Chapter 1
Introduction

eThinking in Circuits with PSpice

Mechanical Engineering
National Central University

February 13, 2012 – February 11, 2022

Outlines

1. Electrical Components
   - Quantities
   - Relationships
2. Electrical Laws
   - Ohm's law
   - Faraday's law
   - Henry's law
3. Electrical Sources
   - Ideal independent sources
   - Ideal dependent sources

Electrical Components

Passive() elements: resistor, capacitor, inductor, transformer
Active() elements: transistor, motor, generator.

- Charge(): $+$q & -q, $\pm 1.602 \times 10^{-19}$ coulomb()

Electrical Components

Passive() elements: resistor, capacitor, inductor, transformer
Active() elements: transistor, motor, generator.

- Charge(): +q & -q, $\pm 1.602 \times 10^{-19}$ coulomb()
- Current:
  $i = \frac{dq}{dt} = \frac{dq^+}{dt} + \frac{dq^-}{dt} \quad (A = \frac{C}{s}), \quad q(t) = \int_0^t i(\tau) d\tau + q(0)$

  $$\left.\begin{array}{cc} \leftarrow \oplus(q_L^+) & \oplus(q_R^+) \rightarrow \\ \leftarrow \ominus(q_L^-) & \ominus(q_R^-) \rightarrow \end{array}\right\} reference \ direction \rightarrow i$$

  $q = q_R^+ - q_L^+ + (q_R^- - q_L^-)$
  Current Convention: Current has direction. AC & DC

Electrical Components

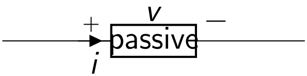
Passive() elements: resistor, capacitor, inductor, transformer
Active() elements: transistor, motor, generator.

- Charge(): $+$q & -q, $\pm 1.602 \times 10^{-19}$ coulomb()
- Current:
  $i = \frac{dq}{dt} = \frac{dq^+}{dt} + \frac{dq^-}{dt} \quad (A = \frac{C}{s}), \quad q(t) = \int_0^t i(\tau)d\tau + q(0)$

  $$\left.\begin{matrix} \leftarrow \oplus(q_L^+) & \oplus(q_R^+) \rightarrow \\ \leftarrow \ominus(q_L^-) & \ominus(q_R^-) \rightarrow \end{matrix}\right\} reference\ direction \rightarrow i$$

  $q = q_R^+ - q_L^+ + (q_R^- - q_L^-)$
  Current Convention: Current has direction. AC & DC
- Voltage: $v = \frac{d\omega}{dq} \quad (V = \frac{J}{C})$
  Voltage Convention: Voltage has polarity. $+$ polarity has higher potential than - polarity. It DOES NOT mean $+$ is of positive value and - is of negative value.

Continued

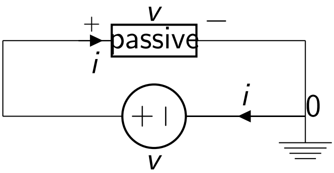


Passive elements: Current entering + consumes power.

- Energy and Power

$$
\begin{aligned}
dw &= v \cdot dq = v\frac{dq}{dt} \cdot dt = vidt \\
w &= \int_{t_1}^{t_2} vidt = \int_{t_1}^{t_2} pdt \\
p &= \frac{dw}{dt} = \frac{vdq}{dt} = vi \quad (volts \times amp = \frac{J}{C} \times \frac{C}{s} = \frac{J}{s} = Watts) \\
P_{av} &= \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} vi\ dt = Average\ power\ over\ t_2 - t_1.
\end{aligned}
$$

Continued

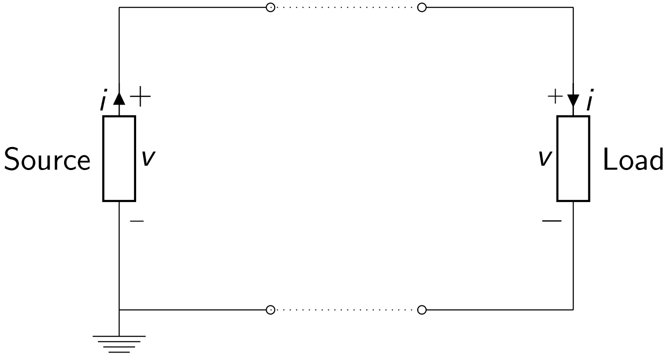


Passive elements: Current entering + consumes power.
Active element: Current leaving + generates power.

- Energy and Power

$$\begin{aligned}
dw &= v \cdot dq = v\frac{dq}{dt} \cdot dt = vidt \\
w &= \int_{t_1}^{t_2} vidt = \int_{t_1}^{t_2} pdt \\
p &= \frac{dw}{dt} = \frac{vdq}{dt} = vi \quad (volts \times amp = \frac{J}{C} \times \frac{C}{s} = \frac{J}{s} = Watts) \\
P_{av} &= \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} vi\ dt = Average\ power\ over\ t_2 - t_1.
\end{aligned}$$

Overall Closed-loop Circuit



Passive reference configuration:

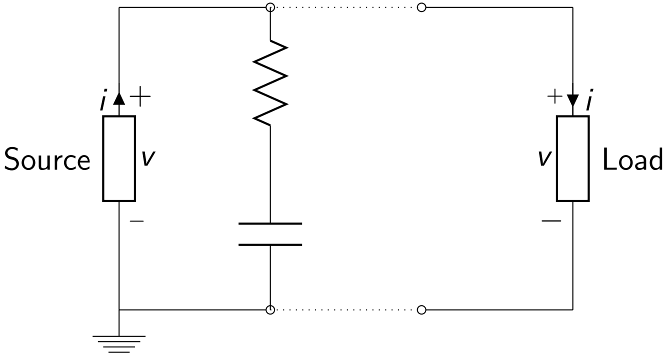
Sources: provide, deliver, send, generate

Loads: absorb, consume, receive, draw

Current has direction.

Voltage has polarities.

Overall Closed-loop Circuit



Passive reference configuration:

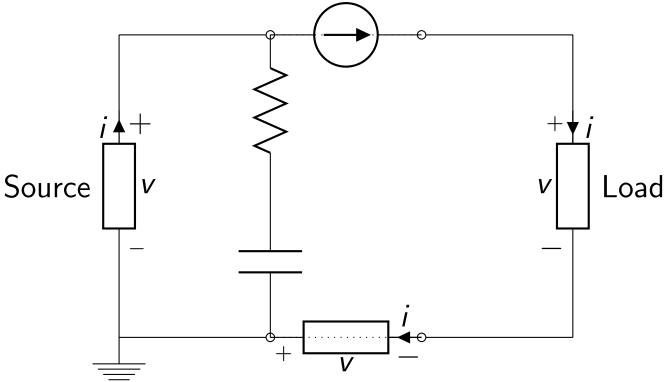
Sources: provide, deliver, send, generate

Loads: absorb, consume, receive, draw

Current has direction.

Voltage has polarities.

Overall Closed-loop Circuit



Passive reference configuration:

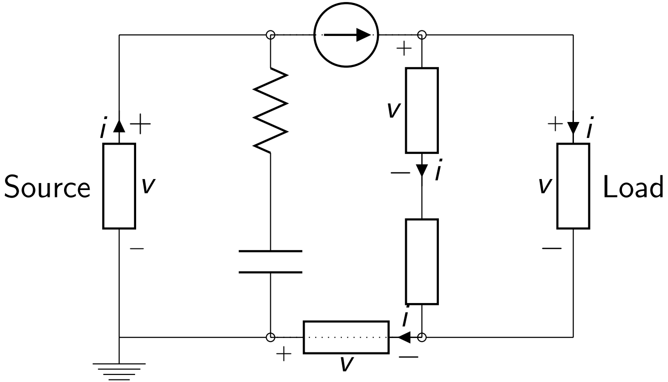
Sources: provide, deliver, send, generate

Loads: absorb, consume, receive, draw

Current has direction.

Voltage has polarities.

Overall Closed-loop Circuit



Passive reference configuration:

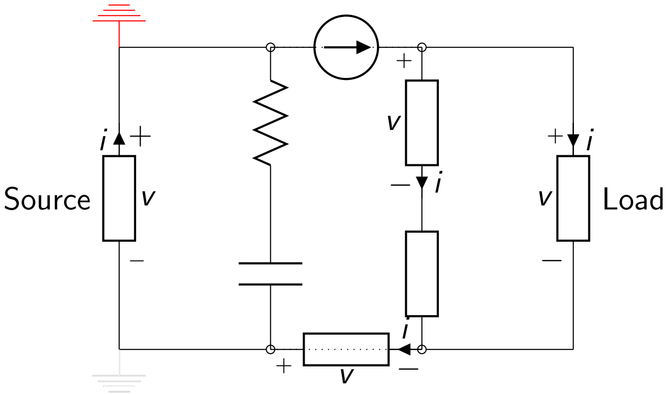
Sources: provide, deliver, send, generate

Loads: absorb, consume, receive, draw

Current has direction.

Voltage has polarities.

Overall Closed-loop Circuit



Passive reference configuration:

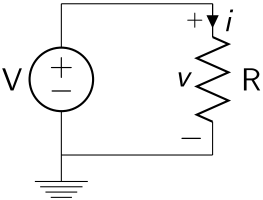
Sources: provide, deliver, send, generate

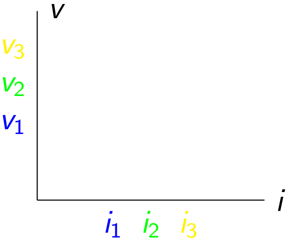
Loads: absorb, consume, receive, draw

Current has direction.

Voltage has polarities.

Resistors



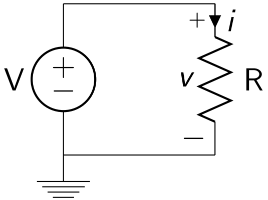


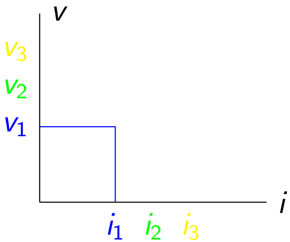
$$v = iR, \quad \text{Current entering } +$$

$$v = -iR, \quad \text{Current entering -}$$

$$\begin{aligned} p &= vi = (iR)i = i^2 R = \frac{v^2}{R} \\ \omega &= \int_{t_1}^{t_2} p dt = R \int_{t_1}^{t_2} i^2 dt = \frac{1}{R} \int_{t_1}^{t_2} v^2 dt \end{aligned}$$

Resistors





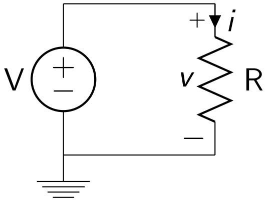
$v = iR,$ Current entering +

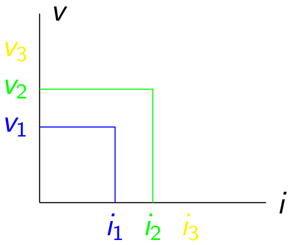
$v = -iR,$ Current entering -

$$p = vi = (iR)i = i^2R = \frac{v^2}{R}$$

$$\omega = \int_{t_1}^{t_2} pdt = R\int_{t_1}^{t_2} i^2dt = \frac{1}{R}\int_{t_1}^{t_2} v^2dt$$

Resistors



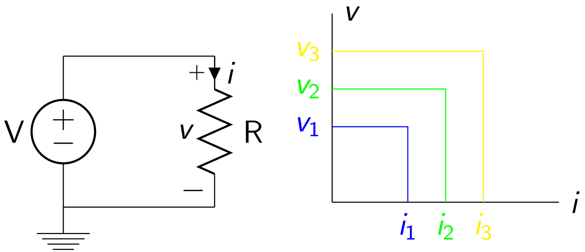


$v = iR$, Current entering +

$v = -iR$, Current entering -

$$
\begin{aligned}
p &= vi = (iR)i = i^2 R = \frac{v^2}{R} \\
\omega &= \int_{t_1}^{t_2} p\,dt = R\int_{t_1}^{t_2} i^2 dt = \frac{1}{R}\int_{t_1}^{t_2} v^2 dt
\end{aligned}
$$

Resistors

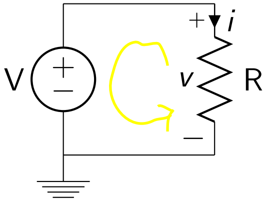


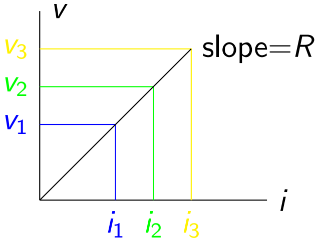
$$v = iR, \quad \text{Current entering} +$$

$$v = -iR, \quad \text{Current entering -}$$

$$\begin{aligned} p &= vi = (iR)i = i^2R = \frac{v^2}{R} \\ \omega &= \int_{t_1}^{t_2} pdt = R\int_{t_1}^{t_2} i^2dt = \frac{1}{R}\int_{t_1}^{t_2} v^2dt \end{aligned}$$

Resistors





$$v = iR, \quad \text{Current entering } +$$

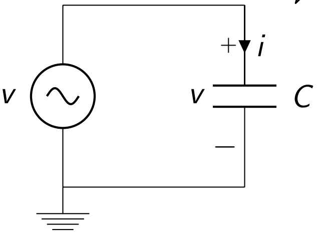
$$v = -iR, \quad \text{Current entering -}$$

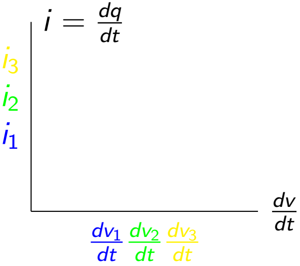
$$i = \frac{V}{R}$$

$$p = vi = (iR)i = i^2 R = \frac{v^2}{R}$$

$$\omega = \int_{t_1}^{t_2} p\,dt = R\int_{t_1}^{t_2} i^2 dt = \frac{1}{R}\int_{t_1}^{t_2} v^2 dt$$

Capacitors





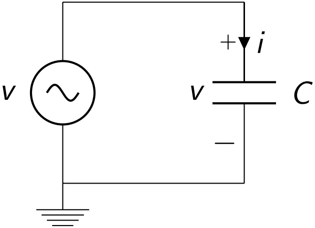
$$i = \frac{dq}{dt} = C\frac{dv}{dt}, \quad \text{Current entering } +$$

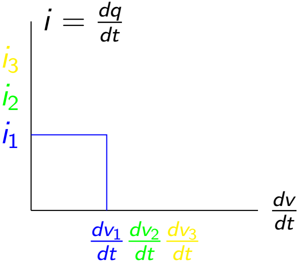
$$i = -C\frac{dv}{dt}, \quad \text{Current entering -}$$

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = \frac{1}{C}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau = v(t_0) + \frac{1}{C}\int_{t_0}^{t}$$

$$p = vi = v(C\frac{dv}{dt})$$

Capacitors



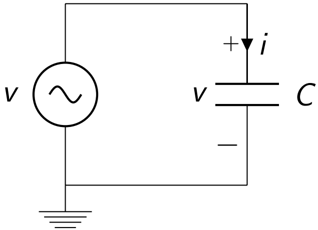


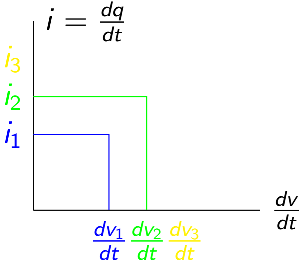
$$i = \frac{dq}{dt} = C\frac{dv}{dt}, \quad \text{Current entering +}$$

$$i = -C\frac{dv}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned} v(t) &= \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = \frac{1}{C}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau = v(t_0) + \frac{1}{C}\int_{t_0}^{t} \\ p &= vi = v(C\frac{dv}{dt}) \end{aligned}$$

Capacitors





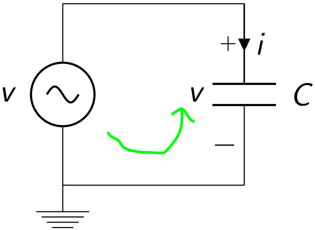
$$i = \frac{dq}{dt} = C\frac{dv}{dt}, \quad \text{Current entering +}$$

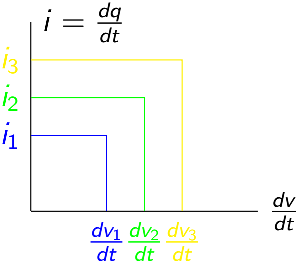
$$i = -C\frac{dv}{dt}, \quad \text{Current entering -}$$

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = \frac{1}{C}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau = v(t_0) + \frac{1}{C}\int_{t_0}^{t}$$

$$p = vi = v(C\frac{dv}{dt})$$

Capacitors



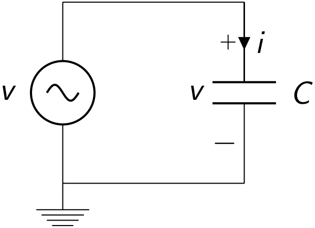


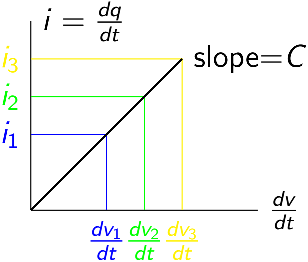
$$i = \frac{dq}{dt} = C\frac{dv}{dt}, \quad \text{Current entering } +$$

$$i = -C\frac{dv}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned} v(t) &= \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = \frac{1}{C}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau = v(t_0) + \frac{1}{C}\int_{t_0}^{t} \\ p &= vi = v(C\frac{dv}{dt}) \end{aligned}$$

Capacitors



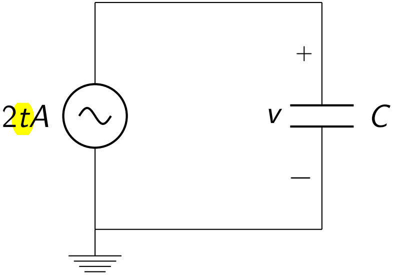


$$i = \frac{dq}{dt} = C\frac{dv}{dt}, \quad \text{Current entering +}$$

$$i = -C\frac{dv}{dt}, \quad \underline{\text{Current entering -}}$$

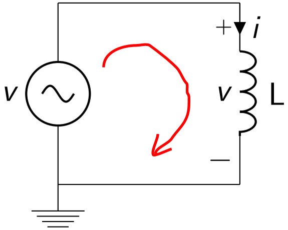
$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = \frac{1}{C}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau = v(t_0) + \frac{1}{C}\int_{t_0}^{t}$$

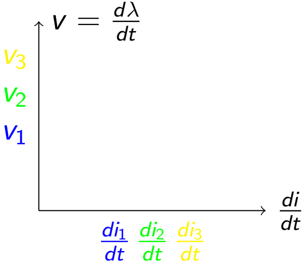
$$p = vi = v(C\frac{dv}{dt})$$



Here, we assume $C = 1$ and $i(t) = 2t$, thus $v(t) = t^2$.

Inductors



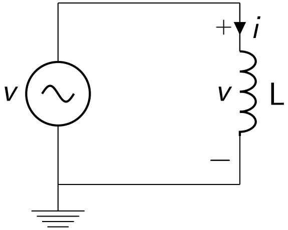


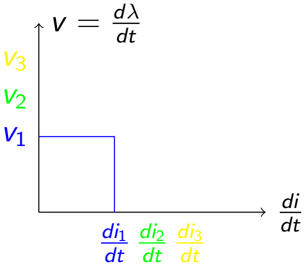
$$v = \frac{d\lambda}{dt} = L\frac{di}{dt}, \quad \text{Current entering } +$$

$$v = -L\frac{di}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned}
i(t) &= \frac{1}{L}\int_{-\infty}^{t} v(\tau)d\tau = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau \\
p(t) &= vi = (L\frac{di}{dt})i \\
w(t) &= \int_{-\infty}^{t} p(\tau)d\tau = L\int_{-\infty}^{t} \frac{di}{d\tau} i \; d\tau = \frac{1}{2}Li^2(t) = \frac{\lambda^2(t)}{2L}
\end{aligned}$$

Inductors



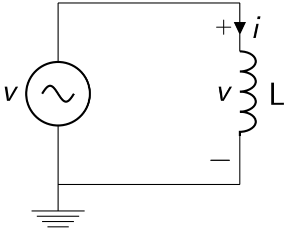


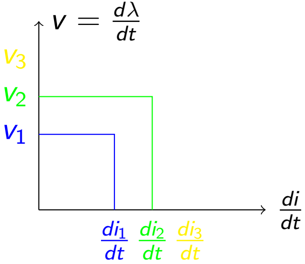
$$v = \frac{d\lambda}{dt} = L\frac{di}{dt}, \quad \text{Current entering } +$$

$$v = -L\frac{di}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned}
i(t) &= \frac{1}{L}\int_{-\infty}^{t} v(\tau)d\tau = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau \\
p(t) &= vi = (L\frac{di}{dt})i \\
w(t) &= \int_{-\infty}^{t} p(\tau)d\tau = L\int_{-\infty}^{t} \frac{di}{d\tau} i \, d\tau = \frac{1}{2}Li^2(t) = \frac{\lambda^2(t)}{2L}
\end{aligned}$$

Inductors



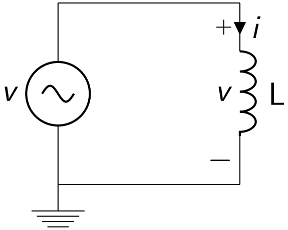


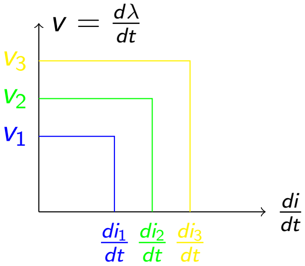
$$v = \frac{d\lambda}{dt} = L\frac{di}{dt}, \quad \text{Current entering } +$$

$$v = -L\frac{di}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned}
i(t) &= \frac{1}{L}\int_{-\infty}^{t} v(\tau)d\tau = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau \\
p(t) &= vi = (L\frac{di}{dt})i \\
w(t) &= \int_{-\infty}^{t} p(\tau)d\tau = L\int_{-\infty}^{t} \frac{di}{d\tau} i \, d\tau = \frac{1}{2}Li^2(t) = \frac{\lambda^2(t)}{2L}
\end{aligned}$$

Inductors



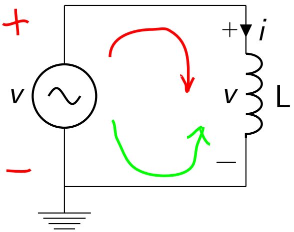


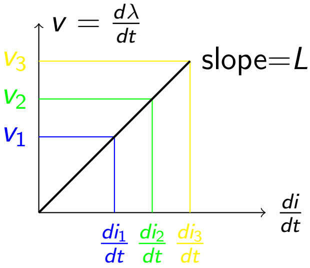
$$v = \frac{d\lambda}{dt} = L\frac{di}{dt}, \quad \text{Current entering } +$$

$$v = -L\frac{di}{dt}, \quad \text{Current entering -}$$

$$\begin{aligned}
i(t) &= \frac{1}{L}\int_{-\infty}^{t} v(\tau)d\tau = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau \\
p(t) &= vi = (L\frac{di}{dt})i \\
w(t) &= \int_{-\infty}^{t} p(\tau)d\tau = L\int_{-\infty}^{t} \frac{di}{d\tau} i \, d\tau = \frac{1}{2}Li^2(t) = \frac{\lambda^2(t)}{2L}
\end{aligned}$$

Inductors





$$v = \frac{d\lambda}{dt} = L\frac{di}{dt}, \quad \text{Current entering } +$$

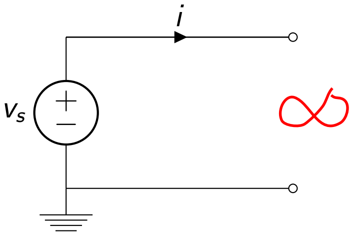
$$v = -L\frac{di}{dt}, \quad \text{Current entering -}$$

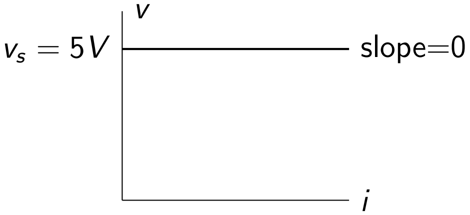
$$i(t) = \frac{1}{L}\int_{-\infty}^{t} v(\tau)d\tau = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau = i(t_0) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau$$

$$p(t) = vi = (L\frac{di}{dt})i$$

$$w(t) = \int_{-\infty}^{t} p(\tau)d\tau = L\int_{-\infty}^{t} \frac{di}{d\tau} i \, d\tau = \frac{1}{2}Li^2(t) = \frac{\lambda^2(t)}{2L}$$

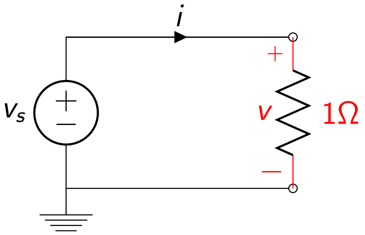
Ideal independent VOLTAGE source

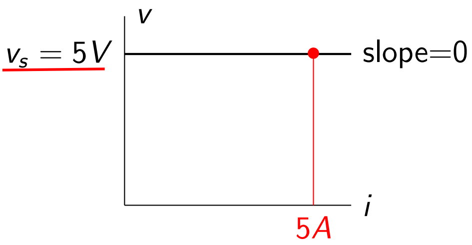




Regardless of the load, the source ALWAYS provides fixed voltage V_s, thus load is always fixed too due to the parallel structure. But the current i provided by voltage source will change.

Ideal independent VOLTAGE source

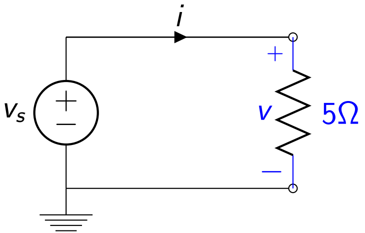


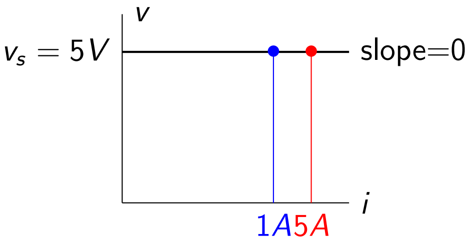


$$i = \frac{5}{1} = 5A,$$

Regardless of the load, the source ALWAYS provides fixed voltage V_s, thus load is always fixed too due to the parallel structure. But the current i provided by voltage source will change.

Ideal independent VOLTAGE source

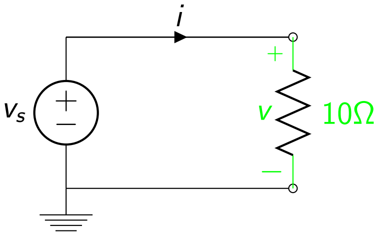


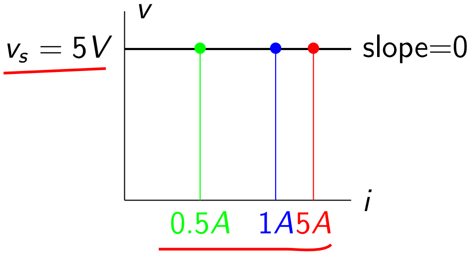


$$i = \frac{5}{1} = 5A, \quad i = \frac{5}{5} = 1A,$$

Regardless of the load, the source ALWAYS provides fixed voltage V_s, thus load is always fixed too due to the parallel structure. But the current i provided by voltage source will change.

Ideal independent VOLTAGE source

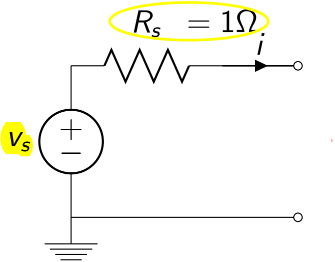


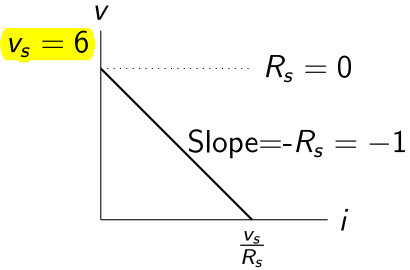


$$i = \frac{5}{1} = 5A, \quad i = \frac{5}{5} = 1A, \quad i = \frac{5}{10} = 0.5A$$

Regardless of the load, the source ALWAYS provides fixed voltage V_s, thus load is always fixed too due to the parallel structure. But the current i provided by voltage source will change.

Ideal independent VOLTAGE source with internal resistor

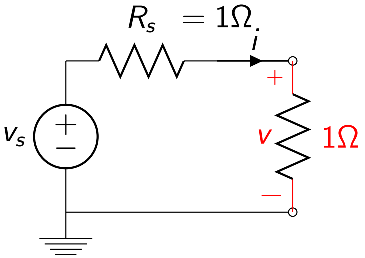


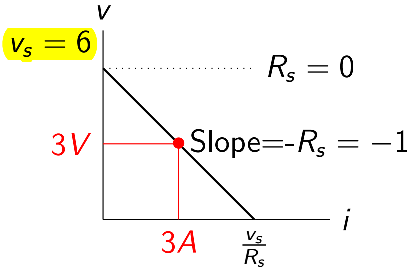


With internal resistor, the output/load voltage and current will change, but the source remains fixed at V_s.

Voltage source in series with a resistor.

Ideal independent VOLTAGE source with internal resistor



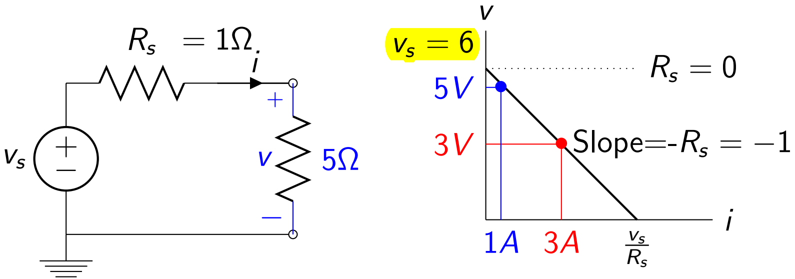


$$i = \frac{6}{2} = 3A,$$

With internal resistor, the output/load voltage and current will change, but the source remains fixed at V_s.

Voltage source in series with a resistor.

Ideal independent VOLTAGE source with internal resistor

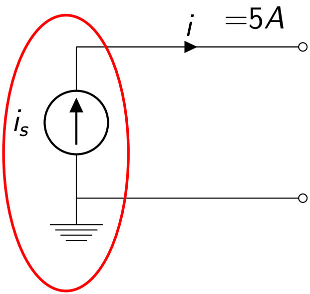


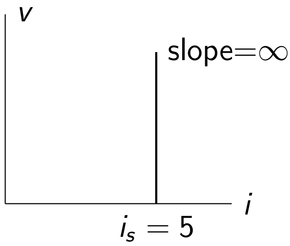
$$i = \frac{6}{2} = 3A, \quad i = \frac{6}{6} = 1A,$$

With internal resistor, the output/load voltage and current will change, but the source remains fixed at V_s.

Voltage source in series with a resistor.

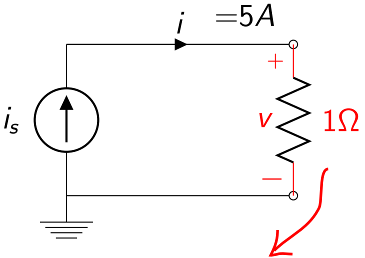
Ideal independent CURRENT source

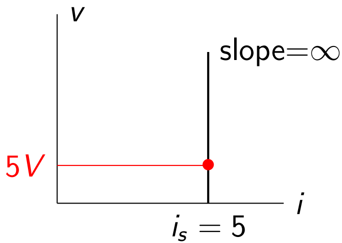




Regardless of loads, the current ALWAYS provides a fixed current I_s. The output current i is fixed too due to series structure. But the output/load voltage v changes accordingly due to parallel structure.

Ideal independent CURRENT source

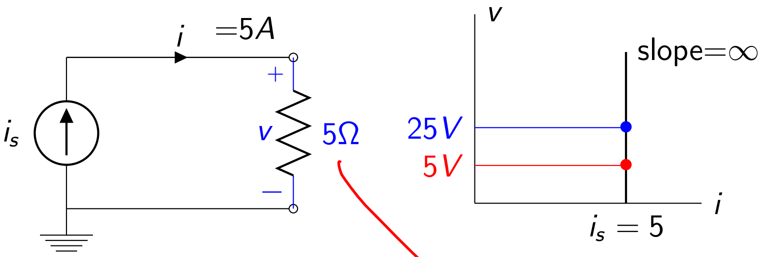




$v = 5 \times 1 = 5V,$

Regardless of loads, the current ALWAYS provides a fixed current I_s. The output current i is fixed too due to series structure. But the output/load voltage v changes accordingly due to parallel structure.

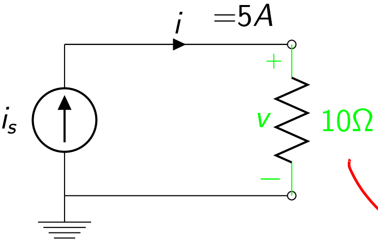
Ideal independent CURRENT source

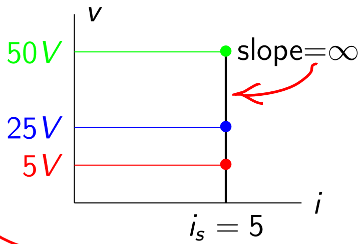


$v = 5 \times 1 = 5\,V$, $v = 5 \times 5 = 25\,V$,

Regardless of loads, the current ALWAYS provides a fixed current I_s. The output current i is fixed too due to series structure. But the output/load voltage v changes accordingly due to parallel structure.

Ideal independent CURRENT source

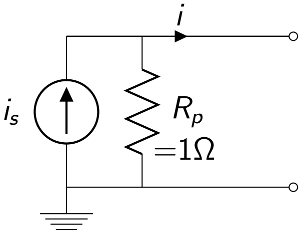


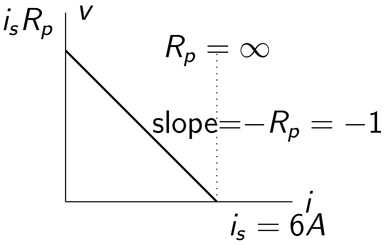


$$v = 5 \times 1 = 5V, \quad v = 5 \times 5 = 25V, \quad v = 5 \times 10 = 50V$$

Regardless of loads, the current ALWAYS provides a fixed current I_s. The output current i is fixed too due to series structure. But the output/load voltage v changes accordingly due to parallel structure.

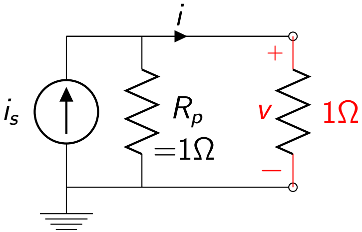
Ideal independent CURRENT source with internal resistor

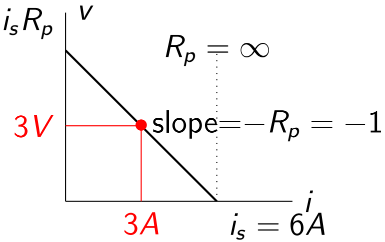




With internal resistor, the output/load voltage and current will change, but the source remains fixed at i_s.
Current source in parallel with a resistor.

Ideal independent CURRENT source with internal resistor



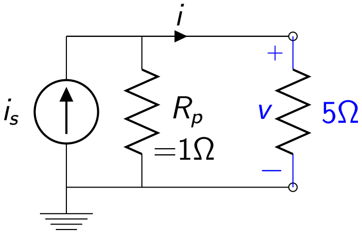


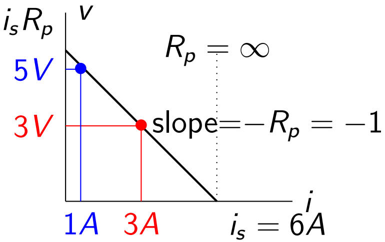
$$v = 3 \times 1 = 3V$$

With internal resistor, the output/load voltage and current will change, but the source remains fixed at i_s.

Current source in parallel with a resistor.

Ideal independent CURRENT source with internal resistor





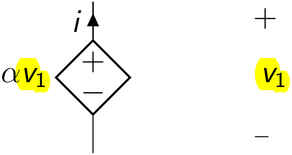
$$v = 3 \times 1 = 3V \quad v = \frac{1 \times 6}{6} \times 5 = 5V$$

With internal resistor, the output/load voltage and current will change, but the source remains fixed at i_s.

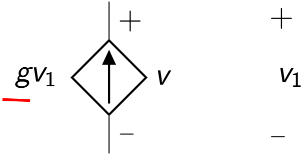
Current source in parallel with a resistor.

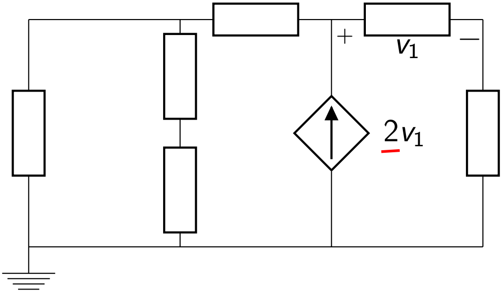
Voltage-controlled

Voltage-Controlled Voltage Source (VCVS):



Voltage-Controlled Current Source (VCCS):

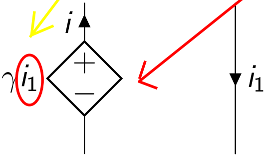




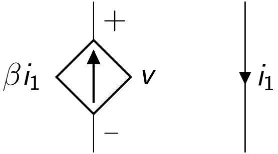
A circuit example

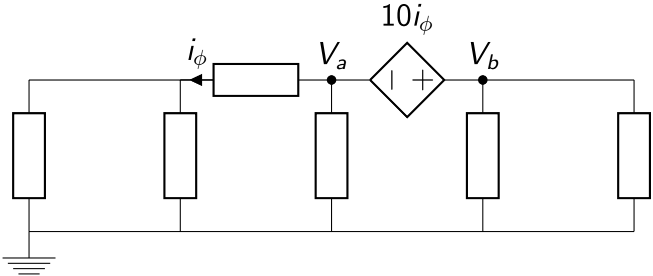
Current-controlled

Current-Controlled Voltage Source (CCVS):



Current-Controlled Current Source (CCCS):





A circuit example