DR. GYURCSEK ISTVÁN

Capacitors and Inductors

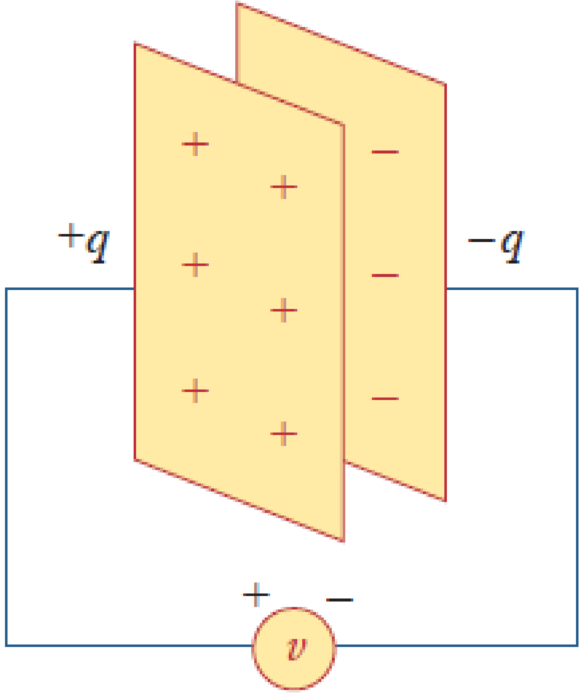
Sources and additional materials (recommended)

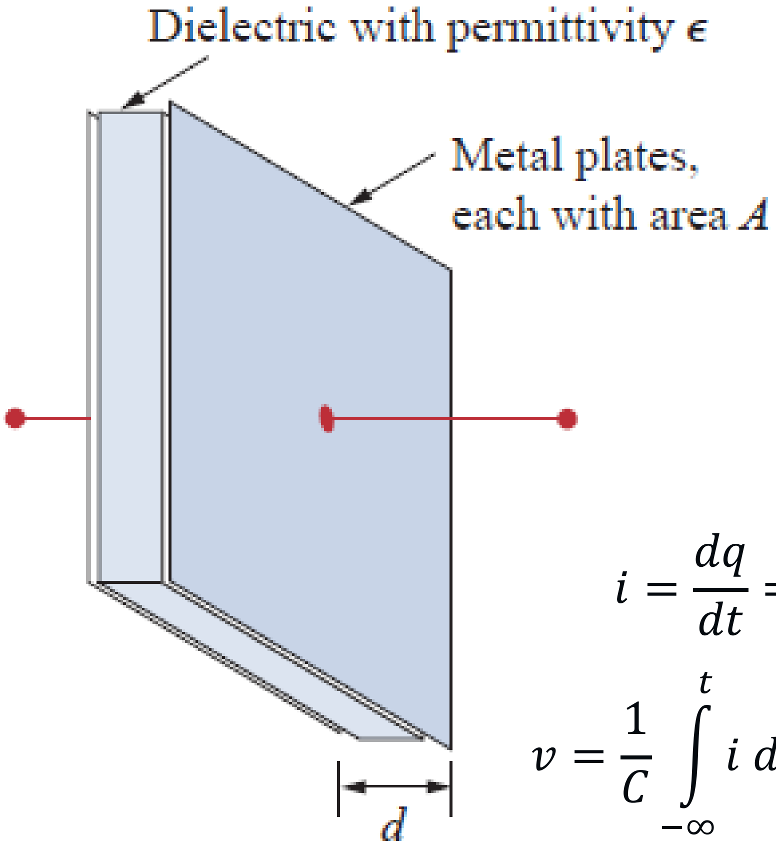
- *Dr. Gyurcsek – Dr. Elmer: Theories in Electric Circuits, GlobeEdit, 2016, ISBN:978-3-330-71341-3*
- *Ch. Alexander, M. Sadiku: Fundamentals of Electric Circuits, 6th Ed., McGraw Hill NY 2016, ISBN: 978-0078028229*
- *Simonyi K.: Villamosságtan. AK Budapest 1983, ISBN:9630534134*
- *Dr. Selmeczi K. – Schnöller A.: Villamosságtan 1. MK Budapest 2002, TK szám: 49203/I*
- *Dr. Selmeczi K. – Schnöller A.: Villamosságtan 2. TK Budapest 2002, ISBN:9631026043*
- *Zombory L.: Elektromágneses terek. MK Budapest 2006, (www.electro.uni-miskolc.hu)*

Progress in Content

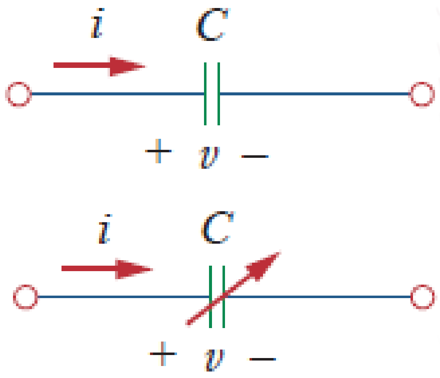
- ❑ **Capacitance (Properties, Series and Parallel Connections)**
- ❑ Inductance (Properties, Series and Parallel Connections)
- ❑ Applications (Integrator, Differentiator)

Capacitors





Symbols



$$i = \frac{dq}{dt} = C\frac{dv}{dt} \leftarrow linear\ element$$

$$v = \frac{1}{C}\int_{-\infty}^{t} i\,dt \rightarrow v = \frac{1}{C}\int_{t_0}^{t} i\,dt + v(t_0)$$

$$C = \frac{q}{v}\,, \qquad [F] = \left[\frac{C}{V}\right]$$

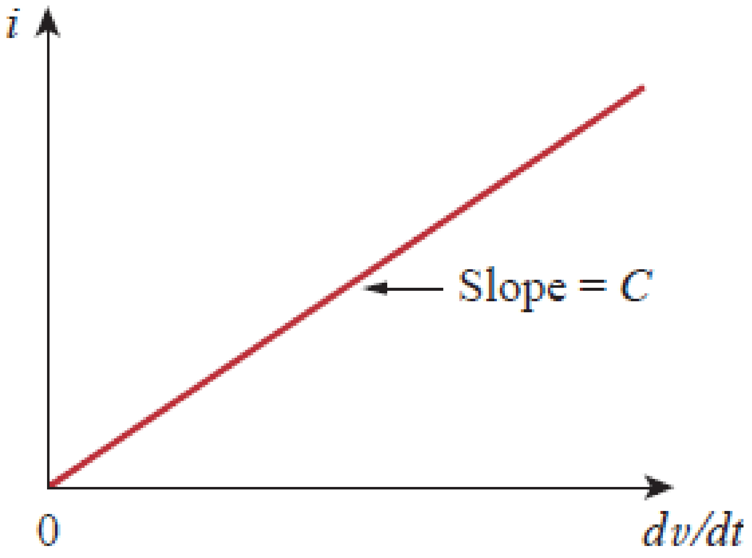
$$C = \varepsilon\frac{A}{d}$$

Memory element (*v* depends on past history of *i*.)

Properties of Capacitors

Property of linearity

$$i = C\frac{dv}{dt} \rightarrow$$



Energy stored in EF

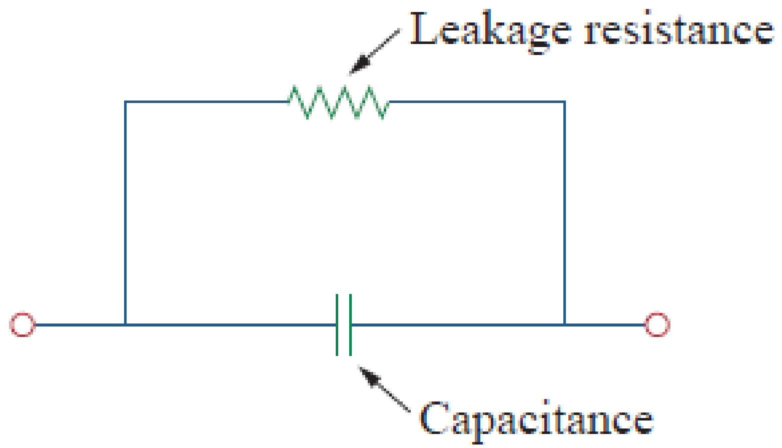
$$i = C\frac{dv}{dt} \rightarrow p = vi = vC\frac{dv}{dt}$$

$$w = \int_{-\infty}^{t} p\,dt = C\int_{-\infty}^{t} v\frac{dv}{dt}dt = C\int_{v(-\infty)}^{v(t)} v\,dv = \frac{1}{2}Cv^2\Big|_{v(-\infty)}^{v(t)}$$

$$v(-\infty) = 0 \rightarrow w = \frac{1}{2}Cv^2 \qquad q = Cv \rightarrow w = \frac{1}{2}Cv^2 = \frac{q^2}{2C}$$

Properties

- ❑ Linear element
- ❑ Energy storage (memory) element
- ❑ Open circuit on DC
- ❑ $v(-0) = v(+0)$
- ❑ Ideal C → no dissipated energy
- ❑ Real capacitor model →



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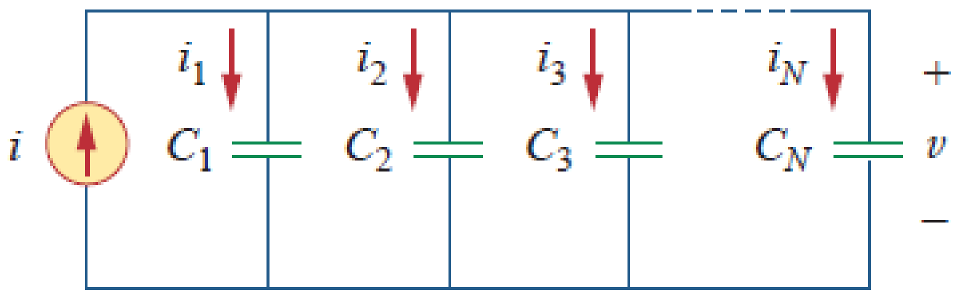
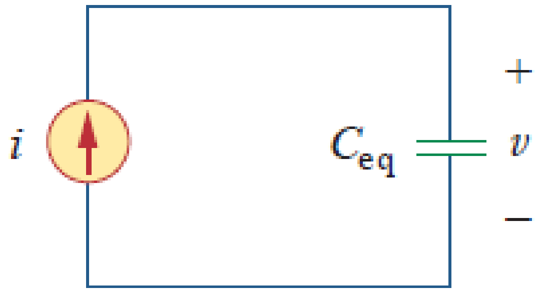
Parallel Capacitors

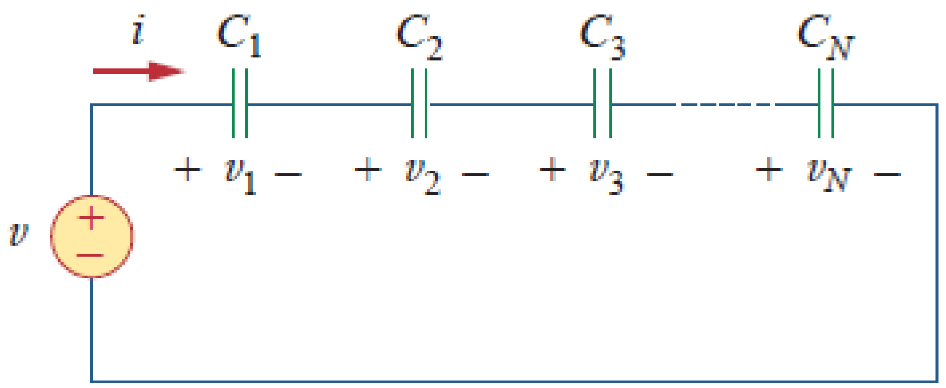


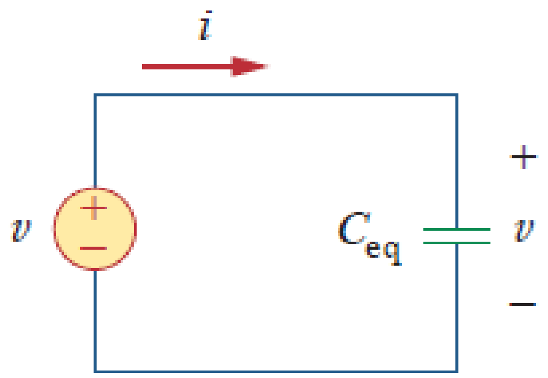


$$i = i_1 + i_2 + i_3 + \cdots + i_N$$

$$i = C_1 \frac{dv}{dt} + C_2 \frac{dv}{dt} + C_3 \frac{dv}{dt} + \cdots + C_N \frac{dv}{dt} \qquad i = \left(\sum_{k=1}^{N} C_k \right) \frac{dv}{dt} \rightarrow C_{eq} = \sum_{k=1}^{N} C_k$$

Series Capacitors





$$v = v_1 + v_2 + v_3 + \cdots + v_N$$

$$v = \frac{1}{C_1}\int_{t0}^{t} i(t)dt + v_1(t_0) + \frac{1}{C_2}\int_{t0}^{t} i(t)dt + v_2(t_0) + \cdots + \frac{1}{C_N}\int_{t0}^{t} i(t)dt + v_N(t_0)$$

$$v = \left(\sum_{k=1}^{N}\frac{1}{C_k}\right)\int_{t0}^{t} i(t)dt + v(t_0) \rightarrow \frac{1}{C_{eq}} = \sum_{k=1}^{N}\frac{1}{C_k} \quad \left(\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \rightarrow C_{eq} = \frac{C_1 \cdot C_2}{C_1 + C_2}\right)$$

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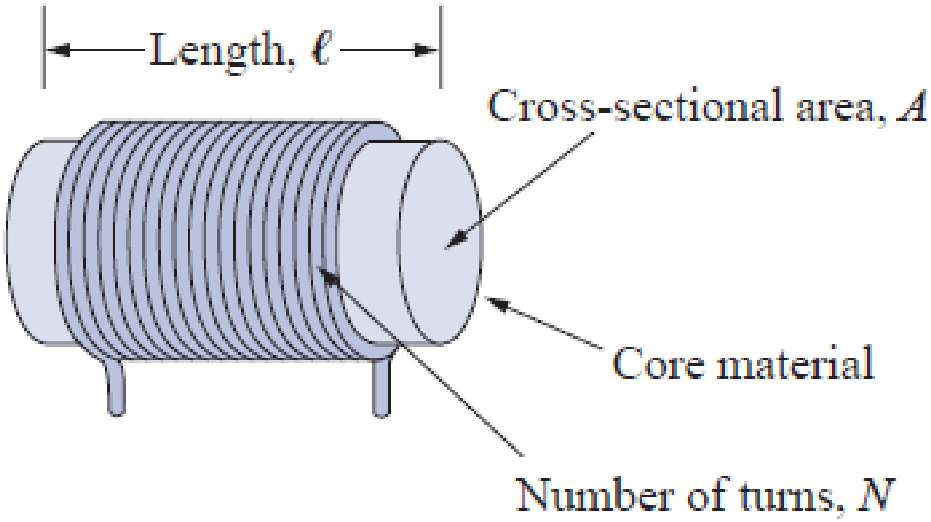
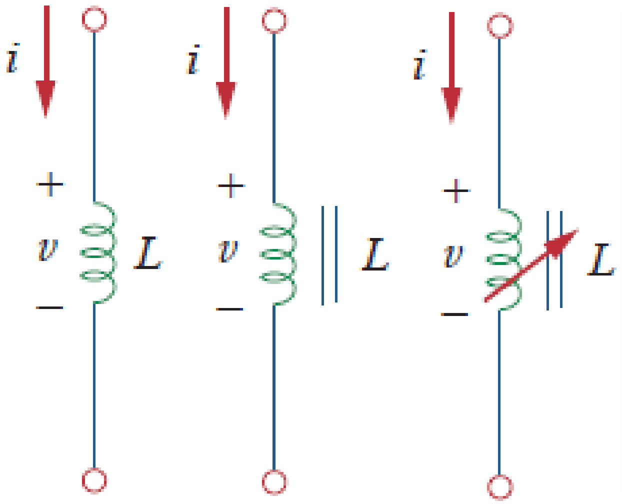
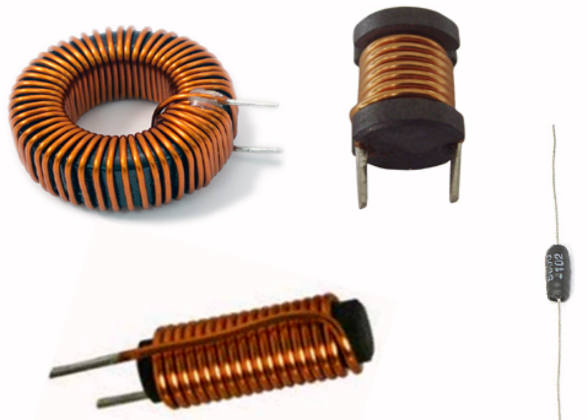


Symbols





Practical Inductors

$$\left.\begin{array}{l}(coil\ flux) \rightarrow \Psi(t) = L \cdot i(t) \\ \\ (Faraday) \rightarrow v(t) = \dfrac{d\Psi(t)}{dt}\end{array}\right\} \rightarrow v(t) = L\frac{di(t)}{dt} \qquad di = \frac{1}{L}vdt \rightarrow i = \frac{1}{L}\int_{-\infty}^{t} v(t)dt$$

$$L \rightarrow \quad [H] = \left[\frac{Vs}{A}\right] \qquad \left(L = \mu\frac{N^2 A}{l}\right) \qquad i = \frac{1}{L}\int_{t_0}^{t} v(t)dt + i(t_0)$$

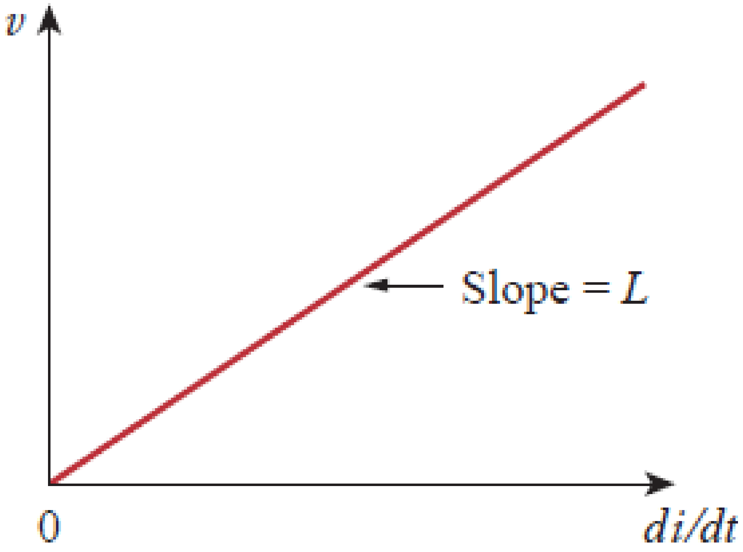
Memory element

(i depends on past history of v.)

Properties of Inductors

Property of linearity

$$v = L\frac{di}{dt} \rightarrow$$



Energy stored in MF

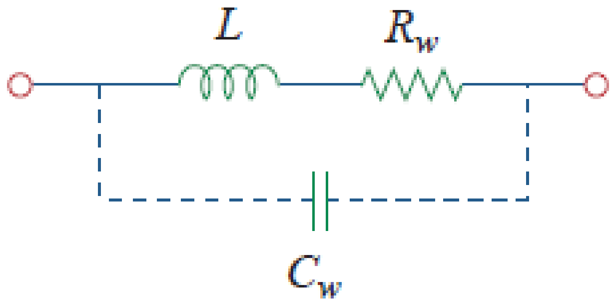
$$v = L\frac{di}{dt} \rightarrow p = vi = \left(L\frac{di}{dt}\right)i$$

$$w = \int_{-\infty}^{t} p\,dt = L\int_{-\infty}^{t} i\frac{di}{dt}dt = L\int_{i(-\infty)}^{i(t)} i\,di = \frac{1}{2}Li^2\Big|_{i(-\infty)}^{i(t)}$$

$$i(-\infty) = 0 \rightarrow w = \frac{1}{2}Li^2$$

Properties

- ❑ Linear element
- ❑ Energy storage (memory) element
- ❑ Short circuit on DC
- ❑ $i(-0) = i(+0)$
- ❑ Ideal L → no dissipated energy
- ❑ Real inductor model →



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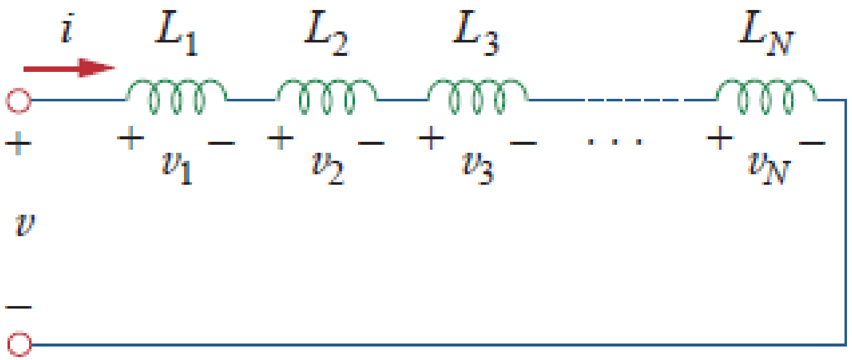
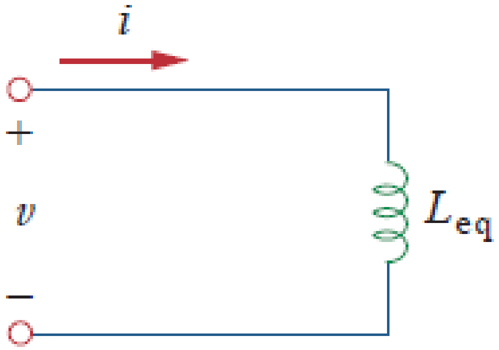
Series Inductors

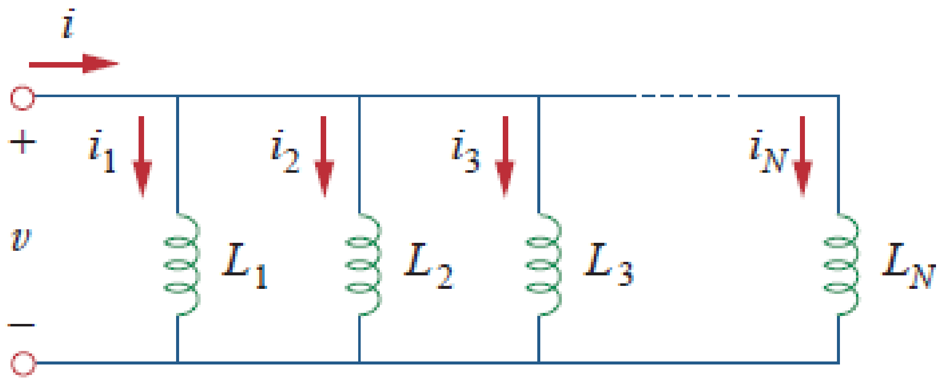


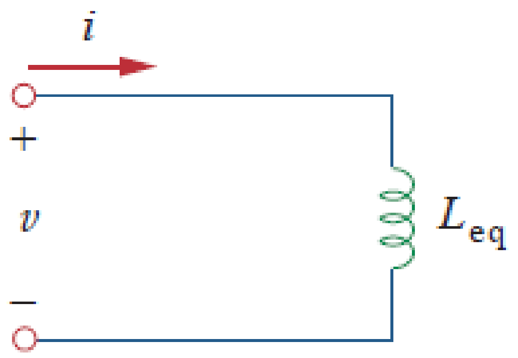


$$v = v_1 + v_2 + v_3 + \cdots + v_N$$

$$v = L_1 \frac{di}{dt} + L_2 \frac{di}{dt} + L_3 \frac{di}{dt} + \cdots + L_N \frac{di}{dt} \qquad v = \left(\sum_{k=1}^{N} L_k \right) \frac{di}{dt} \rightarrow L_{eq} = \sum_{k=1}^{N} L_k$$

Parallel Inductors





$$i = i_1 + i_2 + i_3 + \cdots + i_N$$

$$i = \frac{1}{L_1}\int_{t0}^{t} v(t)dt + i_1(t_0) + \frac{1}{L_2}\int_{t0}^{t} v(t)dt + i_2(t_0) + \cdots + \frac{1}{L_N}\int_{t0}^{t} v(t)dt + i_N(t_0)$$

$$i = \left(\sum_{k=1}^{N}\frac{1}{L_k}\right)\int_{t0}^{t} v(t)dt + i(t_0) \rightarrow \frac{1}{L_{eq}} = \sum_{k=1}^{N}\frac{1}{L_k} \quad \left(\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} \rightarrow L_{eq} = \frac{L_1 \cdot L_2}{L_1 + L_2}\right)$$

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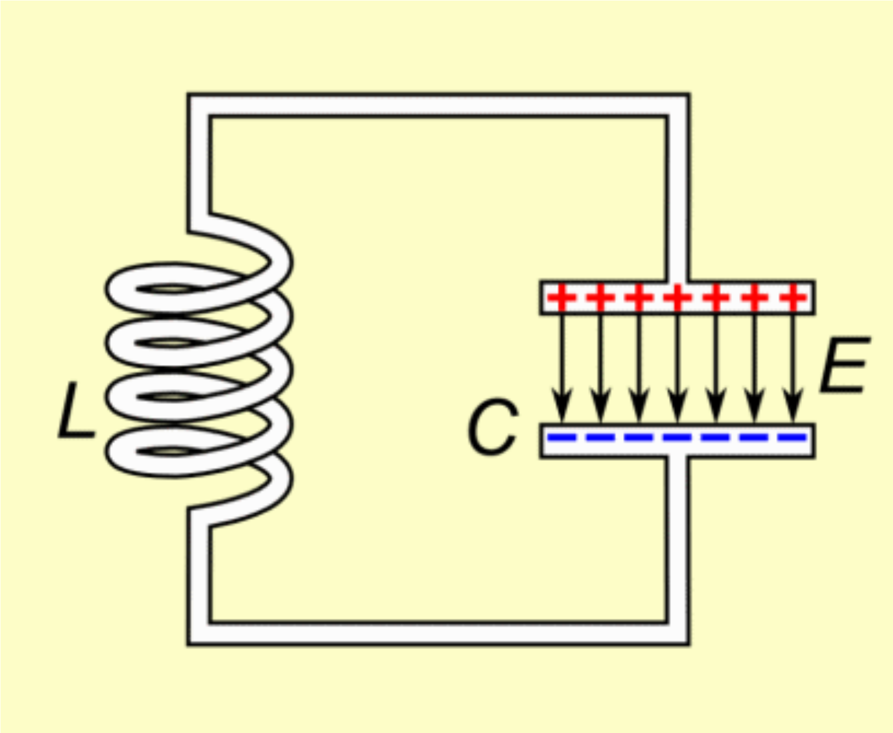
RLC Applications Summary

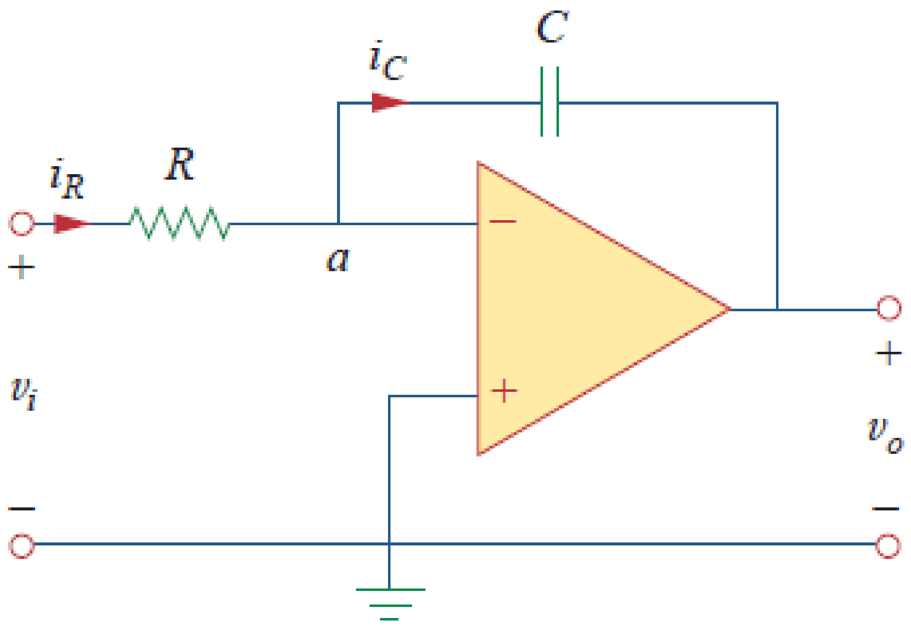


LC special properties
- ❑ Temporary energy storage *(dc app)*
- ❑ C → no abrupt change in voltage *(dc app)*
- ❑ L → no abrupt change in current *(dc app)*
- ❑ Frequency sensitive behavior *(ac app)*

Resistors & Capacitors
- ❑ discrete form
- ❑ IC form

Inductors (coils)
- ❑ discrete form *only*
- ❑ limited in applications *(sensors, motors, etc.)*

Applications – Integrator



$$i_R = i_C \to \frac{v_i}{R} = -C\frac{dv_o}{dt}$$

$$dv_o = -\frac{1}{RC}v_i dt$$

$$v_o(t) - v_o(0) = -\frac{1}{RC}\int_0^t v_i dt$$

$discharge\ integrator \to v_o(0) = 0 \to$ $$v_o(t) = -\frac{1}{RC}\int_0^t v_i(t)dt$$

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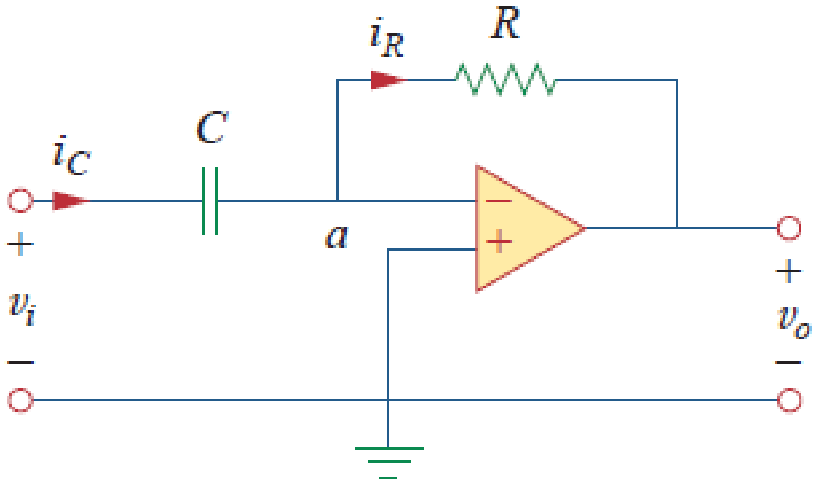
Application – Differentiator



$$i_R = i_C \to -\frac{v_o}{R} = C\frac{dv_i}{dt}$$

$$v_o = -RC\frac{dv_i}{dt}$$

Comments *(opamp application)*

- ❑ Not as popular as integrator
- ❑ Electronically unstable circuit
  (noise sensitive opamp circuit)

Questions