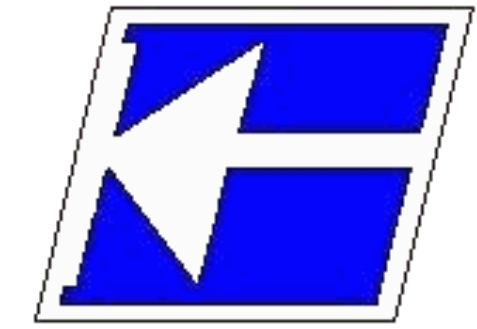




Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina  
Departamento Acadêmico de Eletrônica  
Eletrônica de Potência



# Conversores CC-CC

Prof. Clovis Antonio Petry.

Florianópolis, agosto 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](http://www.ProfessorPetry.com.br)



<https://www.youtube.com>

# Agenda

Esta aula está organizada em:

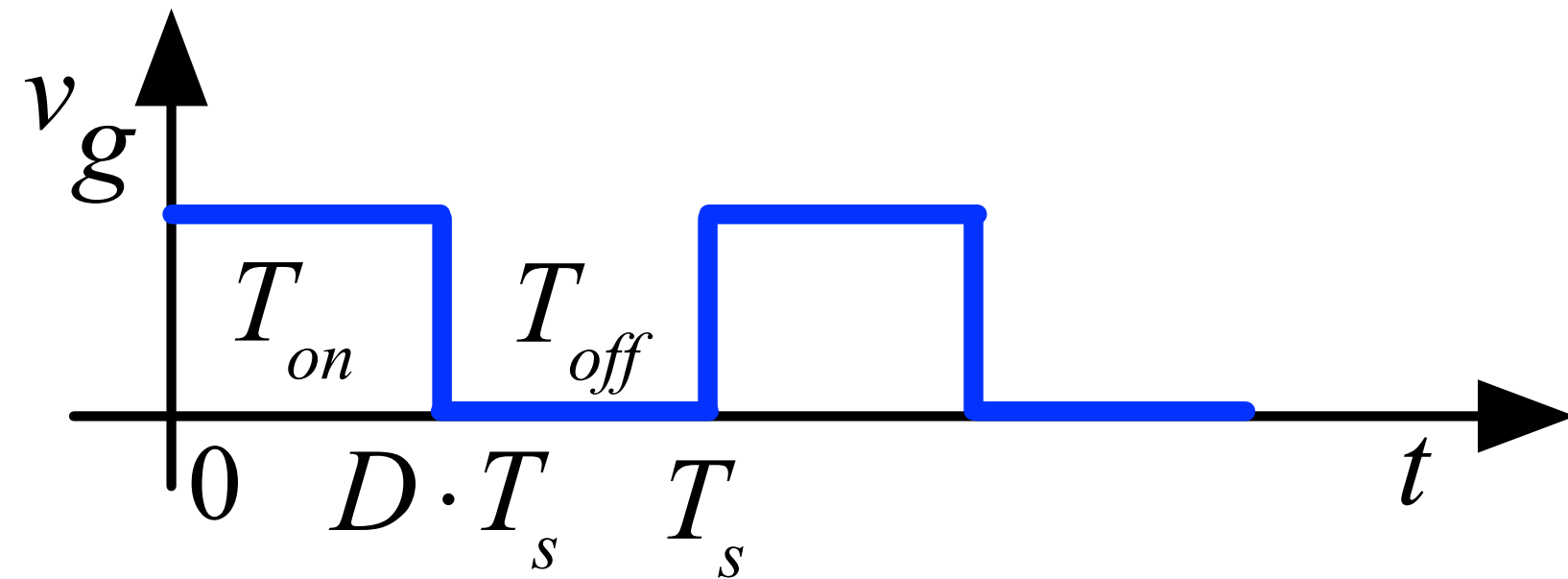
1. Introdução aos conversores cc-cc:
  - Modulação PWM;
  - Princípio de funcionamento.
2. Conversores cc-cc não-isolados:
  - Conversor Buck;
  - Conversor Boost;
  - Conversor Buck-Boost.
3. Conversores cc-cc isolados:
  - Conversor Flyback.



Os conversores cc-cc são utilizados em fontes de alimentação chaveadas e também internamente nos equipamentos eletrônicos no circuito de alimentação dos mesmos.



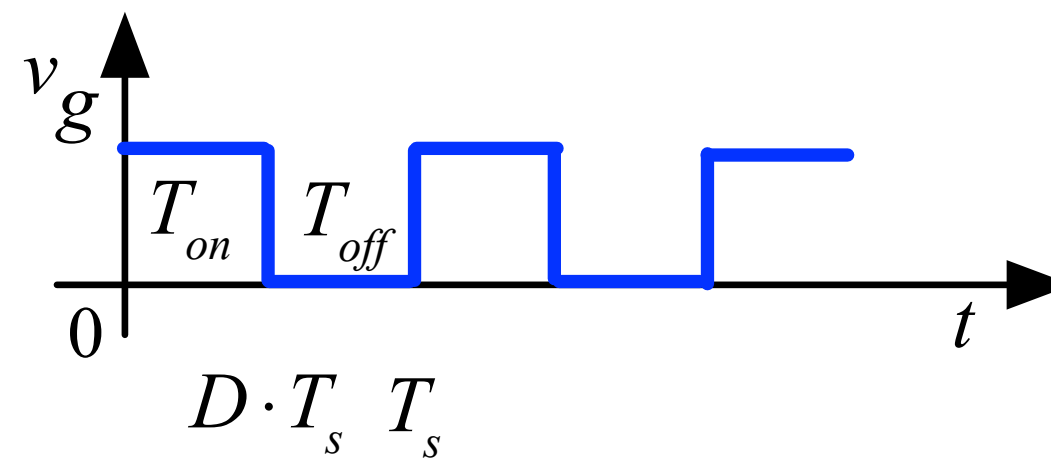
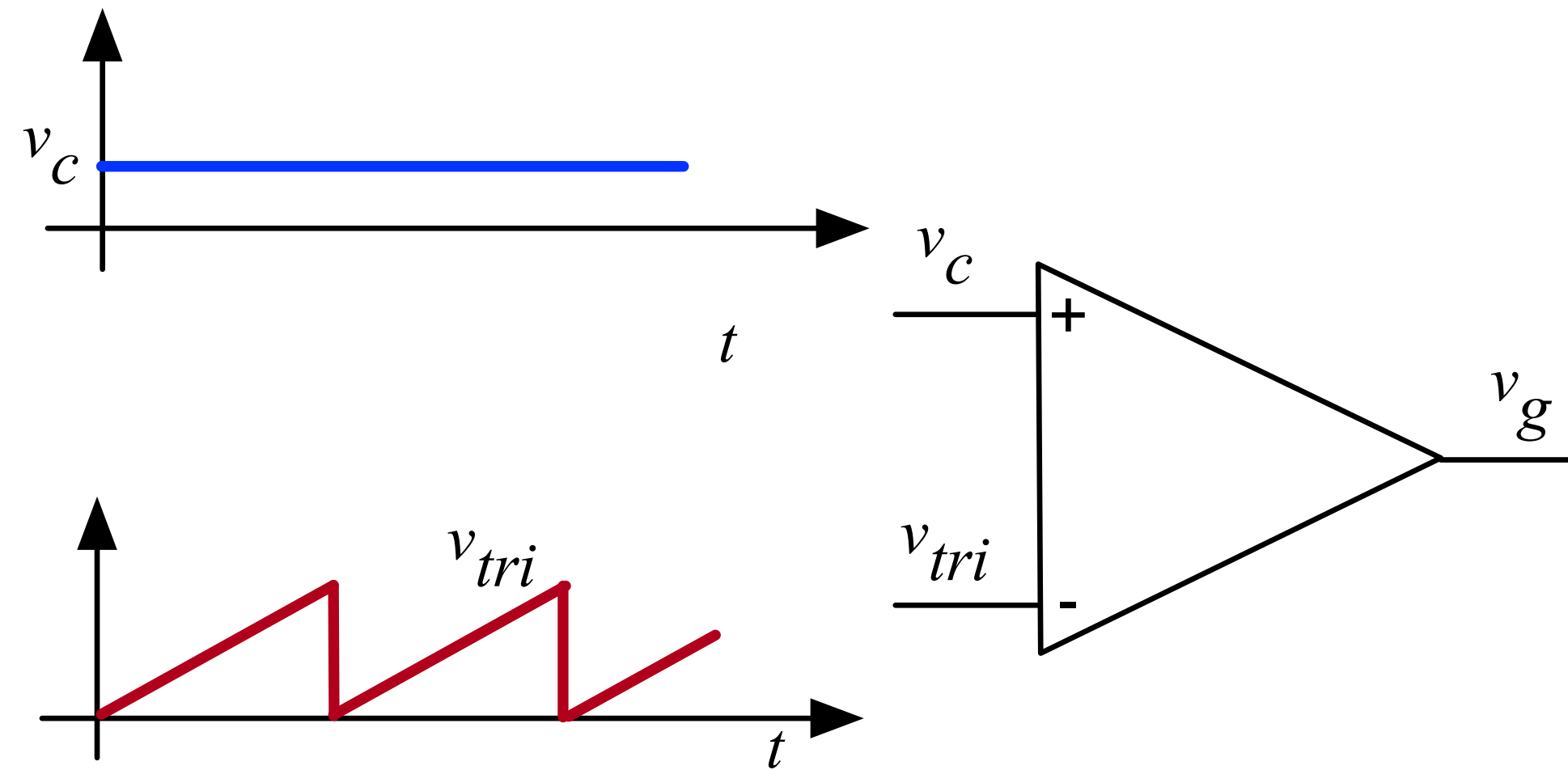
# Modulação PWM



$$T_s = \frac{1}{F_s}$$

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

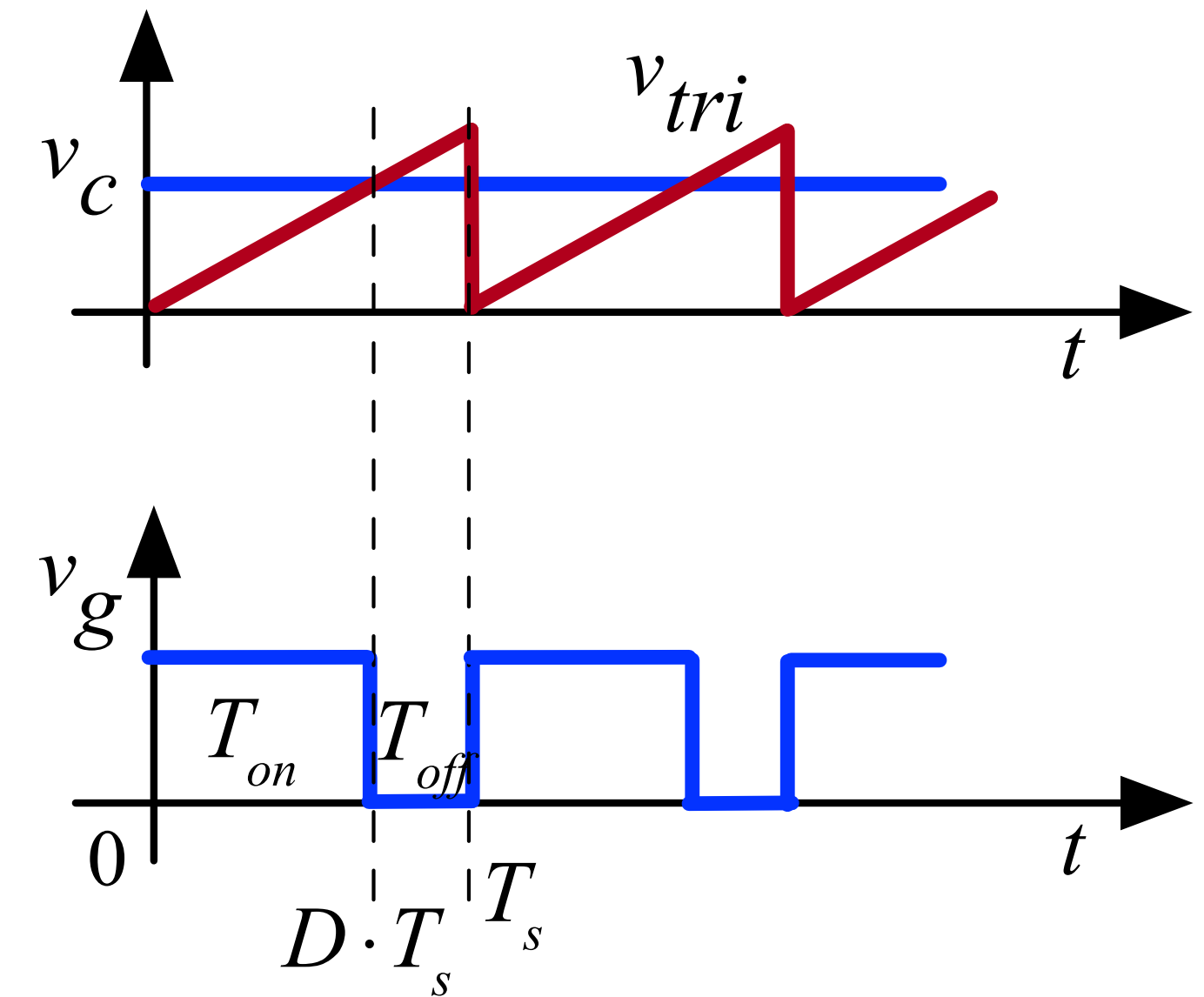
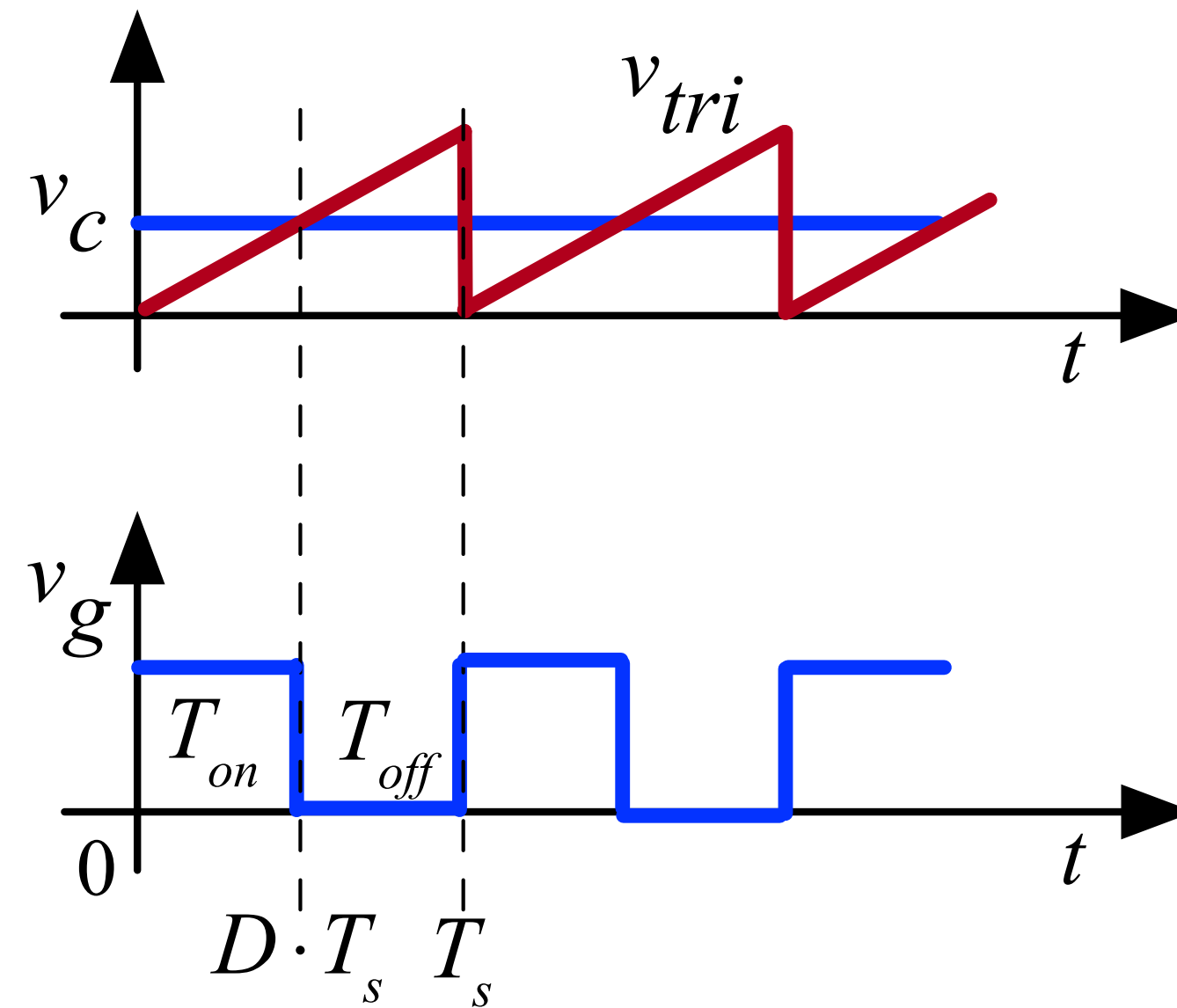
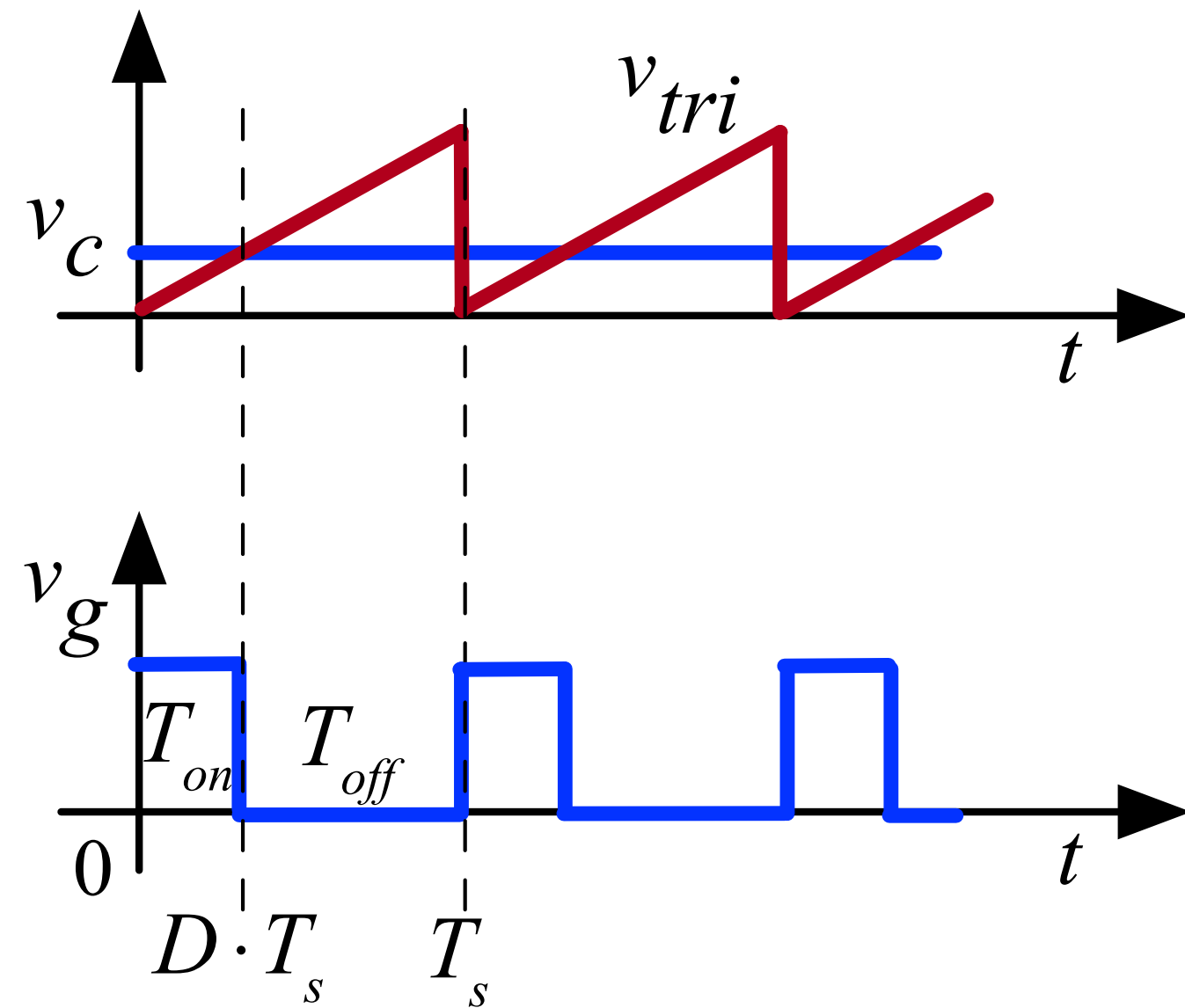
$$T_{of} = T_s - T_{on} = T_s - D \cdot T_s = (1 - D) \cdot T_s$$



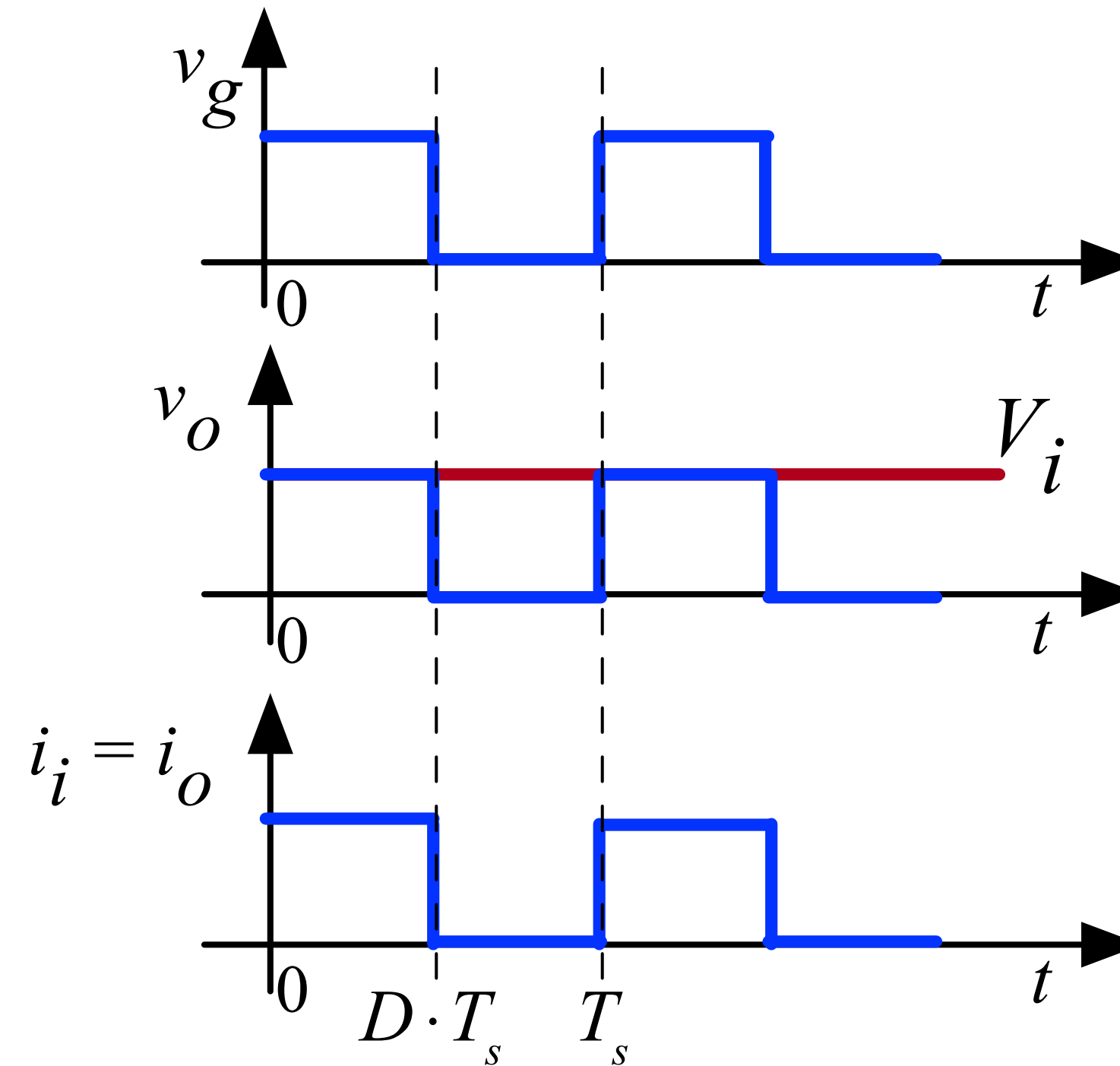
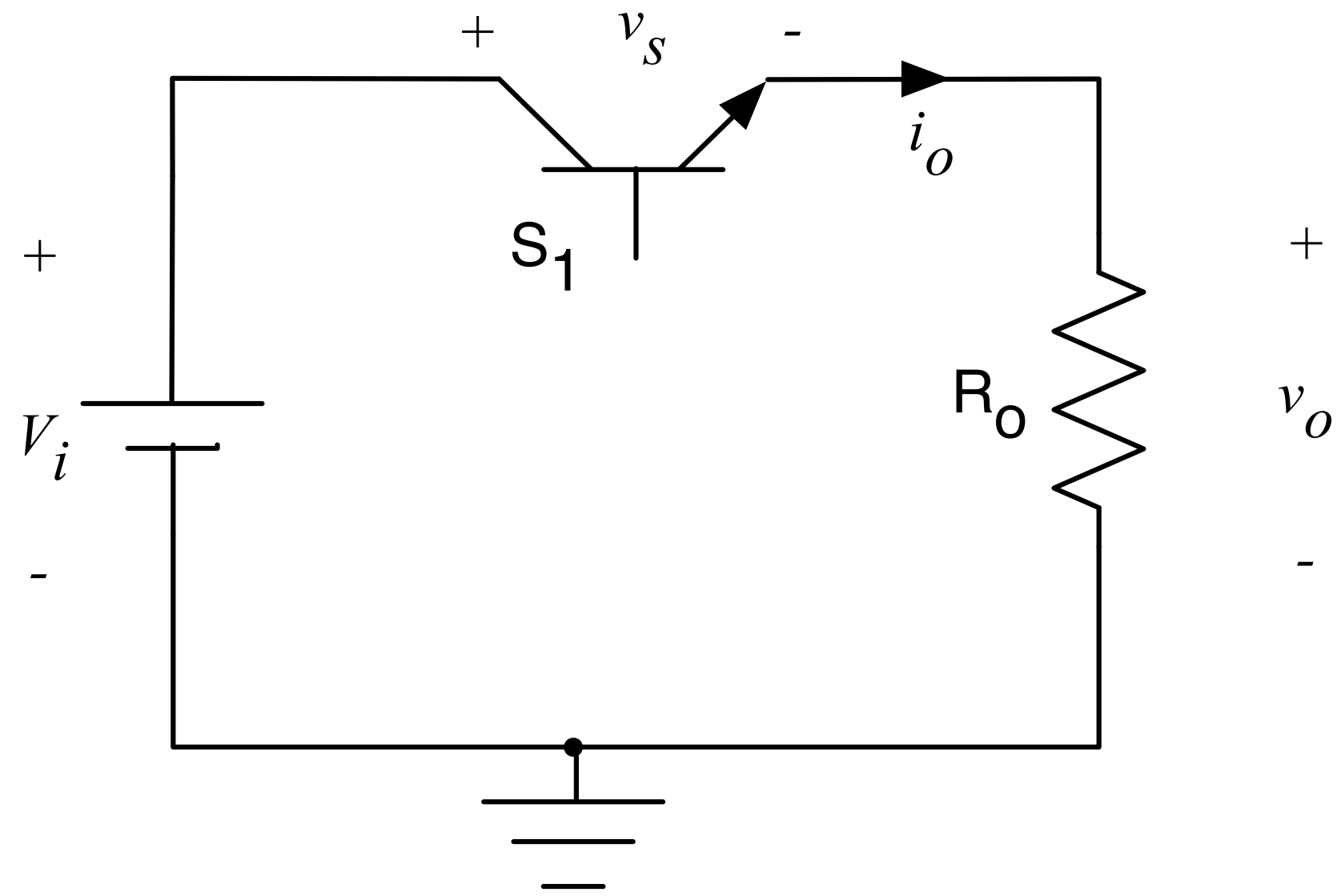
$$D = \frac{T_{on}}{T_s}$$

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

# Modulação PWM



# Princípio de funcionamento



$V_i = \text{definido}$

$$V_{o(\text{max})} = V_i \quad D = \frac{V_o}{V_i}$$

$$V_o = \frac{1}{T_s} \cdot V_i \cdot D \cdot T_s \rightarrow V_o = D \cdot V_i$$

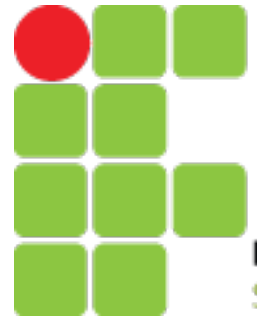
$$I_{o(\text{max})} = \frac{V_{o(\text{max})}}{R_o}$$

$$I_o = \frac{V_o}{R_o}$$

$$I_i = I_o$$

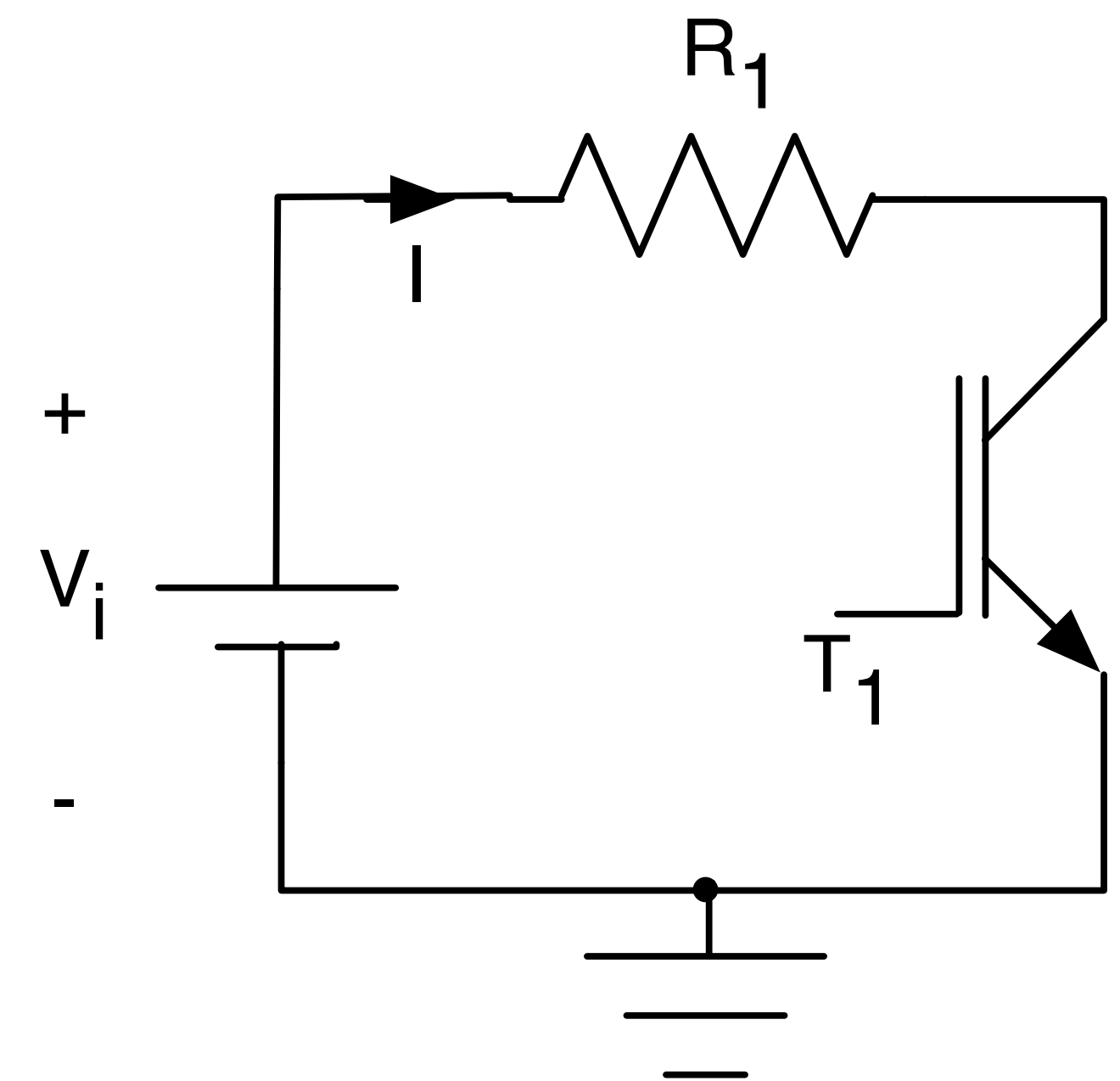
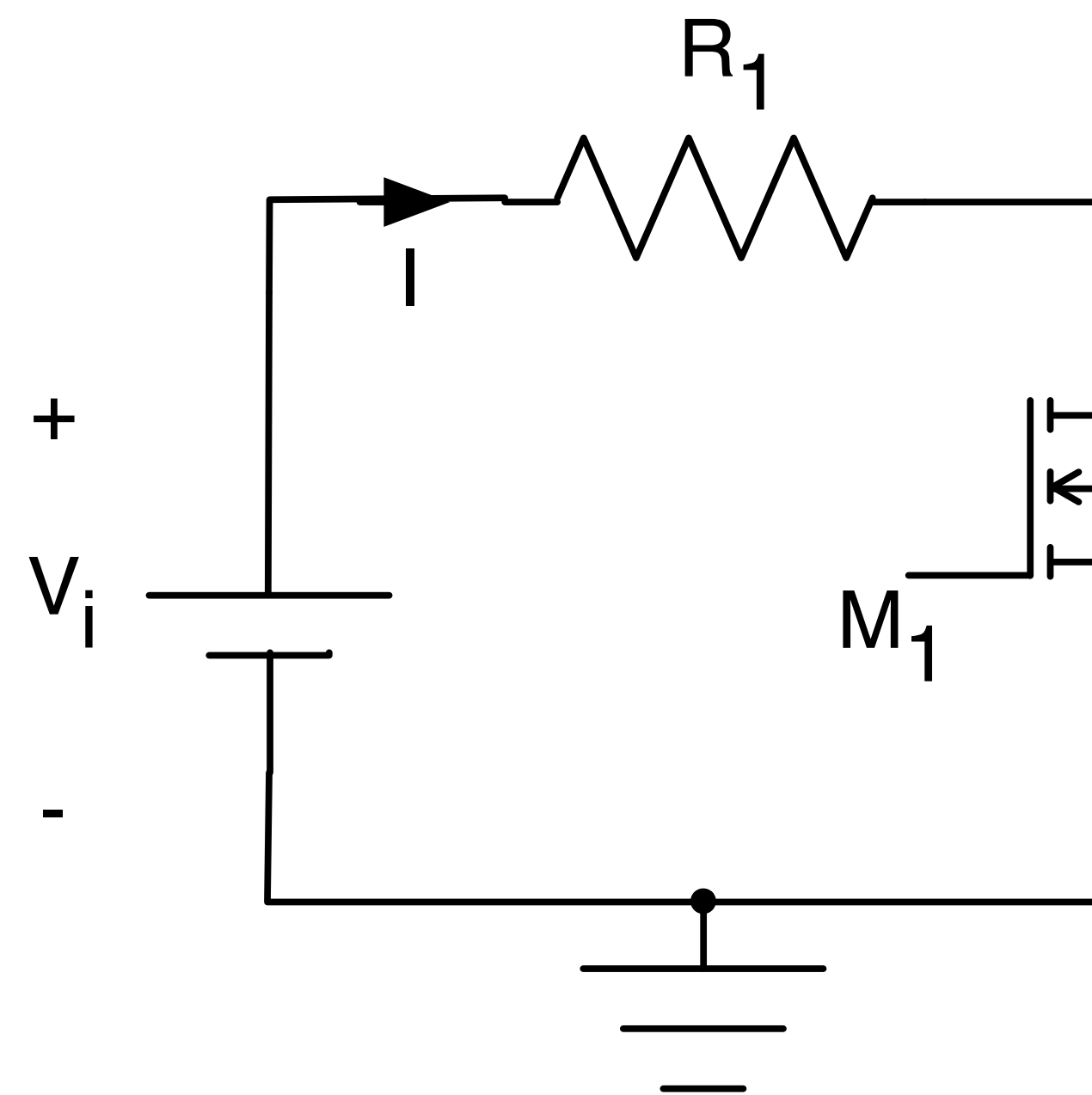
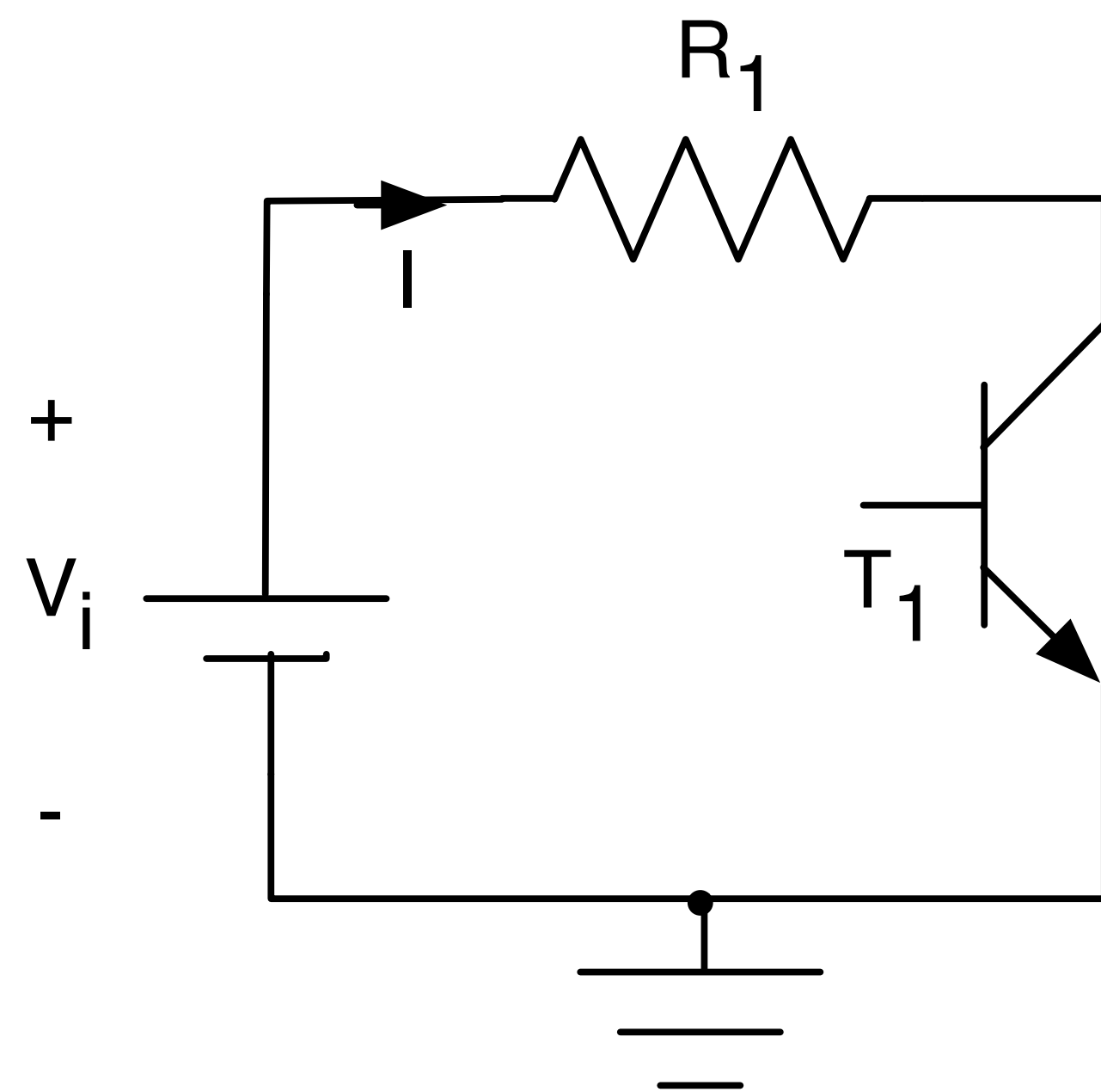
$$P_o = V_o \cdot I_o$$

$$P_i = P_o \rightarrow \eta = 1$$



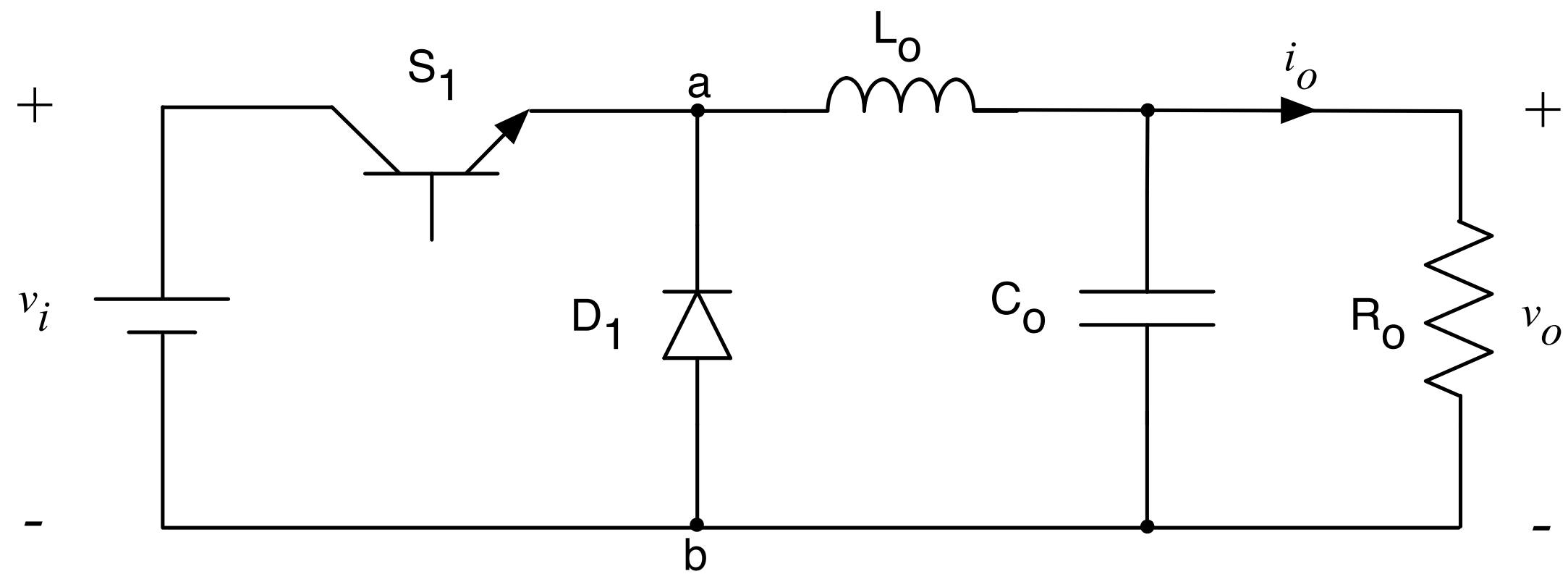
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# Princípio de funcionamento

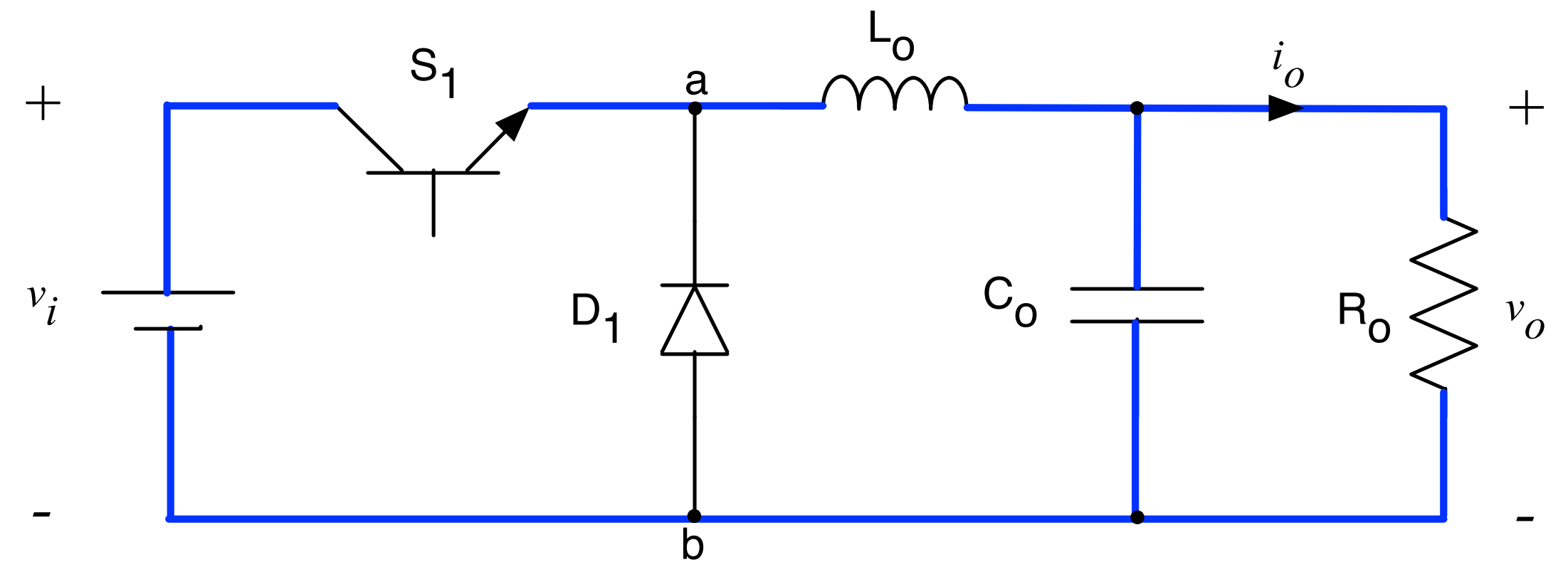




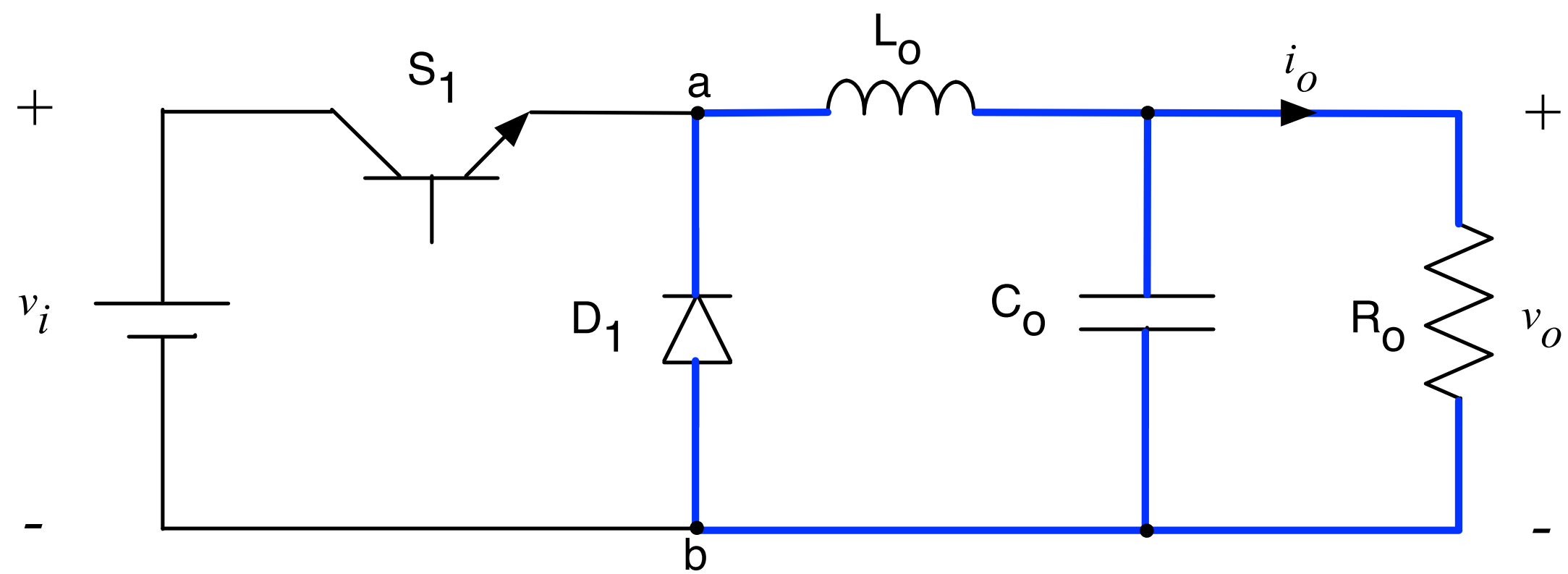
# Conversor Buck



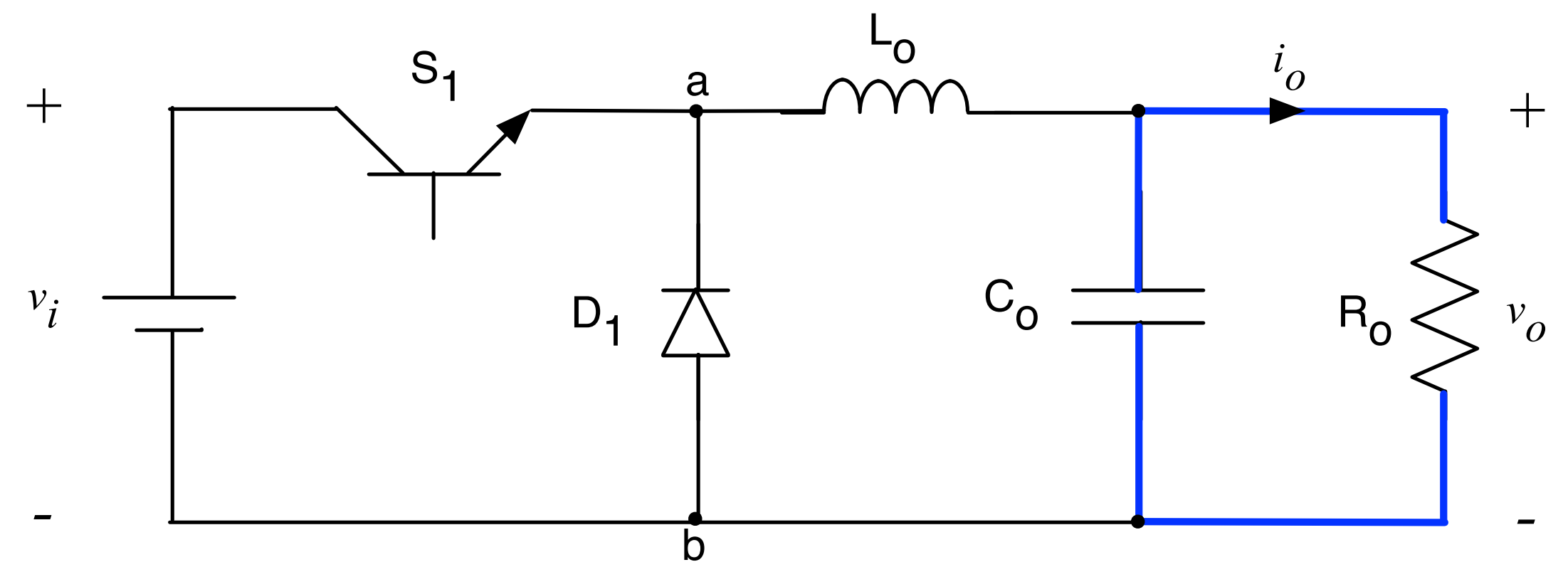
Conversor Buck



Primeira etapa

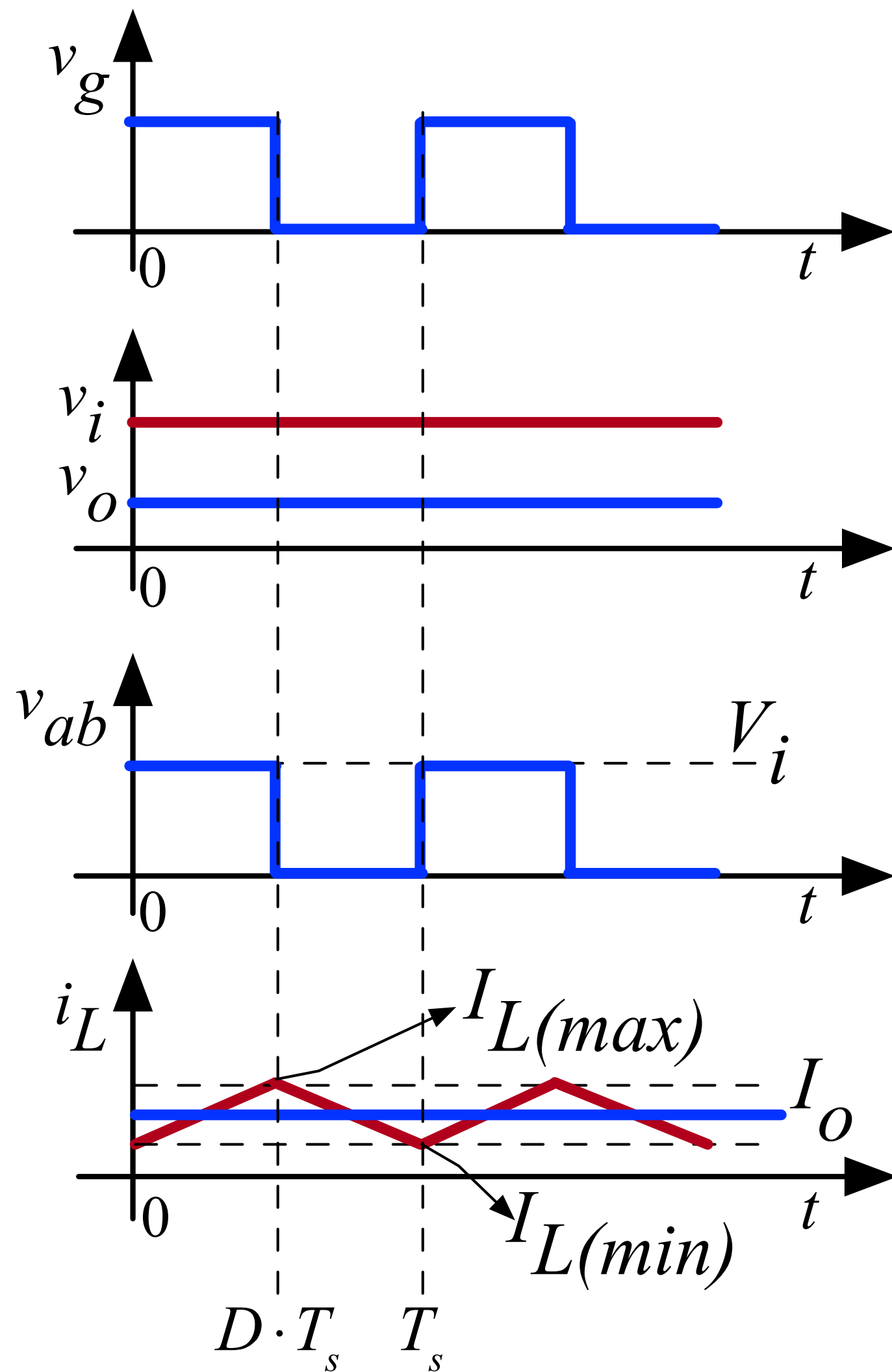


Segunda etapa

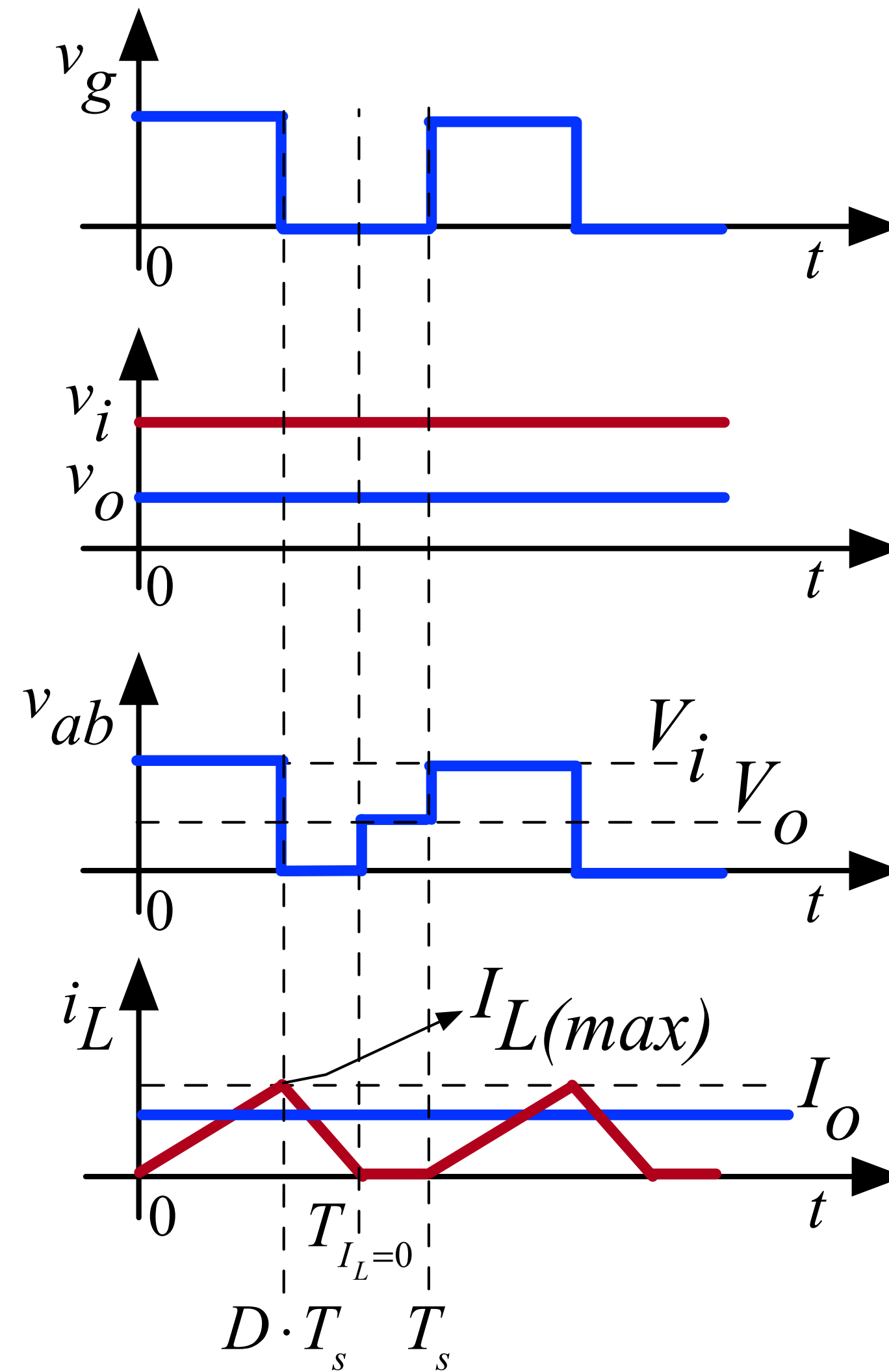


Terceira etapa

# Conversor Buck

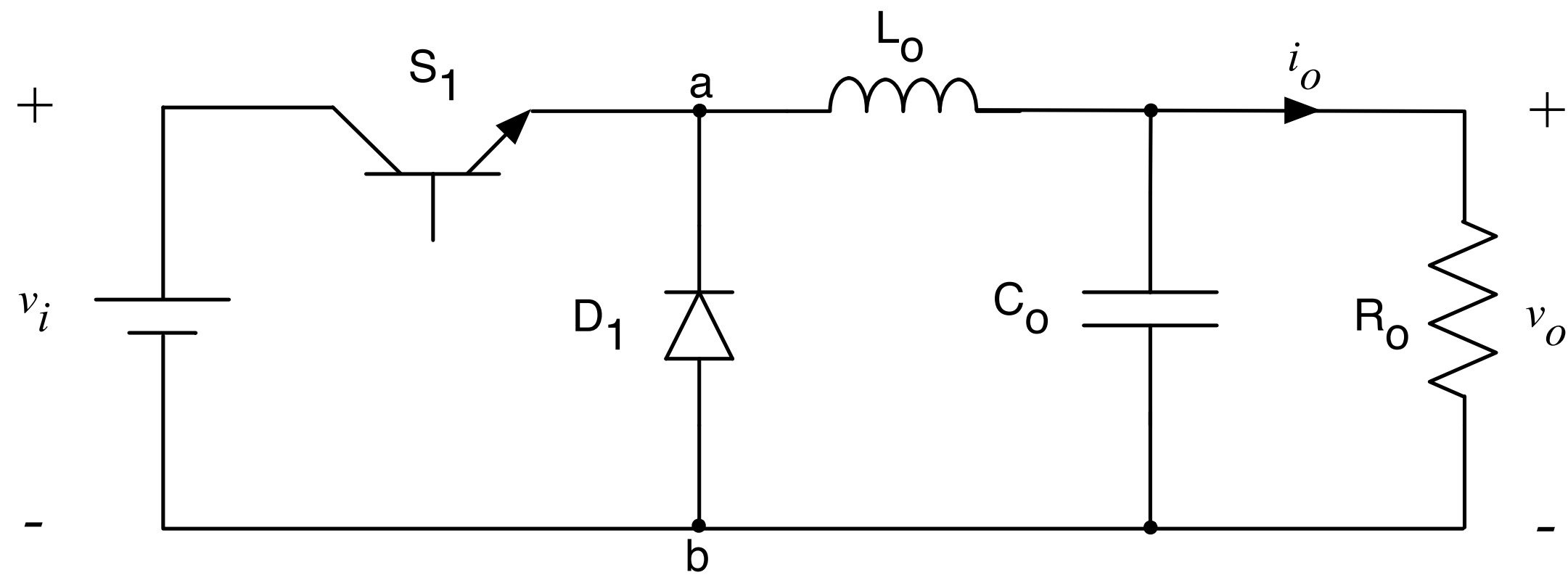


Condução contínua



Condução descontínua

# Conversor Buck



$$V_i = \text{definido}$$

$$V_o = D \cdot V_i$$

Condução contínua

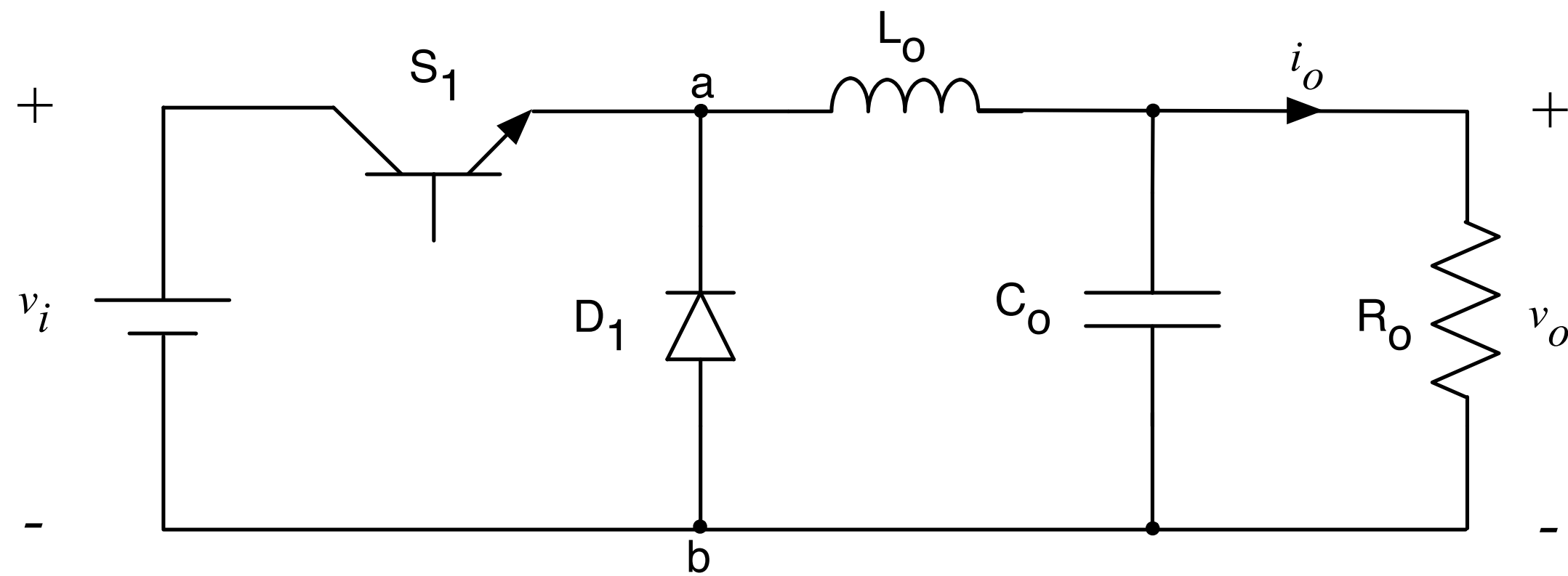
$$V_{ab} = \frac{1}{T_s} \cdot V_i \cdot D \cdot T_s \rightarrow V_{ab} = D \cdot V_i$$

$$V_o = \frac{2 \cdot V_i}{1 + \sqrt{1 + \frac{8 \cdot L_o \cdot F_s}{R_o \cdot D^2}}}$$

Condução descontínua

$$V_{L_o} = 0 \rightarrow V_o = V_i$$

# Conversor Buck



$$\Delta i = \% \cdot I_o [A]$$

$$L_o = \frac{V_i}{\Delta i \cdot F_s} \cdot D \cdot (1 - D)$$

$$\Delta v = \% \cdot V_o [V]$$

$$C_o = \frac{V_i}{31 \cdot \Delta v \cdot L_o \cdot F_s^2}$$

$$I_o = \frac{V_o}{R_o}$$

$$I_{L_o} = I_o$$

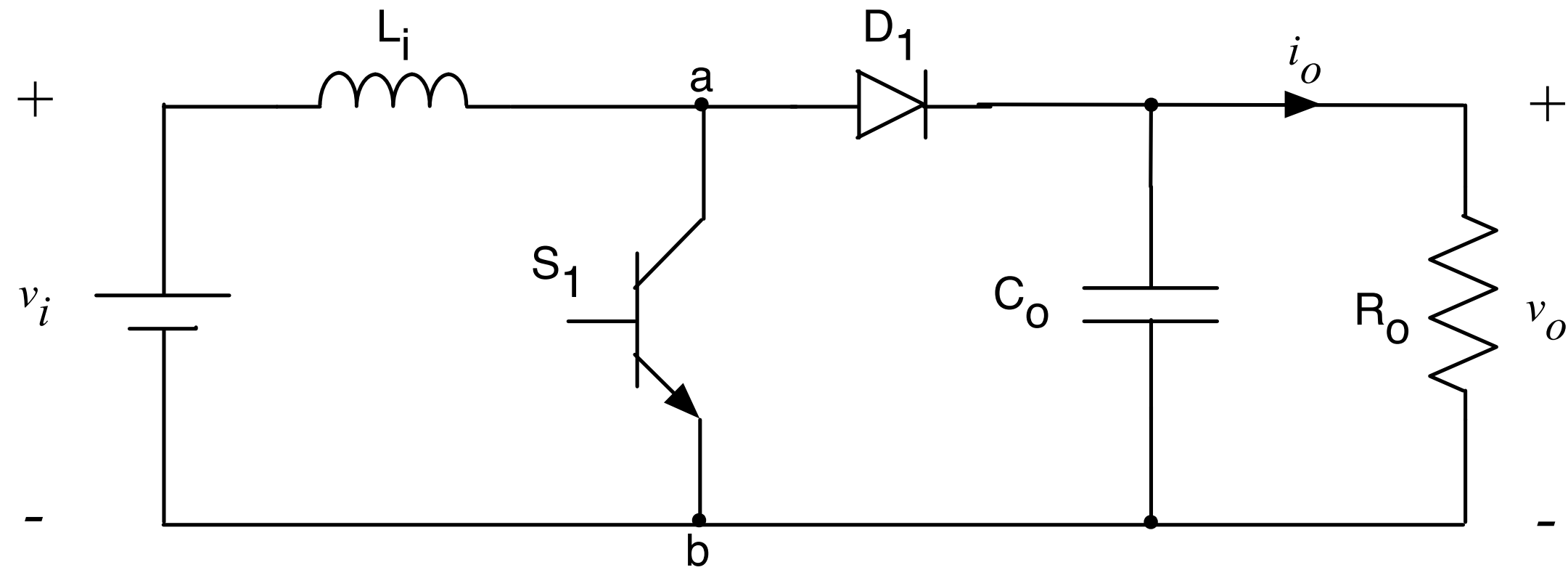
$$I_i = I_{S1} = D \cdot I_o$$

$$I_{D1} = (1 - D) \cdot I_o$$

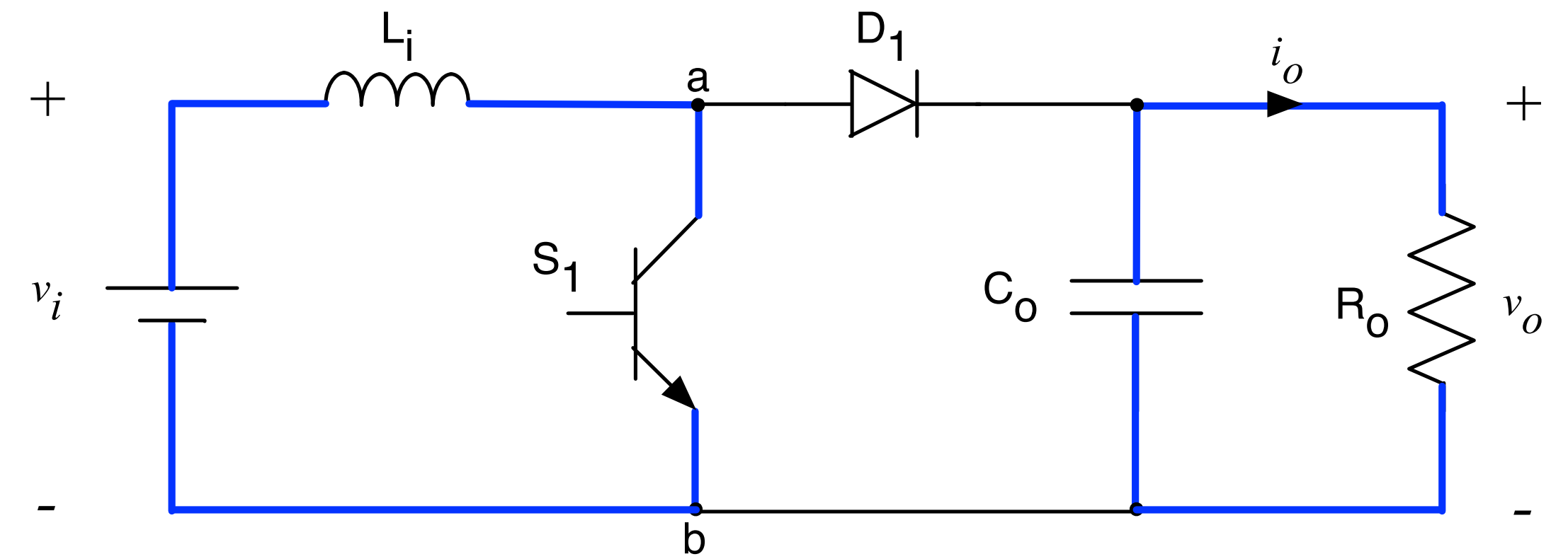
$$I_{L_o(\max)} = I_{S1(\max)} = I_{D1(\max)} = I_o + \frac{\Delta i}{2}$$

$$V_{S1(\max)} = V_{D1(\max)} = V_i$$

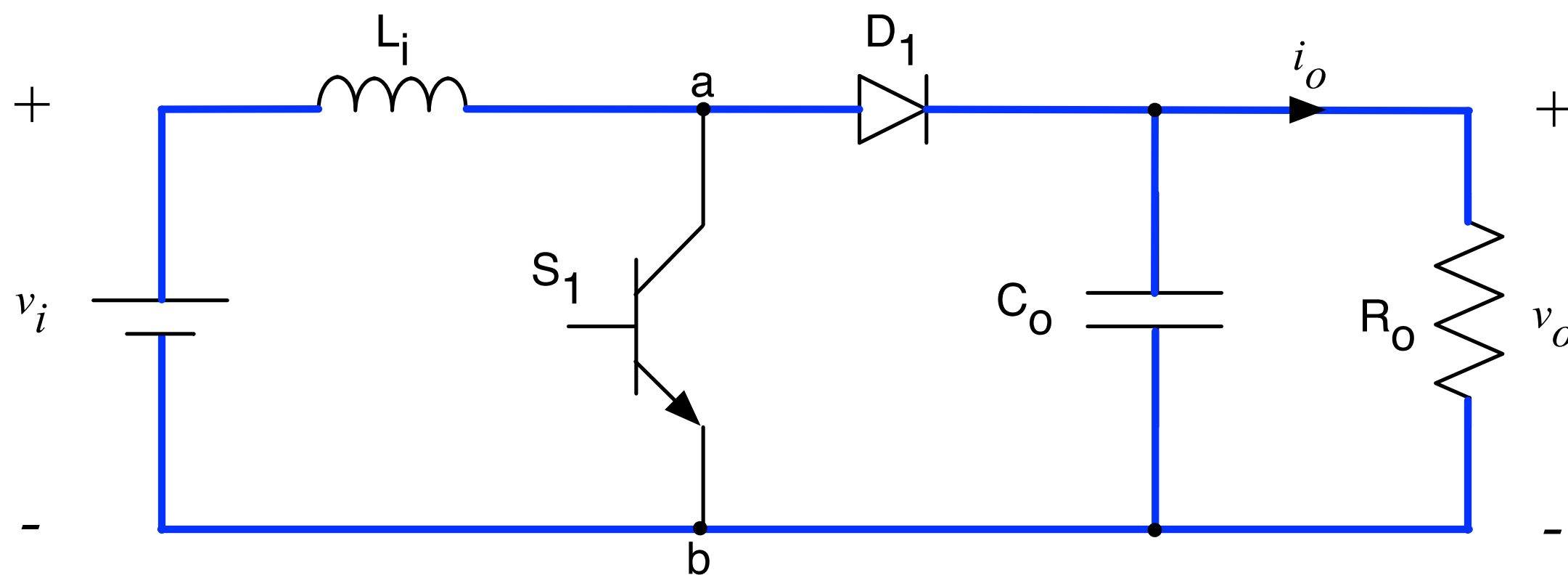
# Conversor Boost



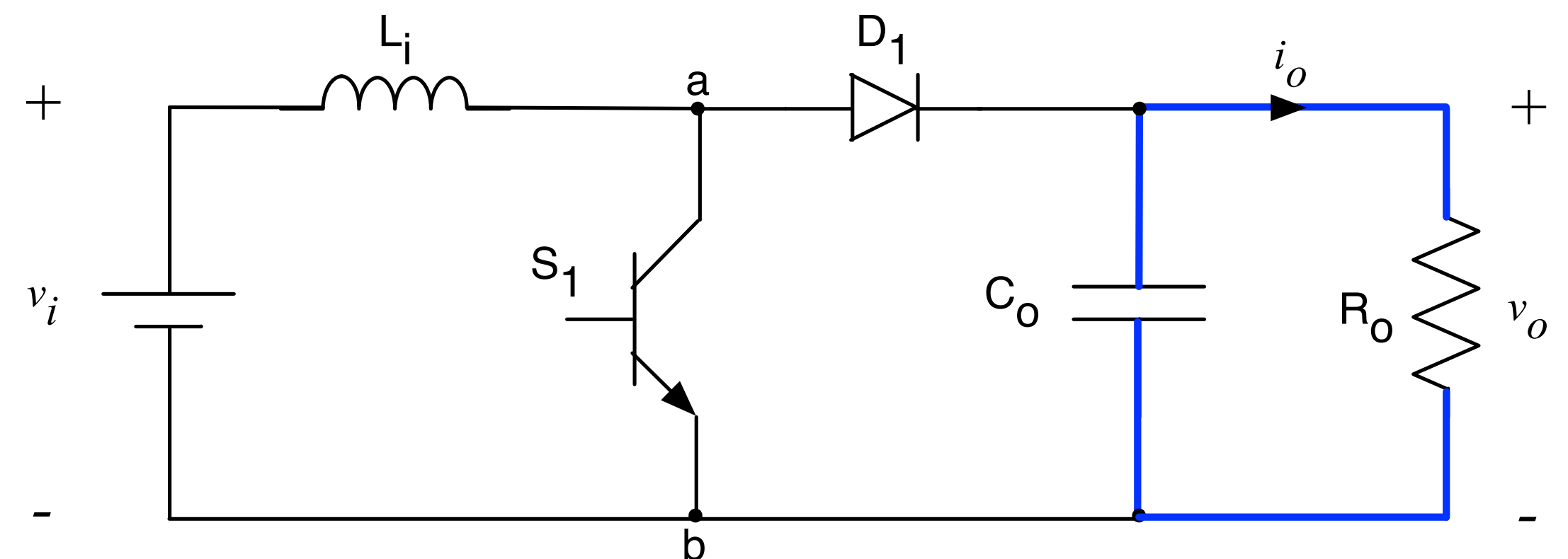
Conversor Boost



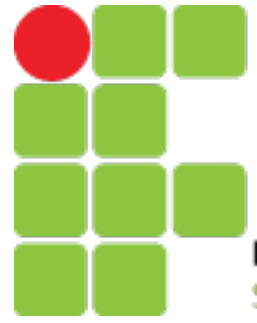
Primeira etapa



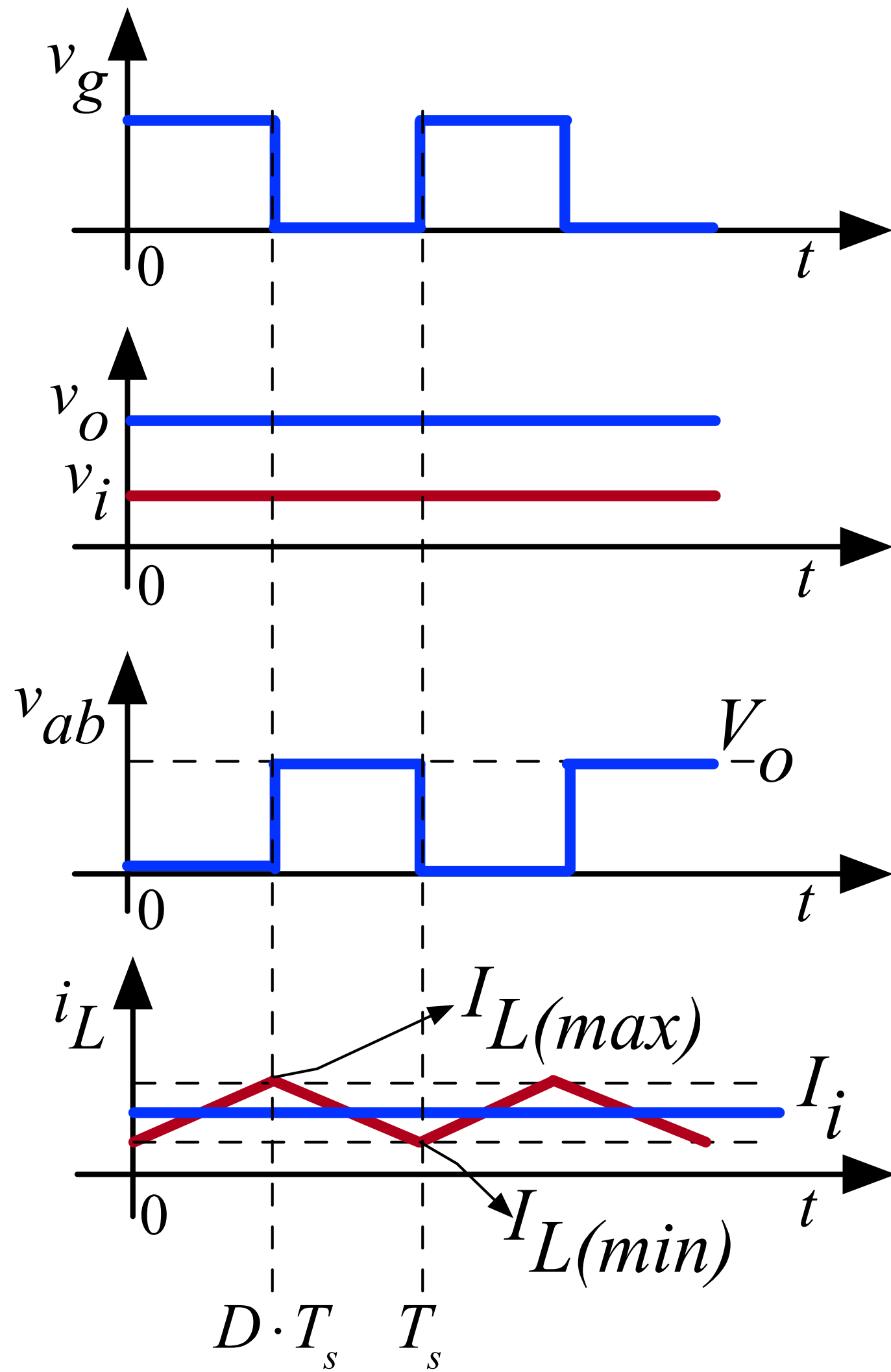
Segunda etapa



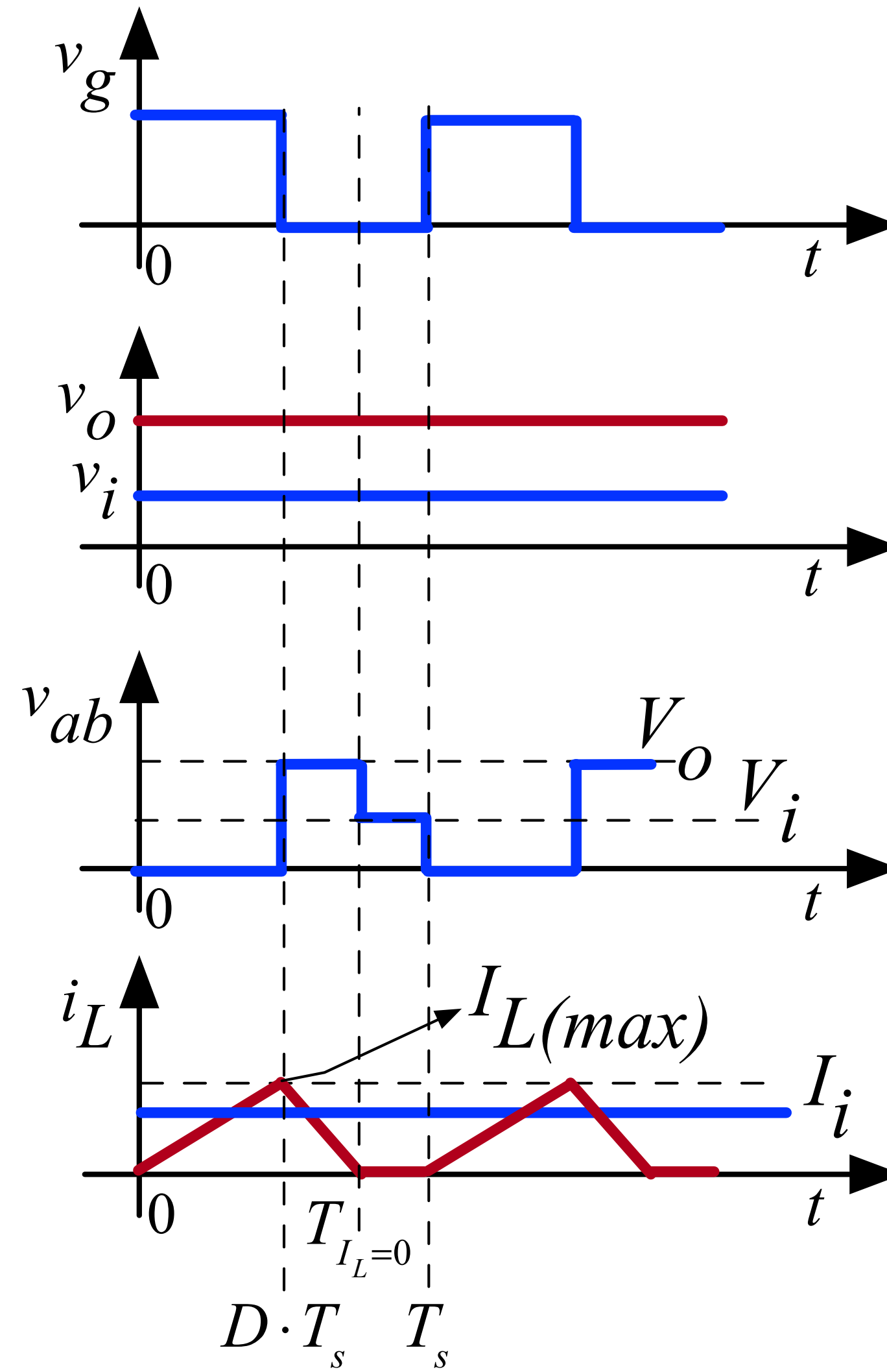
Terceira etapa



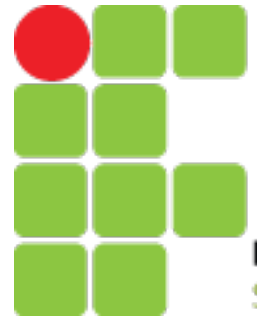
# Conversor Boost



Condução contínua

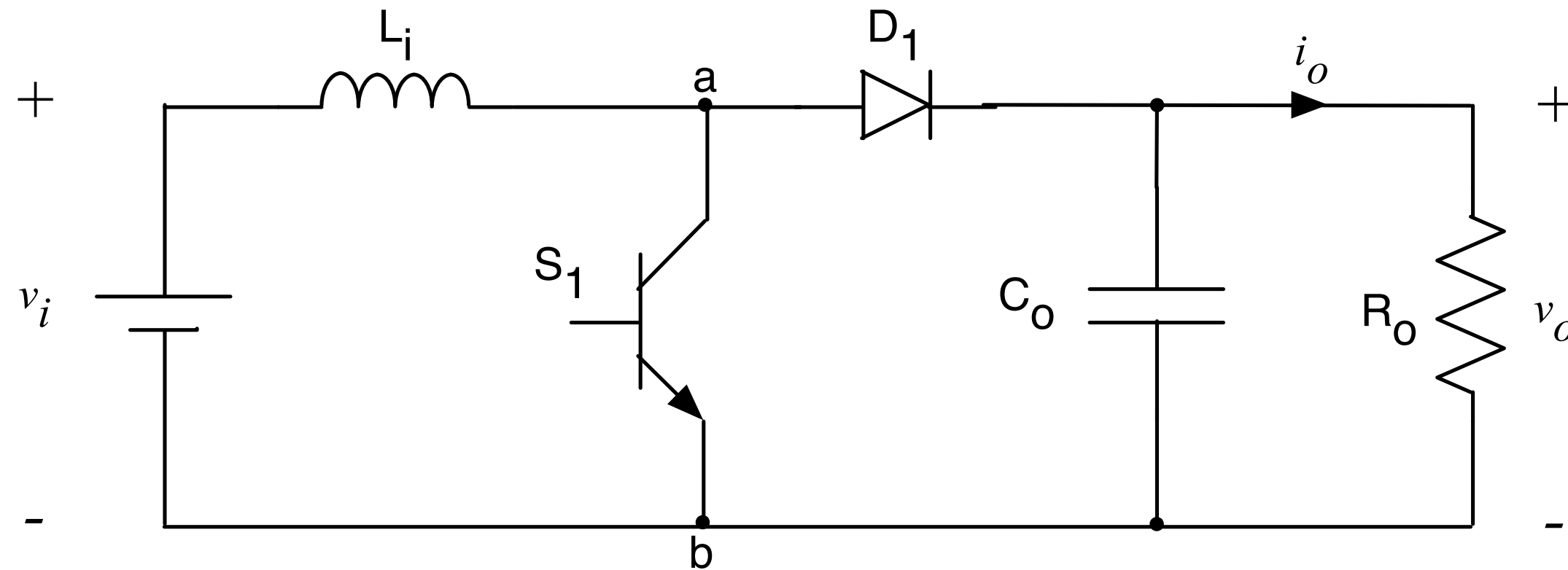


Condução descontínua



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# Conversor Boost



$$V_i = \text{definido}$$

$$V_{ab} = \frac{1}{T_s} \cdot V_o \cdot (T_s - D \cdot T_s) \rightarrow V_{ab} = V_o \cdot (1 - D)$$

$$V_{Lo} = 0 \rightarrow V_{ab} = V_i$$

$$V_i = V_o \cdot (1 - D)$$

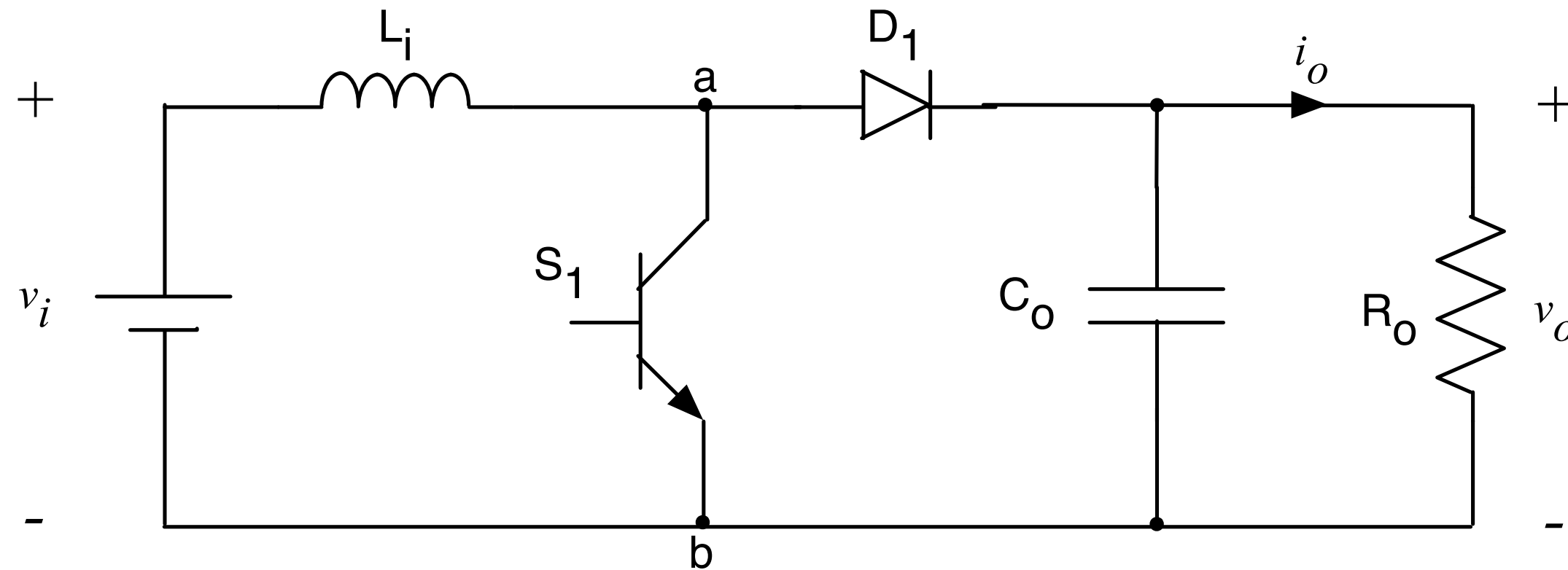
$$V_o = \frac{V_i}{(1 - D)}$$

Condução contínua

$$V_o = V_i \cdot \left( 1 + \frac{V_i \cdot D^2}{2 \cdot F_s \cdot L_i \cdot I_o} \right)$$

Condução descontínua

# Conversor Boost



$$\Delta i = \% \cdot I_i [A]$$

$$L_i = \frac{V_i}{\Delta i \cdot F_s} \cdot D$$

$$\Delta v = \% \cdot V_o [V]$$

$$C_o = \frac{I_o}{\Delta v \cdot F_s} \cdot \frac{V_o - V_i}{V_o}$$

$$I_o = \frac{V_o}{R_o}$$

$$I_{Li} = I_i = \frac{P_i}{V_i} \rightarrow P_i = P_o \rightarrow \eta = 1$$

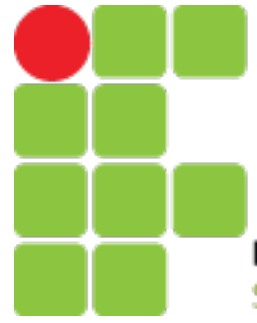
$$I_{Li(\max)} = I_{S1(\max)} = I_{D1(\max)} = I_i + \frac{\Delta i}{2}$$

$$I_{S1} = D \cdot I_i$$

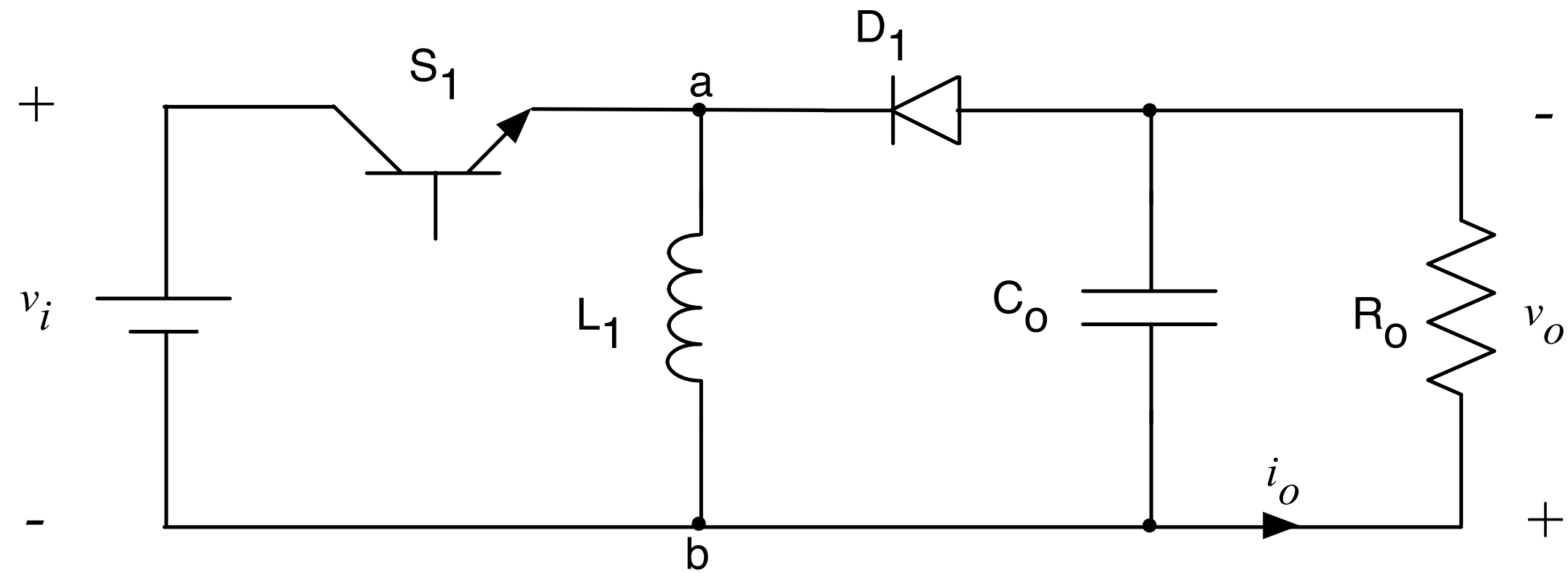
$$I_{D1} = (1 - D) \cdot I_i$$

$$V_{S1(\max)} = V_{D1(\max)} = V_o$$

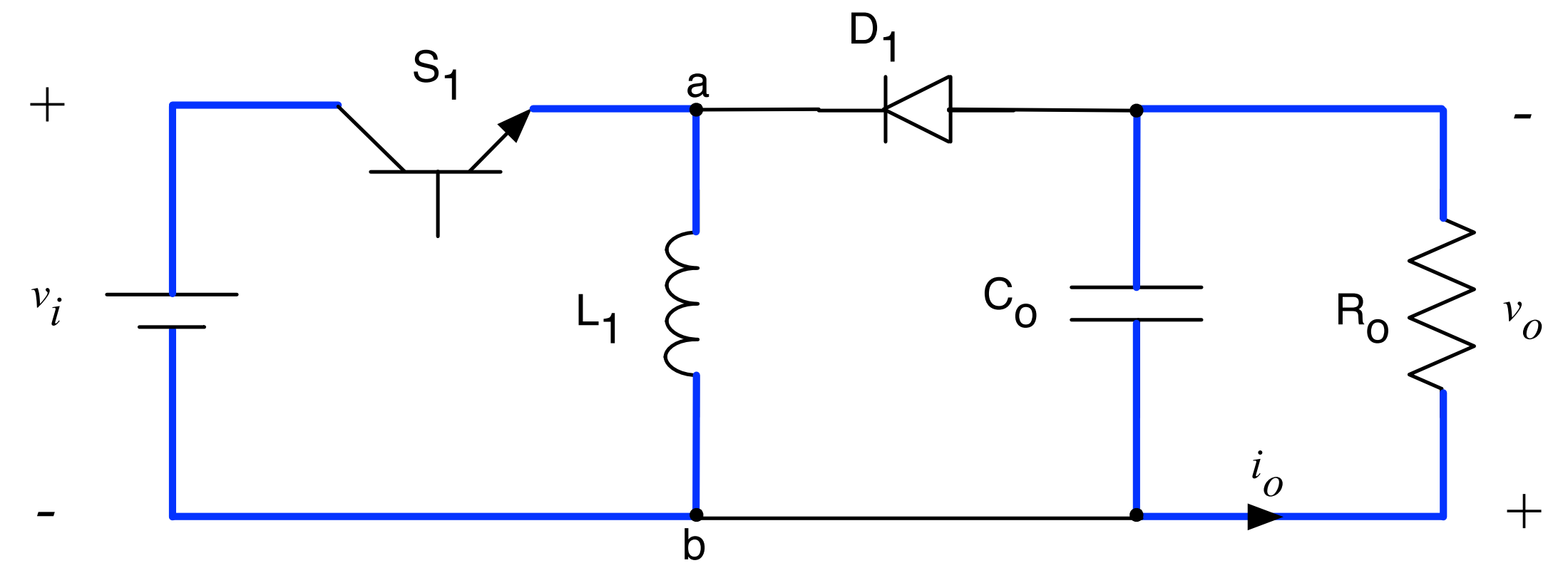




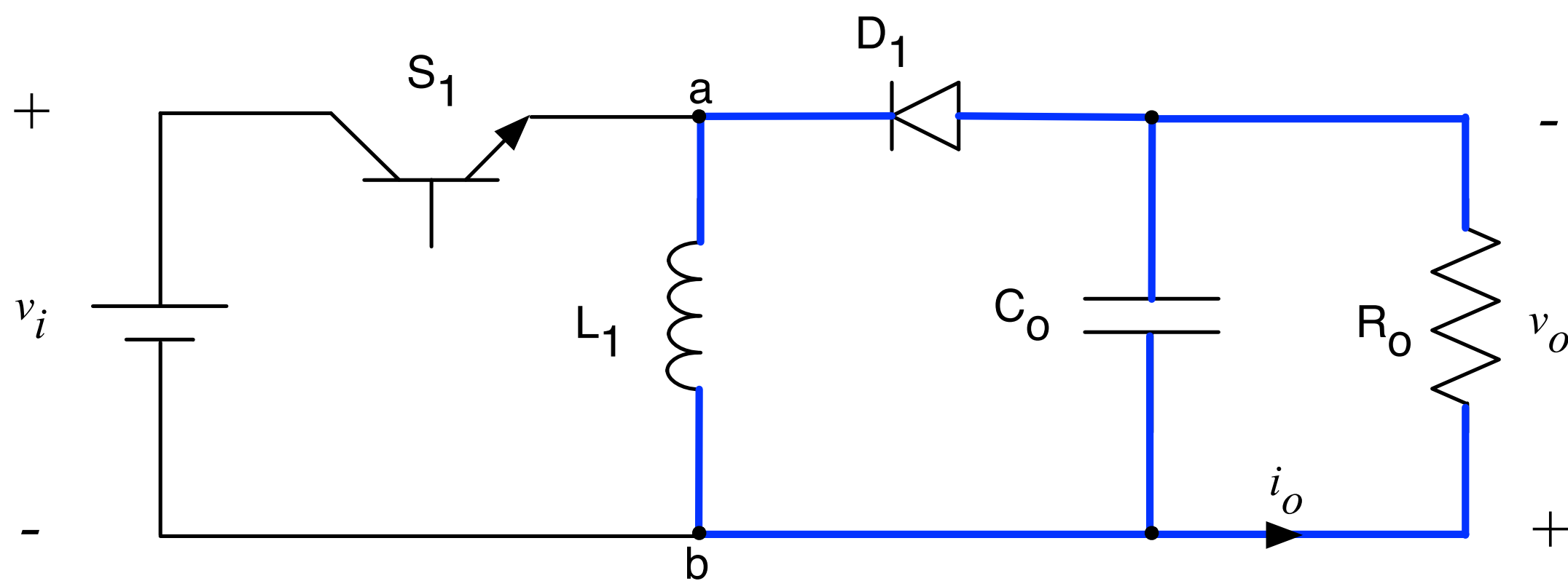
# Conversor Buck-Boost



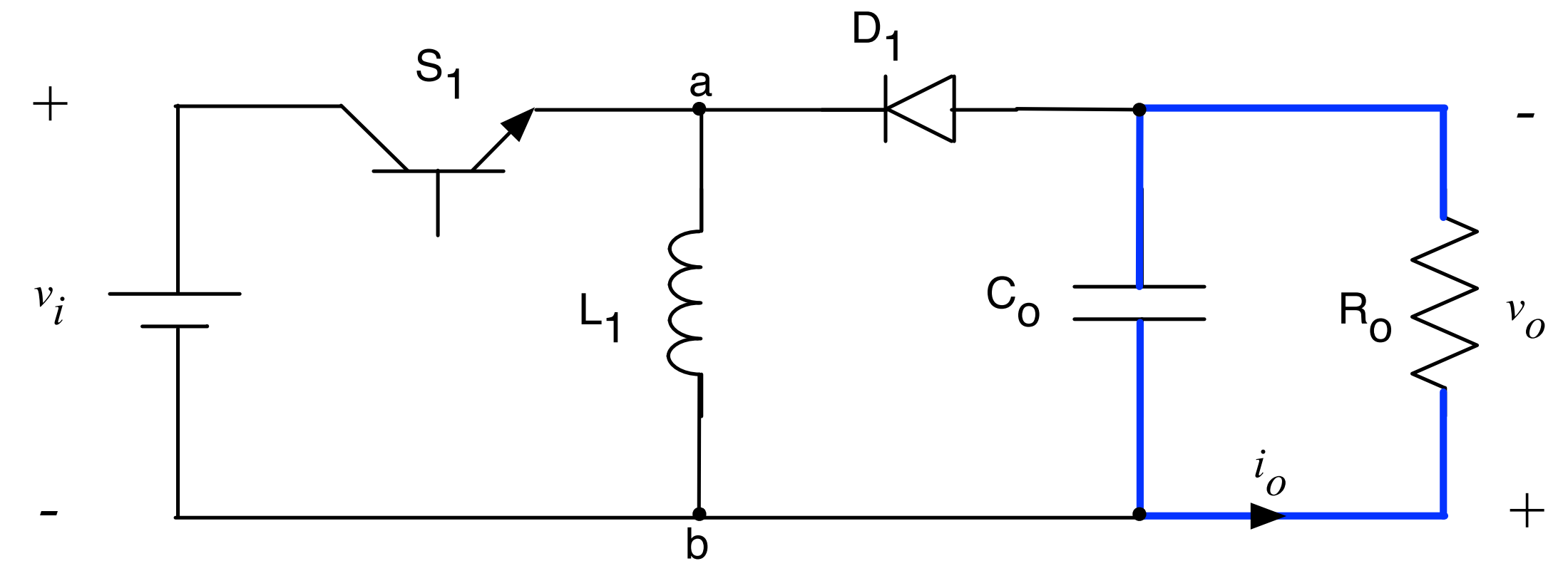
Conversor Buck-Boost



Primeira etapa

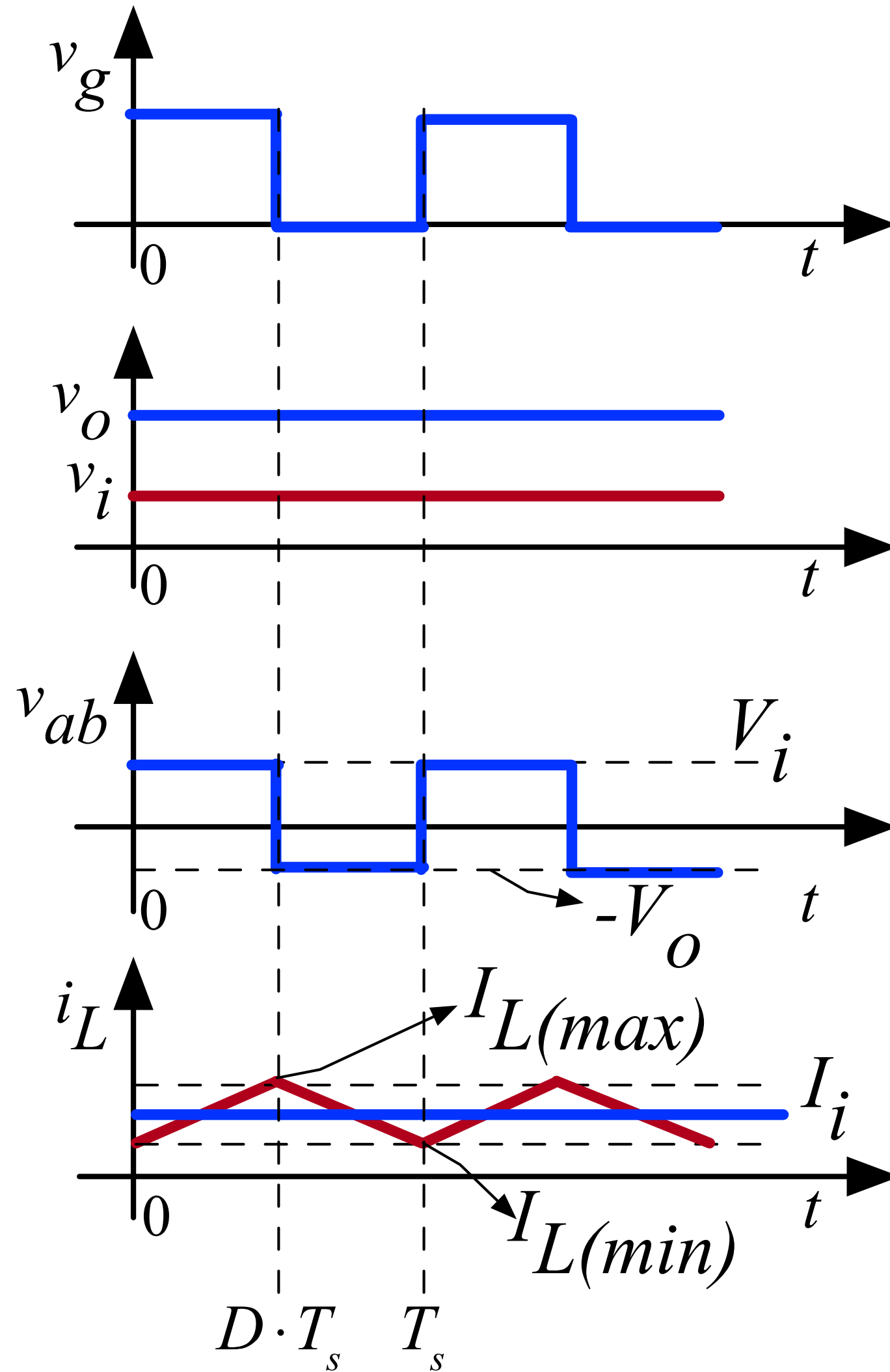


Segunda etapa

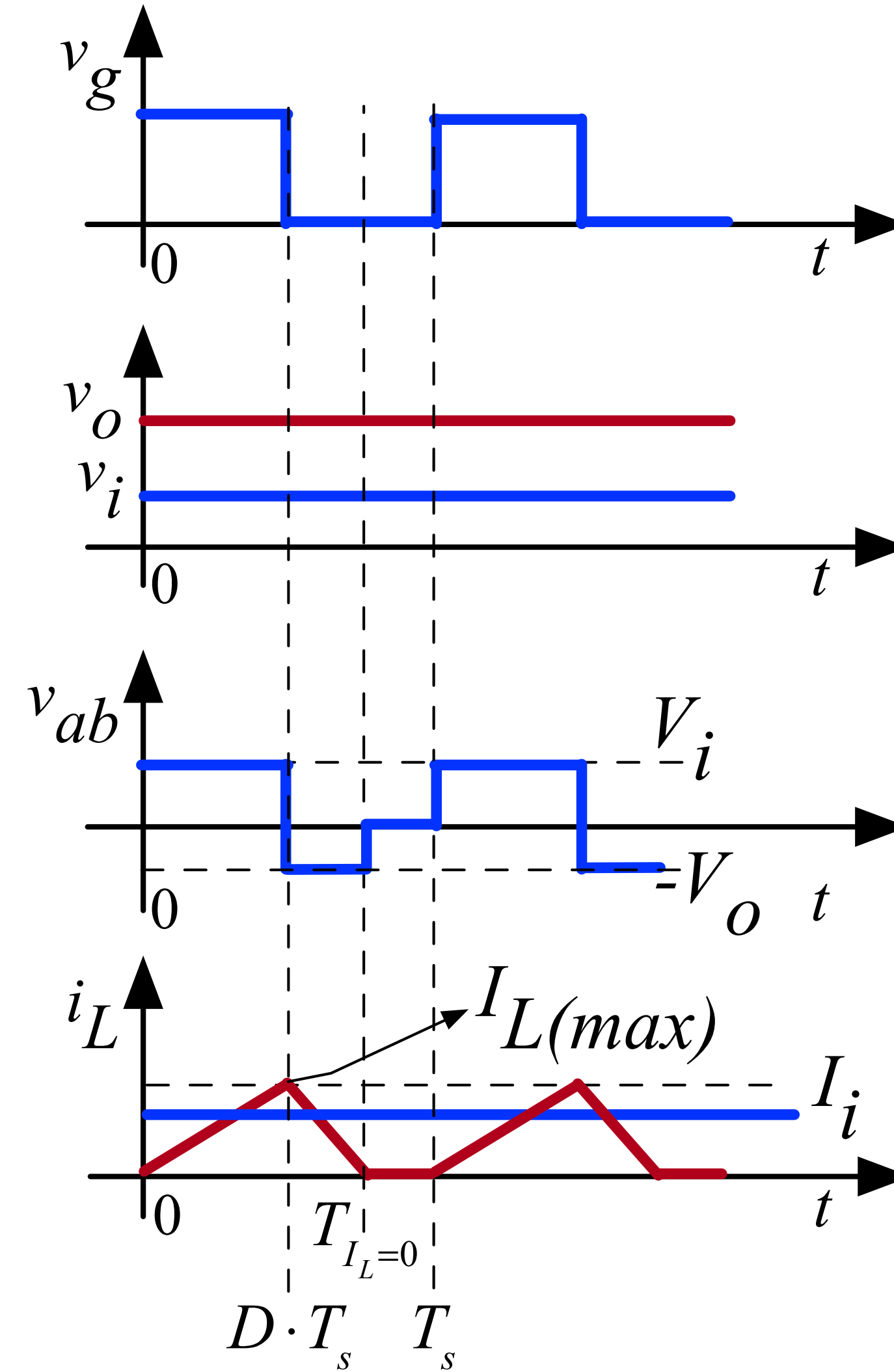


Terceira etapa

# Conversor Buck-Boost

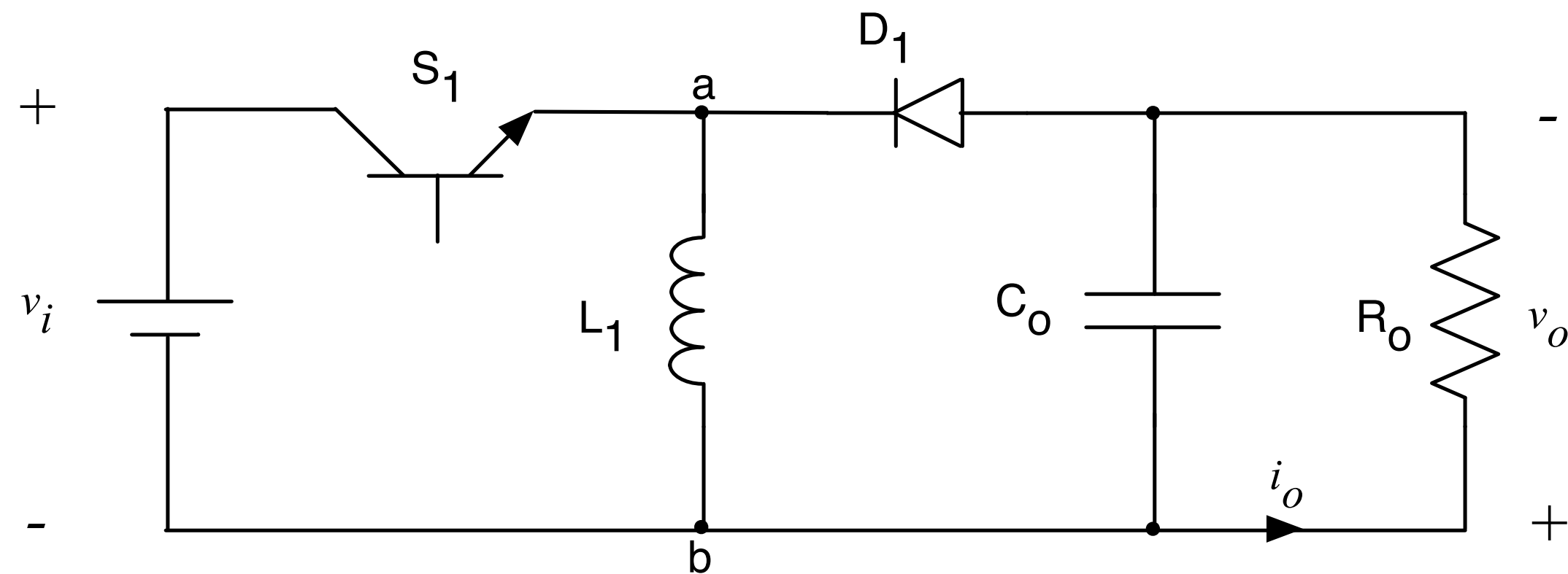


Condução contínua



Condução descontínua

# Conversor Buck-Boost



$V_i = \text{definido}$

$$V_{ab} = \frac{1}{T_s} \cdot \left[ (V_i \cdot D \cdot T_s) + (-V_o \cdot (T_s - D \cdot T_s)) \right] \rightarrow V_{ab} = V_i \cdot D - V_o \cdot (1 - D)$$

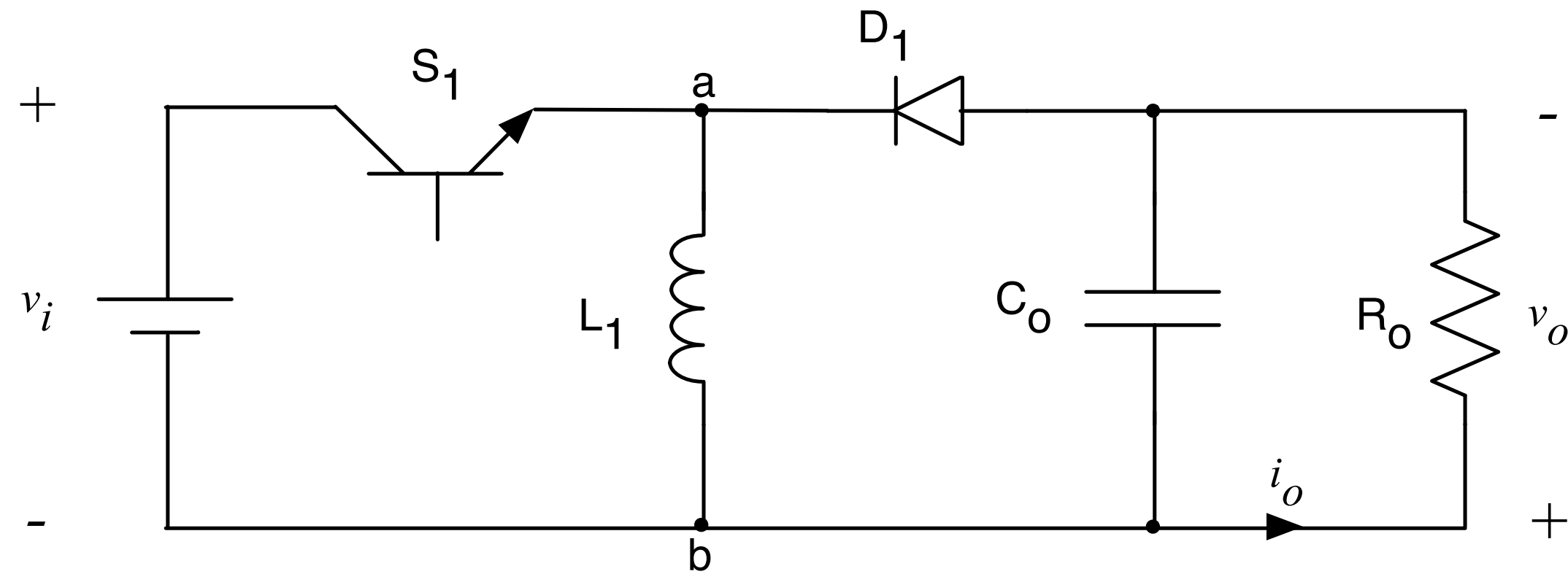
$$V_{Lo} = 0 \rightarrow V_{ab} = 0 = V_i \cdot D - V_o \cdot (1 - D)$$

$$V_o = V_i \cdot \frac{D}{1 - D}$$

Condução contínua

$$V_o = V_i \cdot D \cdot \sqrt{\frac{R_o}{2 \cdot F_s \cdot L_i}} \quad \text{Condução descontínua}$$

# Conversor Buck-Boost



$$\Delta i = \% \cdot I_i [A] \rightarrow \Delta i = \% \cdot I_o [A] \quad L_1 = \frac{V_o}{\Delta i \cdot F_s} \cdot (1 - D)$$

$$\Delta v = \% \cdot V_o [V]$$

$$C_o = \frac{D \cdot I_o}{\Delta v \cdot F_s}$$

$$I_o = \frac{V_o}{R_o}$$

$$I_{D1} = I_o$$

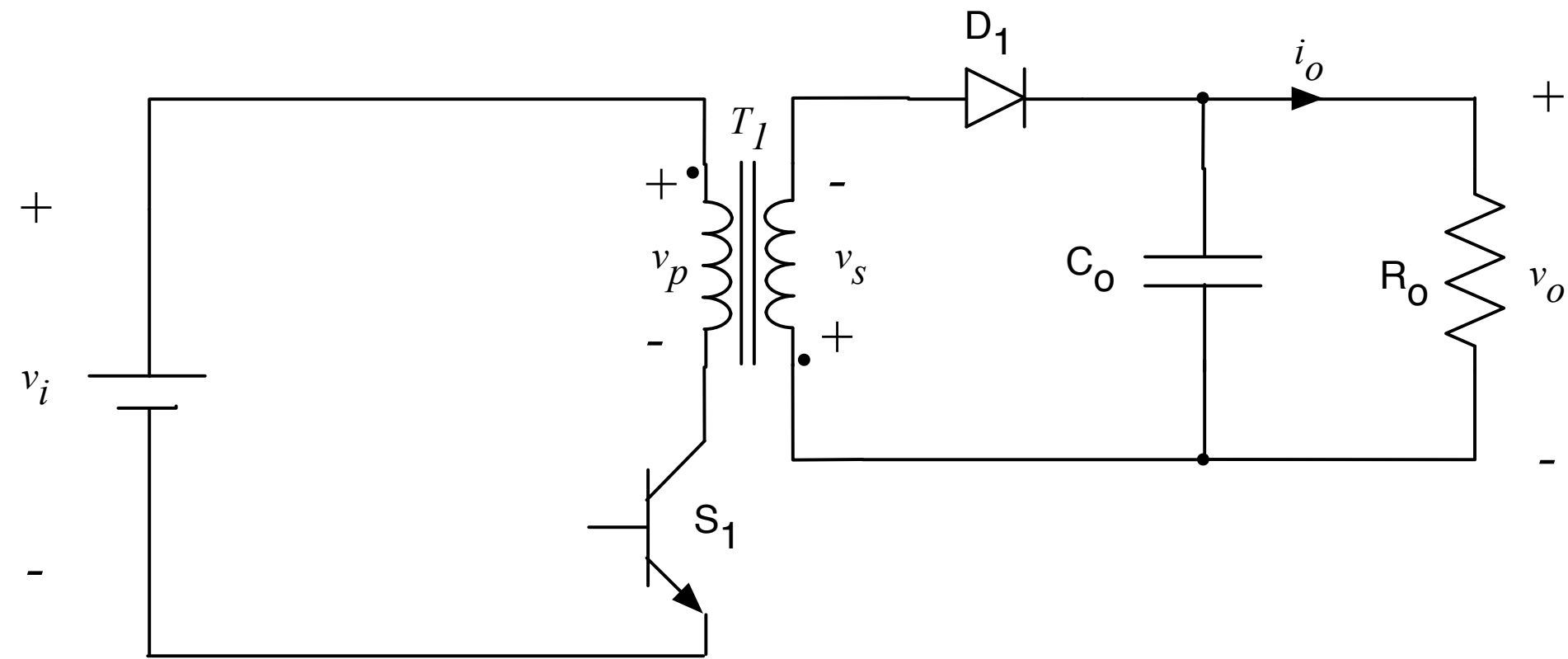
$$I_{S1} = I_i = \frac{P_i}{V_i} \rightarrow P_i = P_o \rightarrow \eta = 1$$

$$I_{L1} = I_i + I_o$$

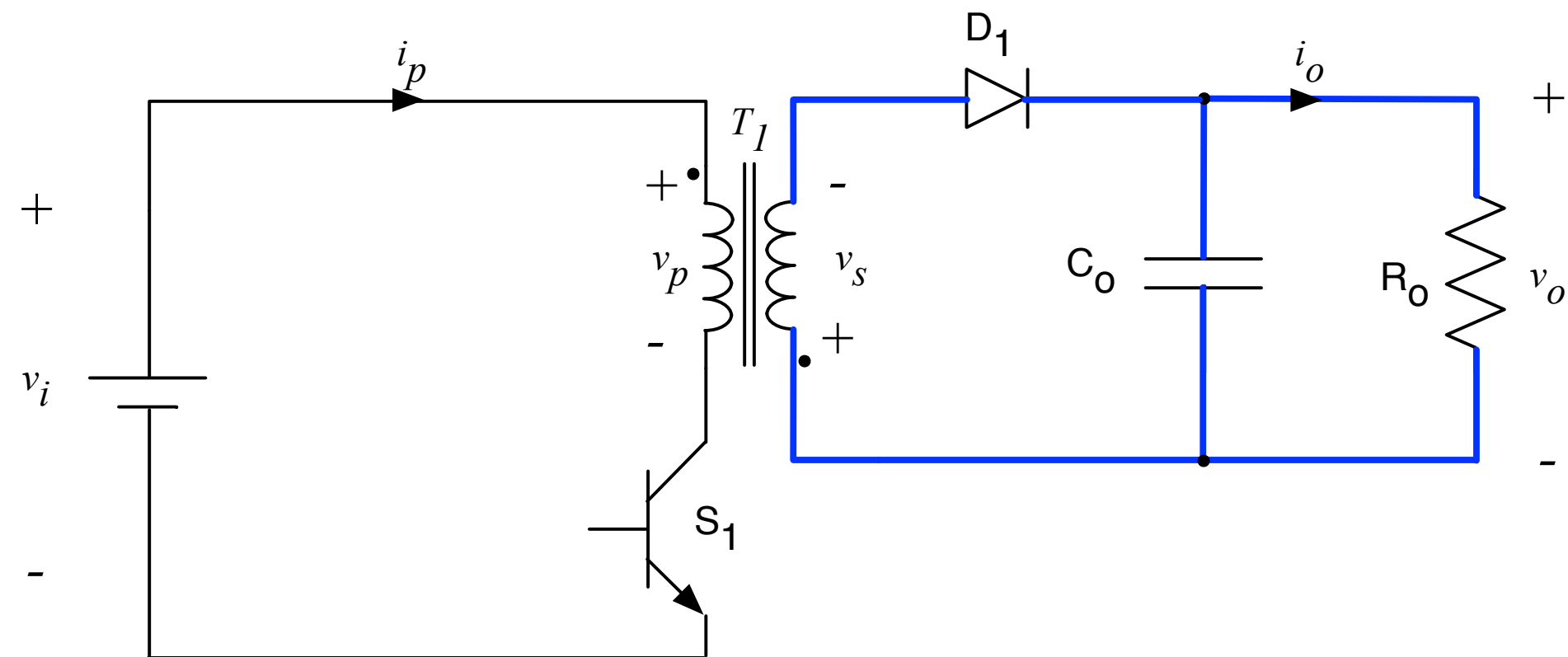
$$I_{L1(\max)} = I_{S1(\max)} = I_{D1(\max)} = I_{L1} + \frac{\Delta i}{2}$$

$$V_{S1(\max)} = V_{D1(\max)} = V_i + V_o$$

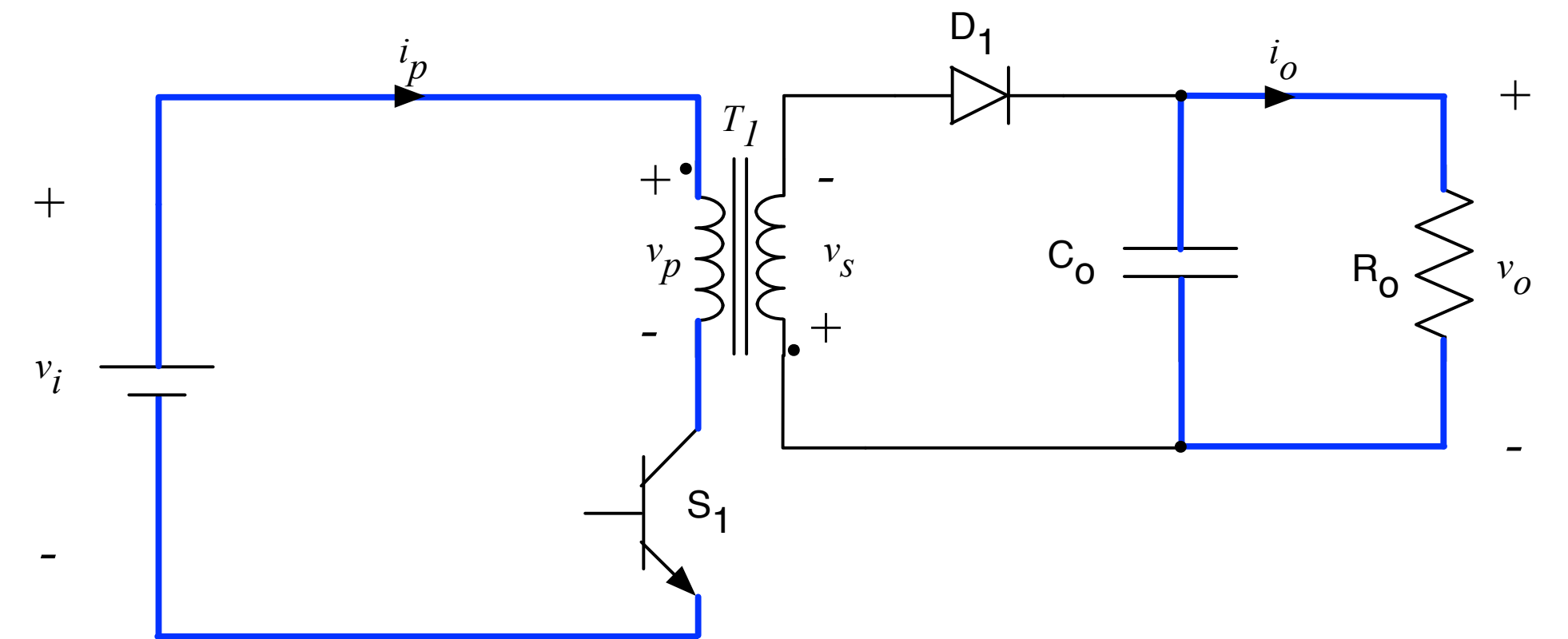
# Conversor Flyback



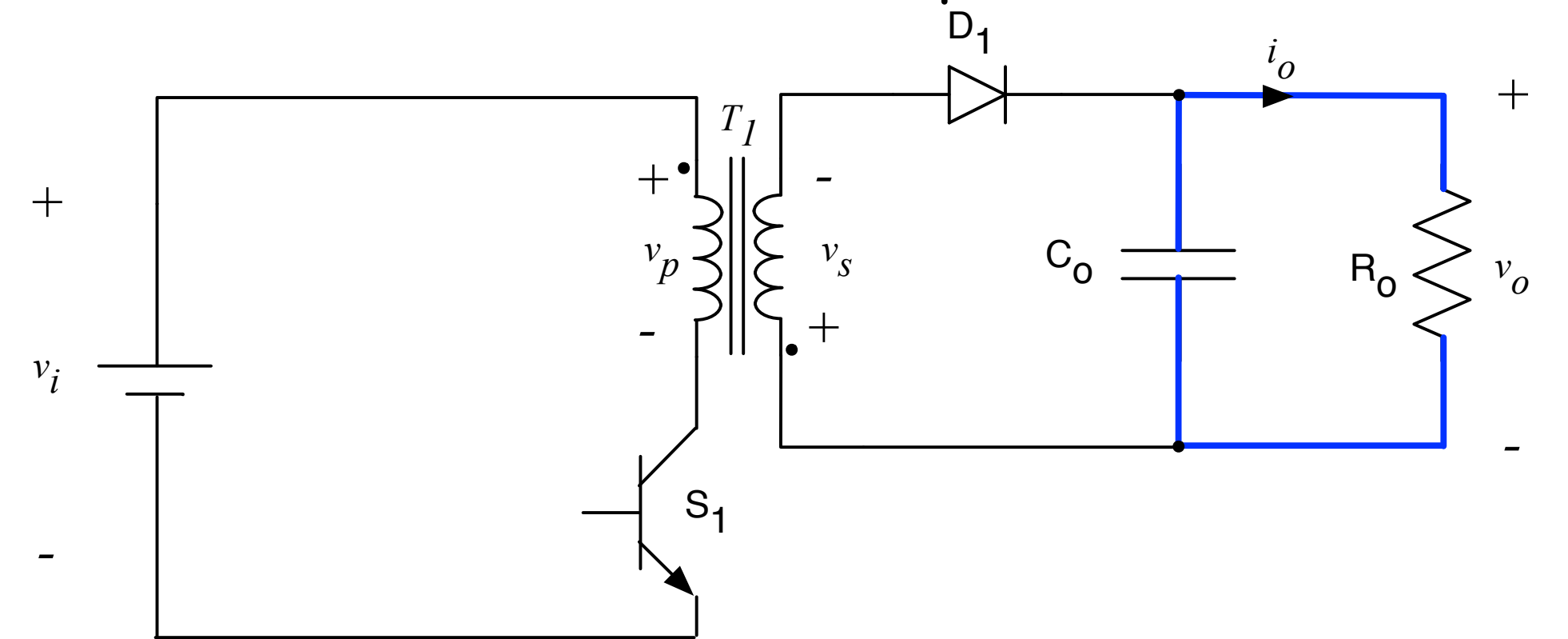
Conversor Flyback



Segunda etapa

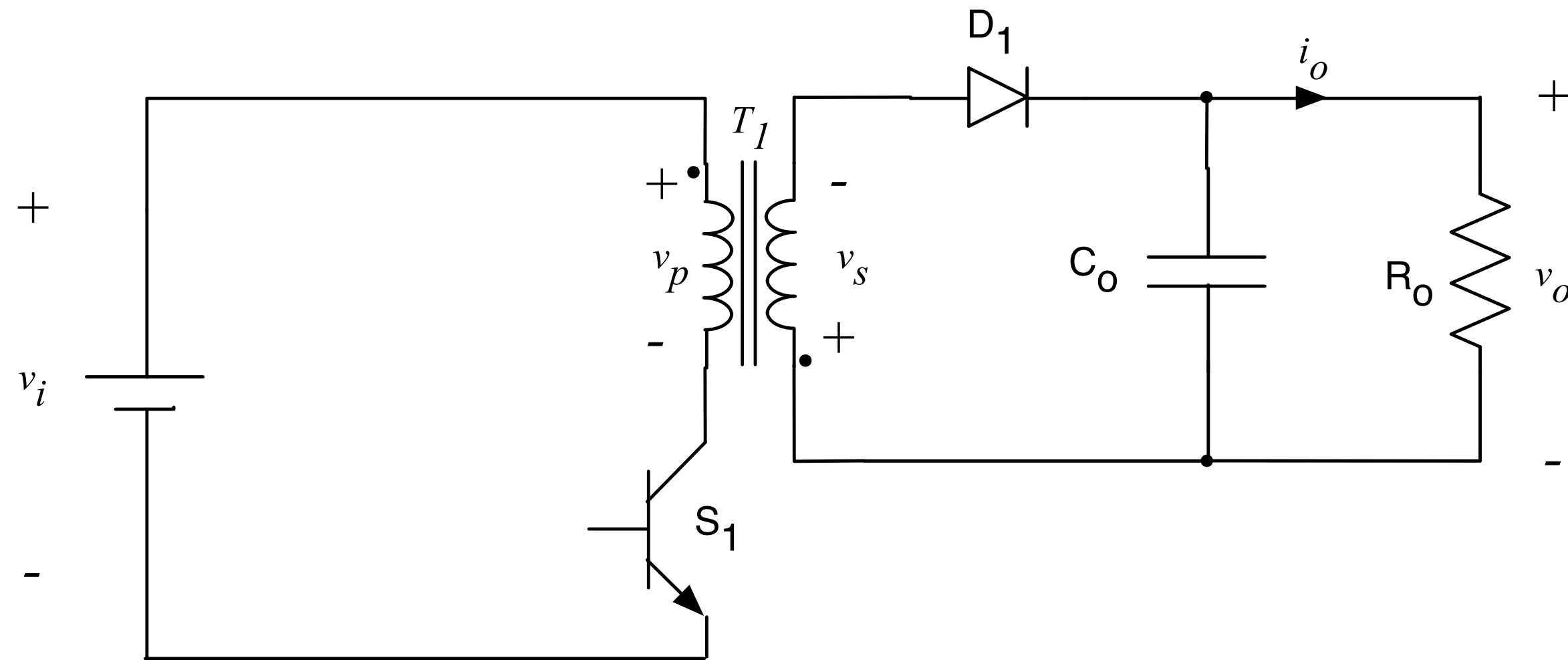
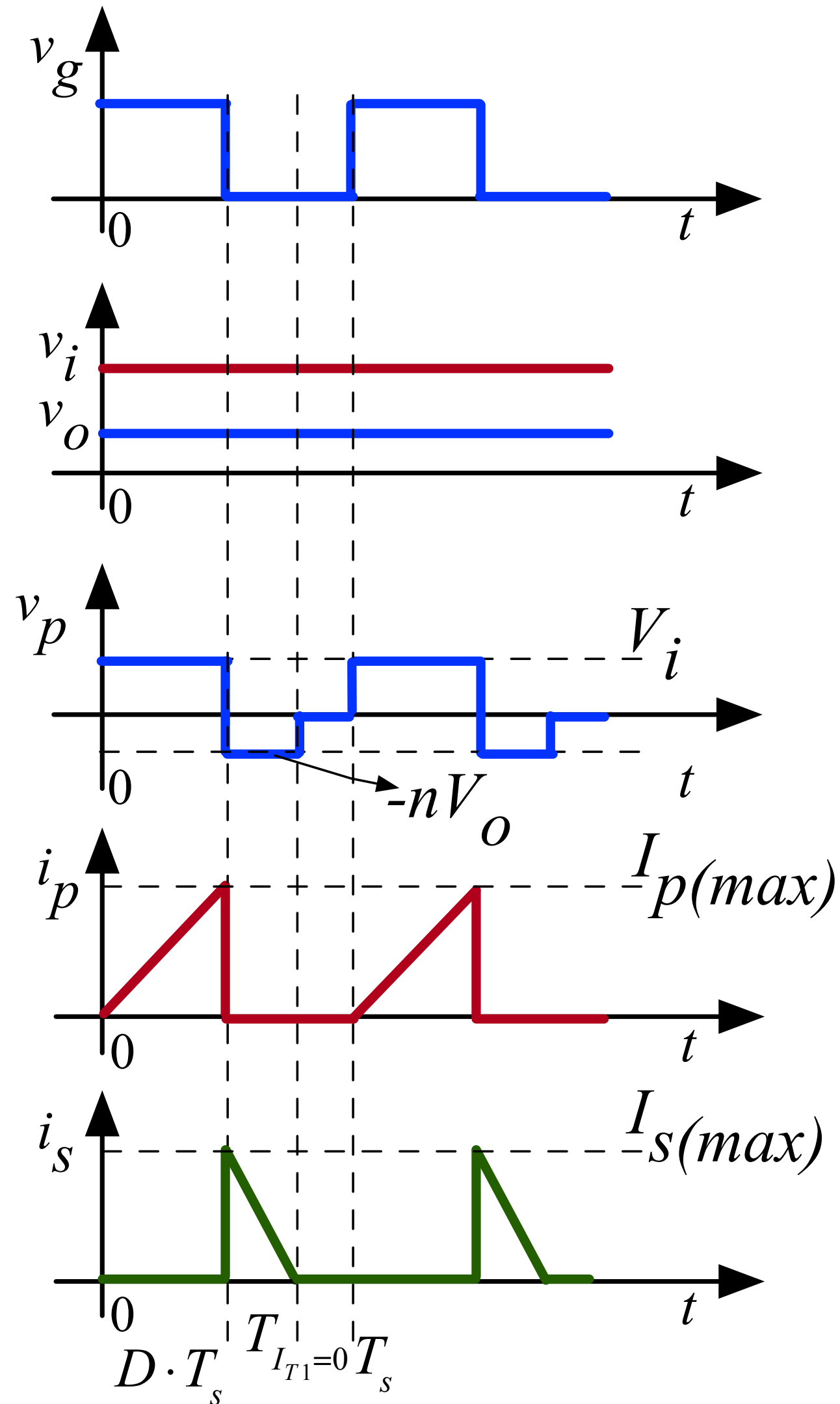


Primeira etapa



Terceira etapa

# Conversor Flyback

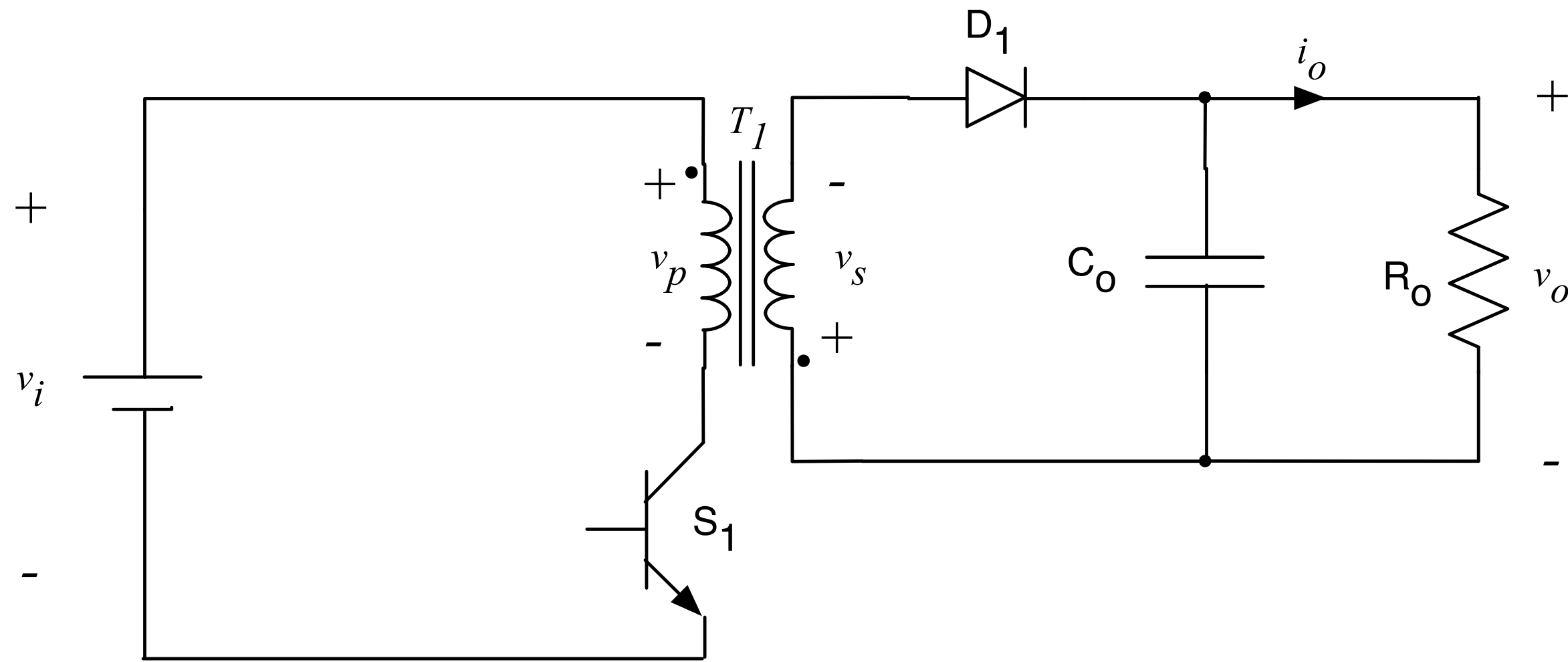


$V_i = \text{definido}$

$$V_p = \frac{1}{T_s} \cdot \left[ (V_i \cdot D \cdot T_s) + (-n \cdot V_o \cdot (T_s - D \cdot T_s)) \right] \rightarrow n = \frac{V_p}{V_s} \rightarrow \frac{n \cdot V_o}{V_i} = \frac{D}{1-D}$$

$$V'_o = n \cdot V_o \rightarrow V'_o = V_i \cdot \frac{D}{1-D}$$

# Conversor Flyback



$$V_{S1(\max)} = V_i + n \cdot V_o$$

$$V_{D1(\max)} = V_o + \frac{V_i}{n}$$

$$I_o = \frac{V_o}{R_o}$$

$$I_{D1} = I_o$$

$$I_{p(\max)} = I_{S1(\max)} = \frac{V_i \cdot D}{L_1 \cdot F_s}$$

$$I_{S1} = I_i = \frac{P_i}{V_i} \rightarrow P_i = P_o \rightarrow \eta = 1$$

# Próxima Aula

## Conversores cc-ca

