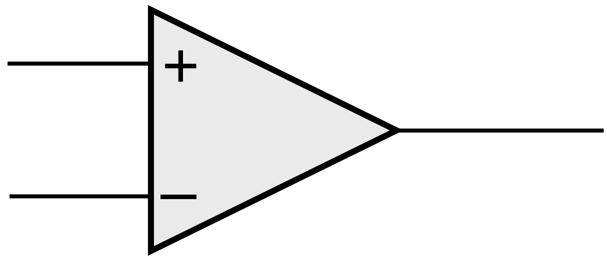
Operational Amplifier Circuits

Review

- Operational amplifier abstraction

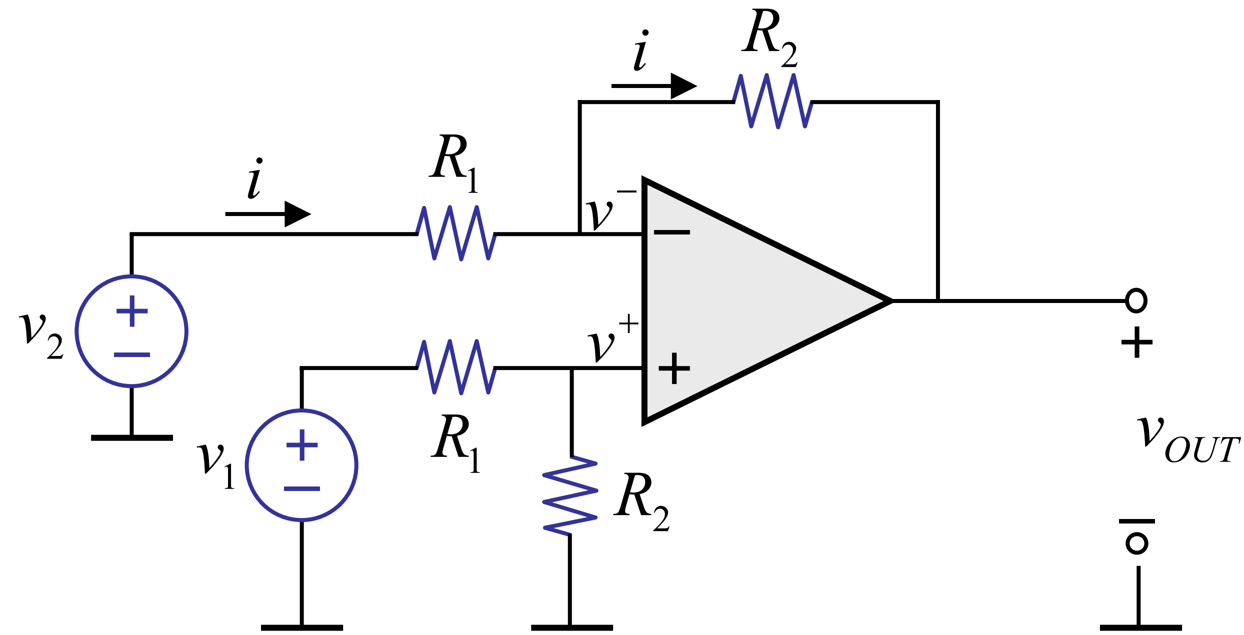


♦ ∞ input resistance
♦ 0 output resistance
♦ Gain "A" very large

- Building block for analog systems
- We will see these examples:
  Digital-to-analog converters
  Filters
  Clock generators
  Amplifiers
  Adders
  Integrators & Differentiators

Reading: Chapter 15.5 & 15.6 of A & L.

Consider this circuit:



$$v^+ = v_1 \frac{R_2}{R_1 + R_2}$$

$$\approx v^-$$

$$i = \frac{v_2 - v^-}{R_1}$$

$$v_{OUT} = v^- - iR_2$$

$$= v^- - \frac{v_2 - v^-}{R_1} \cdot R_2$$

$$= v^- \left[1 + \frac{R_2}{R_1}\right] - v_2 \frac{R_2}{R_1}$$

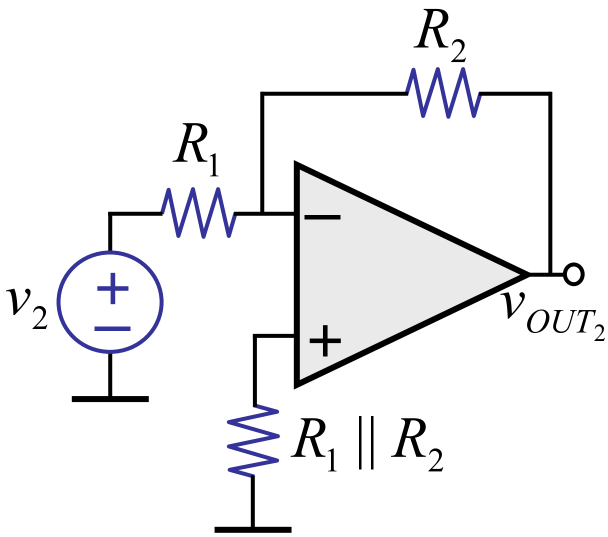
$$= v_1 \frac{R_2}{\cancel{R_1 + R_2}} \cdot \frac{\cancel{R_1 + R_2}}{R_1} - v_2 \frac{R_2}{R_1}$$

$$= \frac{R_2}{R_1}(v_1 - v_2)$$

subtracts!

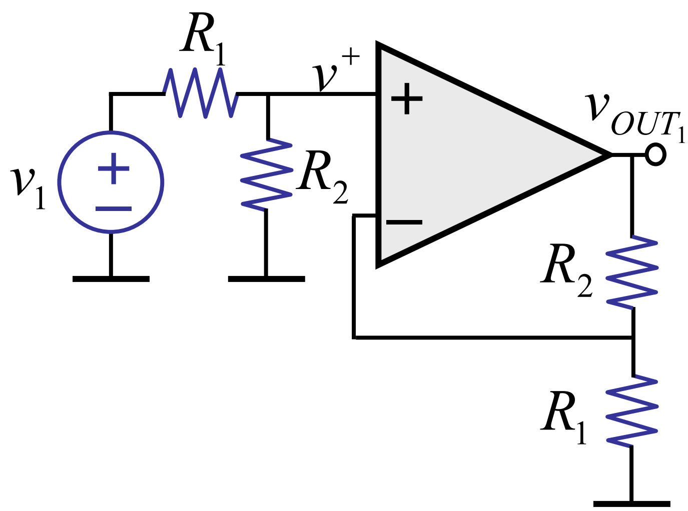
Another way of solving — use superposition

$v_1 \to 0$



$$v_{OUT_2} = -\frac{R_2}{R_1} v_2$$

$v_2 \to 0$



$$v_{OUT_1} = v^+ \cdot \frac{R_1 + R_2}{R_1}$$

$$= \frac{v_1 \cdot R_2}{R_1 + R_2} \cdot \frac{R_1 + R_2}{R_1}$$

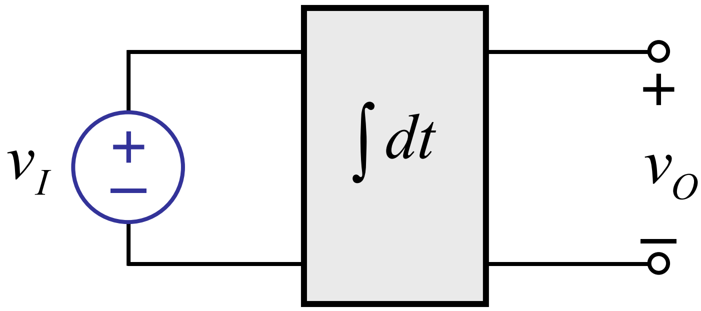
$$= v_1 \frac{R_2}{R_1}$$

$$v_{OUT} = v_{OUT_1} + v_{OUT_2}$$

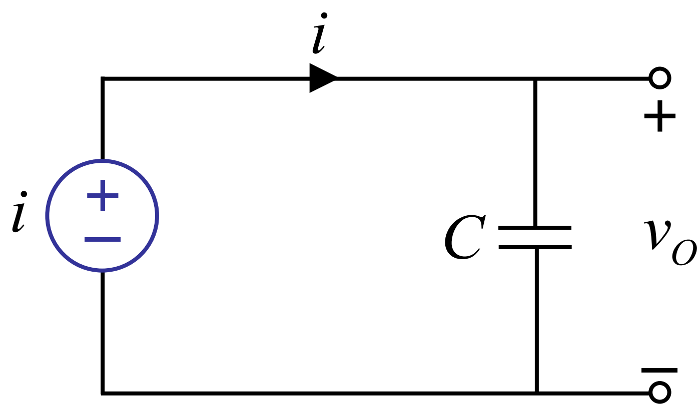
$$= \frac{R_2}{R_1}(v_1 - v_2)$$

Still subtracts!

Let's build an intergrator…



Let's start with the following insight:

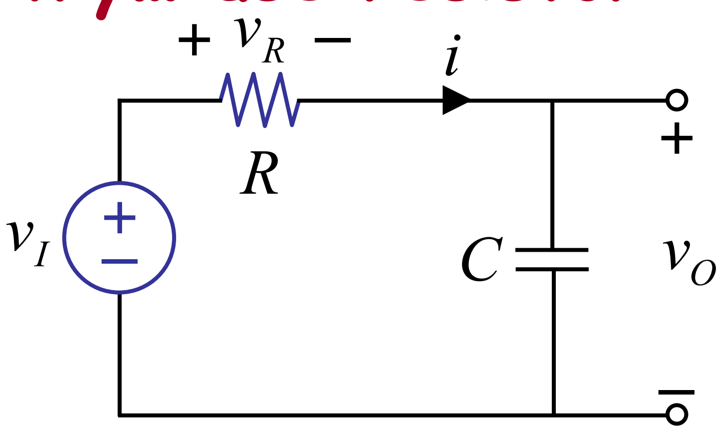


$$v_O = \frac{1}{C}\int_{-\infty}^{t} i\,dt$$

v_O is related to $\int i\,dt$

But we need to somehow convert voltage v_I to current.

First try… use resistor



$$\frac{v_I}{R} \rightarrow i$$

But, v_O must be very small compared to v_R, or else

$$i \neq \frac{v_I}{R}$$

When is v_O small compared to v_R?

$$\underbrace{RC\frac{dv_O}{dt}}_{v_R} + v_O = v_I$$

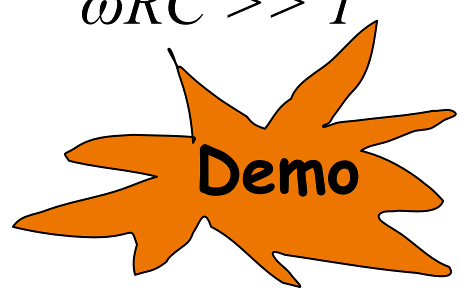
➡ larger the RC, smaller the v_O

when $RC\dfrac{dv_O}{dt} >> v_O$

$$RC\frac{dv_O}{dt} \approx v_I$$

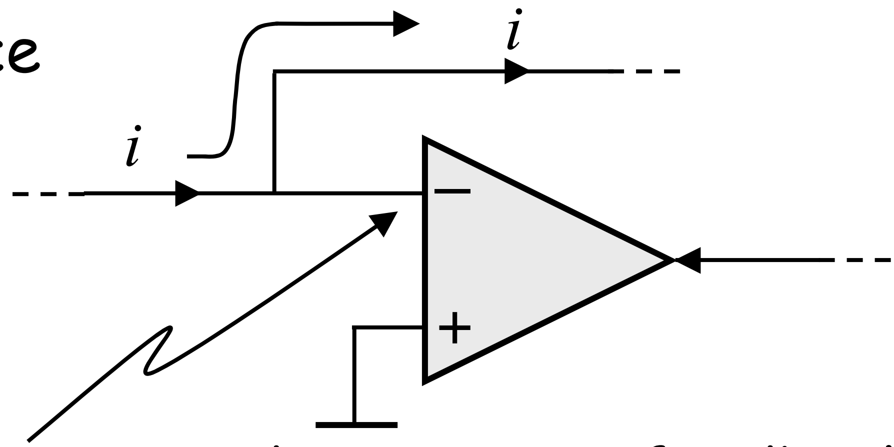
or $$v_O \approx \frac{1}{RC}\int_{-\infty}^{t} v_I \, dt$$

for good integrator
$\omega RC >> 1$



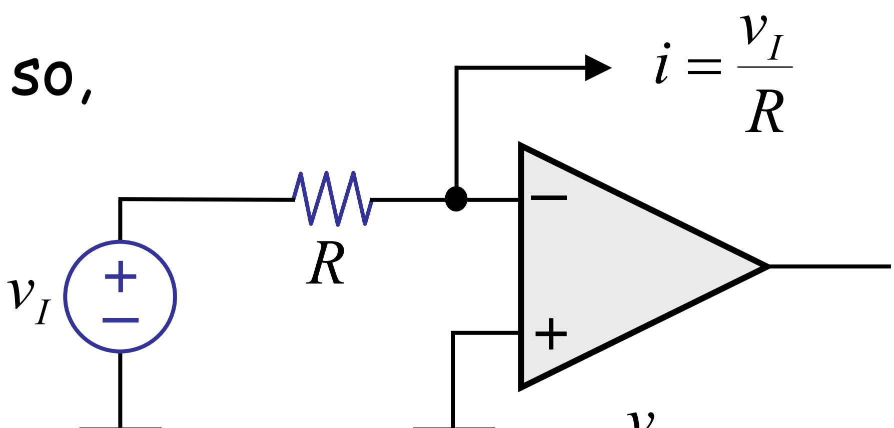
There's a better way…

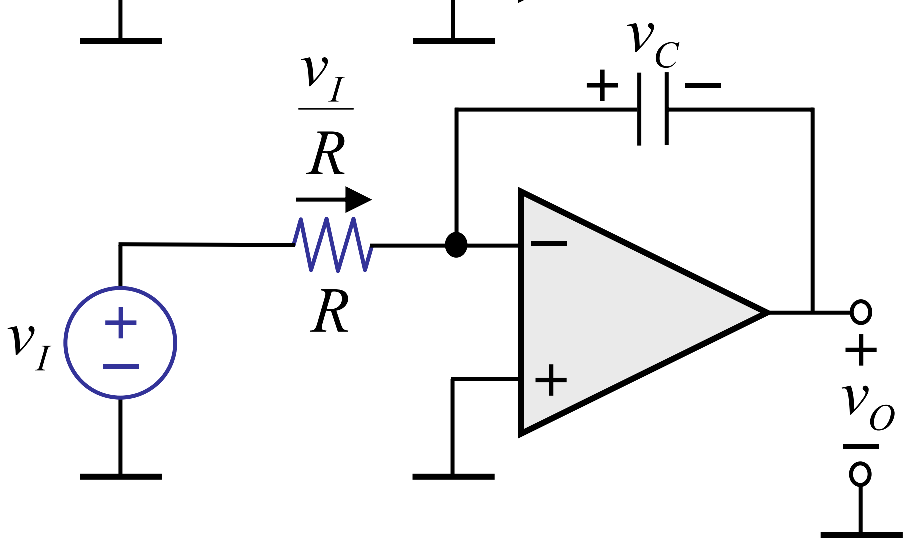
Notice



$v^- \approx 0V$ under negative feedback

so,



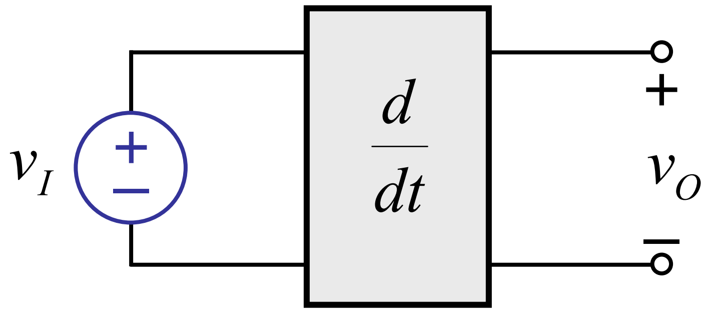


$$v_O = -v_C$$

$$v_O = -\frac{1}{C}\int_{-\infty}^{t}\frac{v_I}{R}dt$$

We have our integrator.

Now, let's build a differentiator…



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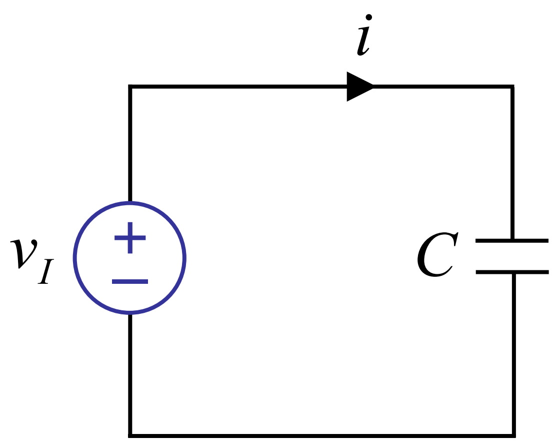


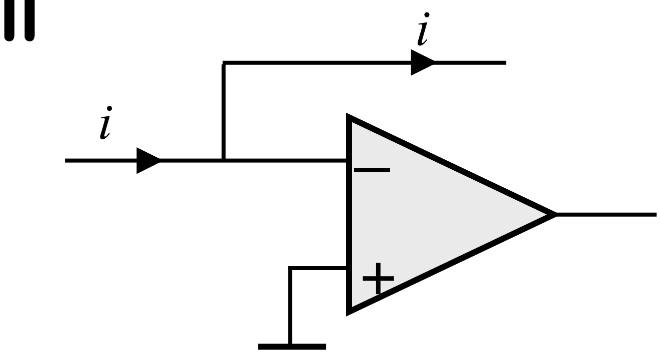
$$i = C\frac{dv_I}{dt}$$

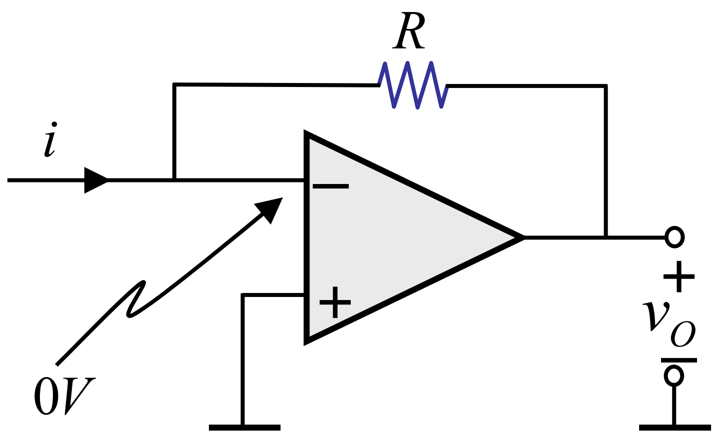
i is related to $\frac{dv_I}{dt}$

But we need to somehow convert current to voltage.

Differentiator…

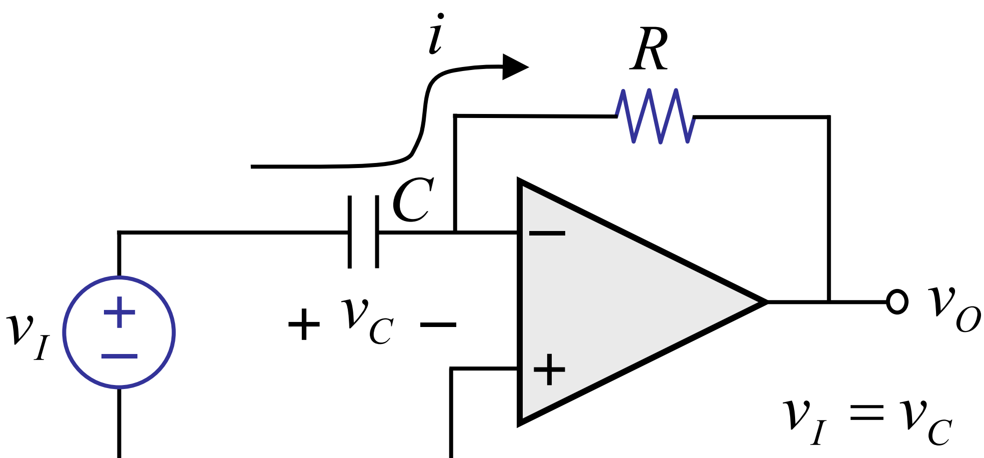
Recall





$v_O = -iR$

current to voltage



$v_I = v_C$

$$i = C\frac{dv_I}{dt}$$

$$v_O = -RC\frac{dv_I}{dt}$$