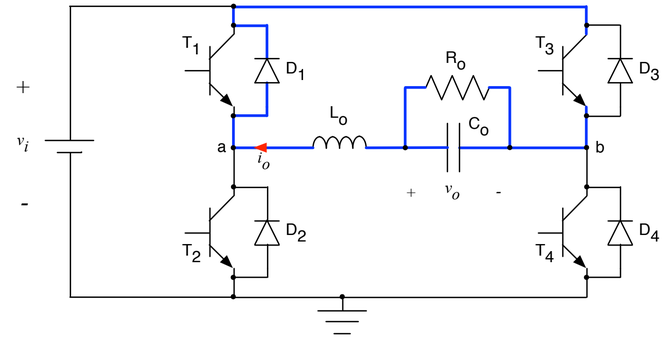
$v_{ab} = 0$ e $i_o > 0$



$v_{ab} = 0$ e $i_o > 0$



$v_{ab} = 0$ e $i_o < 0$



$v_{ab} = 0$ e $i_o < 0$

Próxima Aula

Conversores ca-ca

https://www.apc.com/

https://www.sms.com.br/

http://upsai.com.br/

https://www.zael.com.br/