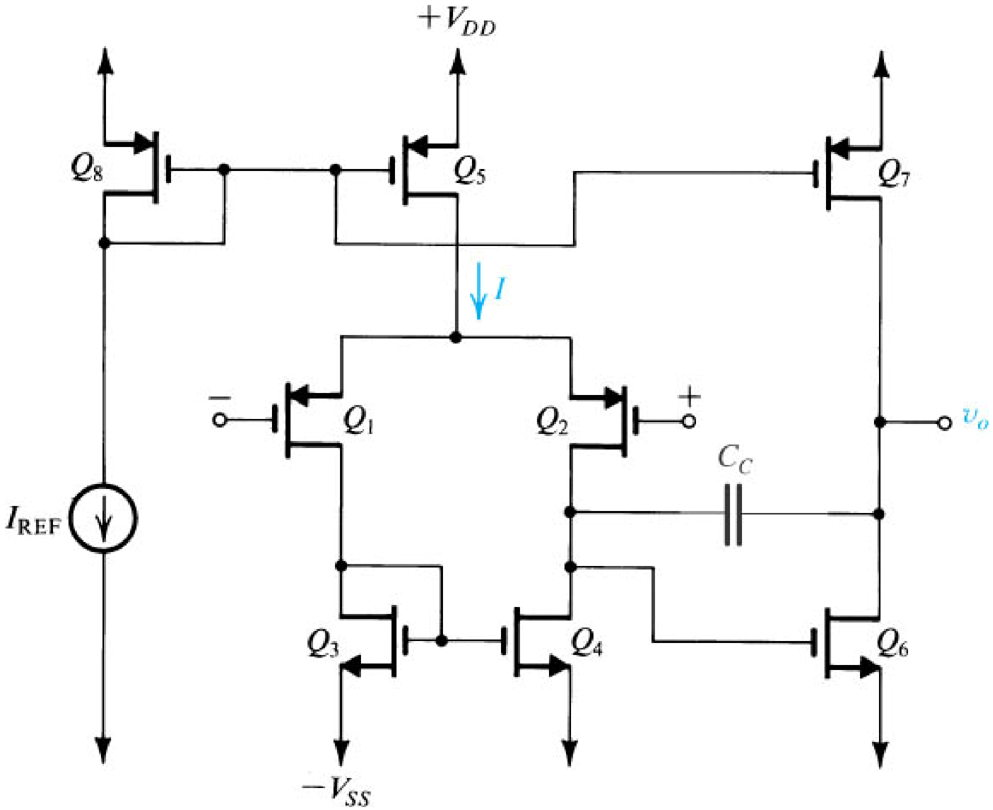
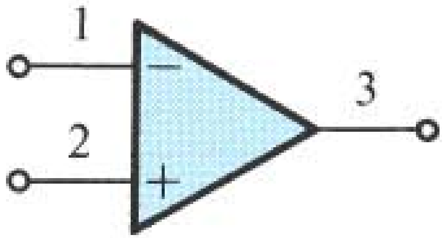
Lect. 13: Operational Amplifiers





Operational amplifier (Op Amp)

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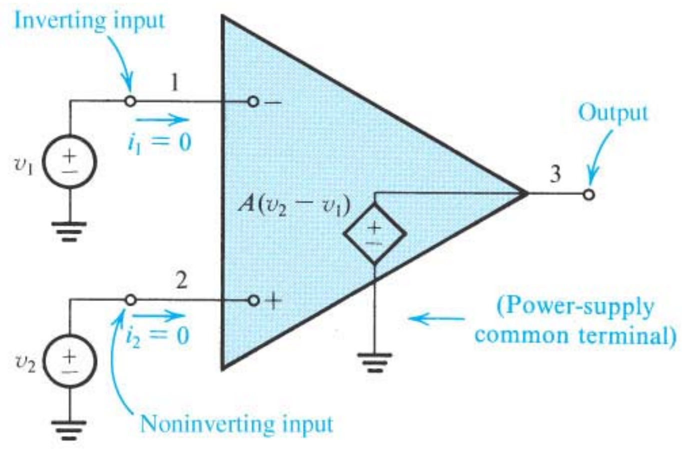

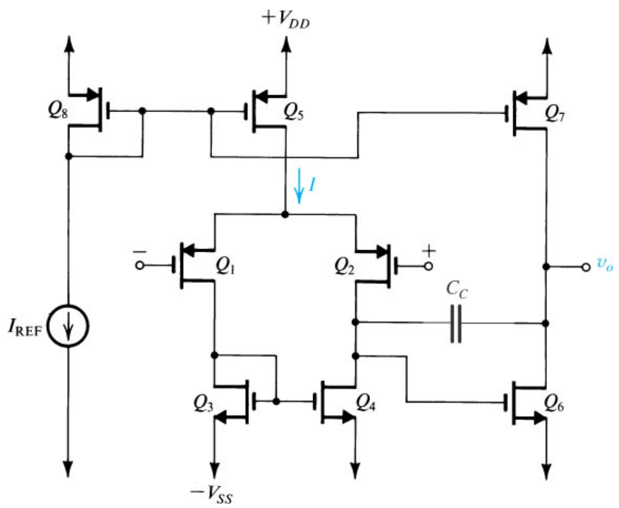

Characteristics of an *ideal* op amp

- Ideal amplifier for voltage difference

R_{in}: Infinite

A_v: Infinite

R_{out}: 0 for voltage output

infinite for current output

➔ transconductance amplifier (OTA)

Zero common-mode gain
(or infinite common-mode rejection)

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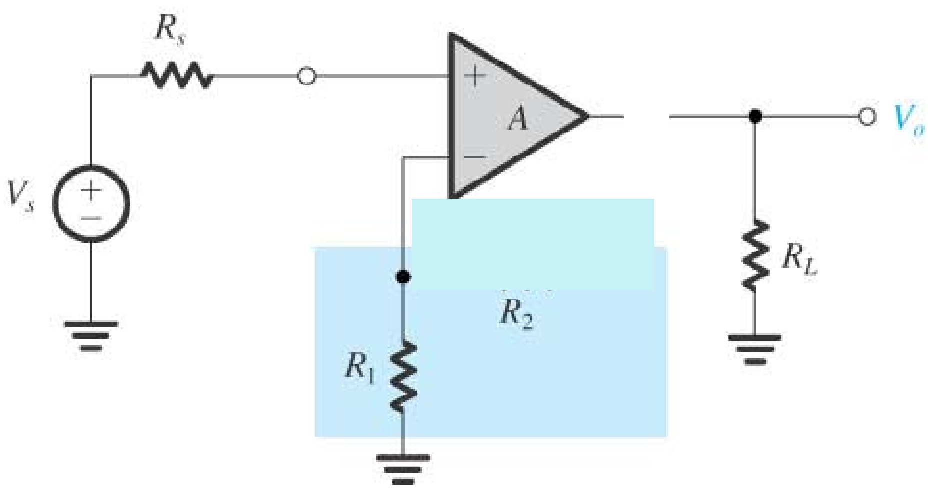
Op amp is very often used with feedback



$V_o = A_v(V_s - 0)$

➔ +/ - supply voltage

With feedback

$$V_o = A_v(V_s - V_o \cdot \frac{R_1}{R_1 + R_2})$$

$$V_o(1 + \frac{A_v R_1}{R_1 + R_2}) = A_v V_s$$

$$\therefore \frac{Vo}{V_s} = \frac{A_v}{1 + \frac{A_v R_2}{R_1 + R_2}} \simeq \frac{R_1 + R_2}{R_1}$$

Remember $A_f = \frac{x_o}{x_s} = \frac{A}{1 + A\beta} \simeq \frac{1}{\beta}$

$\beta = R_1/(R_1+R_2)$

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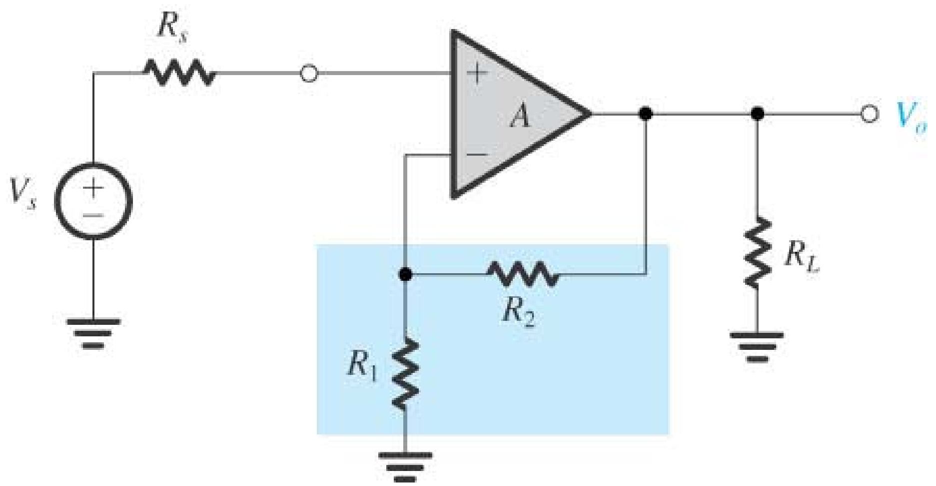

$$\frac{V_o}{V_s} = \frac{A_v}{1 + \dfrac{A_v R_1}{R_1 + R_2}} \simeq \frac{R_1 + R_2}{R_1}$$

The same result can be obtained by assuming $V^+ = V^-$ (virtual short)

$$V_s = V_o \frac{R_1}{R_1 + R_2}$$

$$\therefore \frac{V_o}{V_s} = \frac{R_1 + R_2}{R_2}$$

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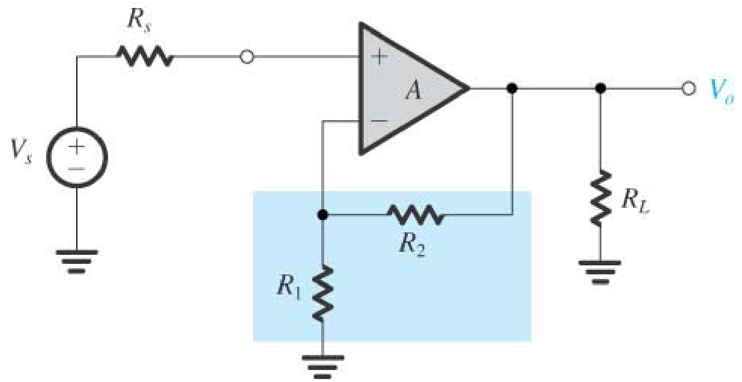
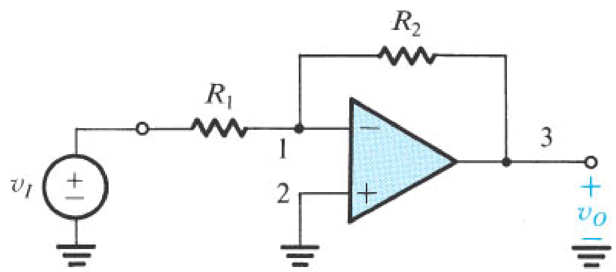
What good is it?



$$\frac{V_o}{V_s} = \frac{R_1 + R_2}{R_2}$$ Voltage amplifier

- Infinite input resistance
- Same gain regardless of R_L
- Gain is stable
  and can be easily changed

Voltage amplifier with negative gain?



$$V_o = -\frac{R_2}{R_1} V_I$$

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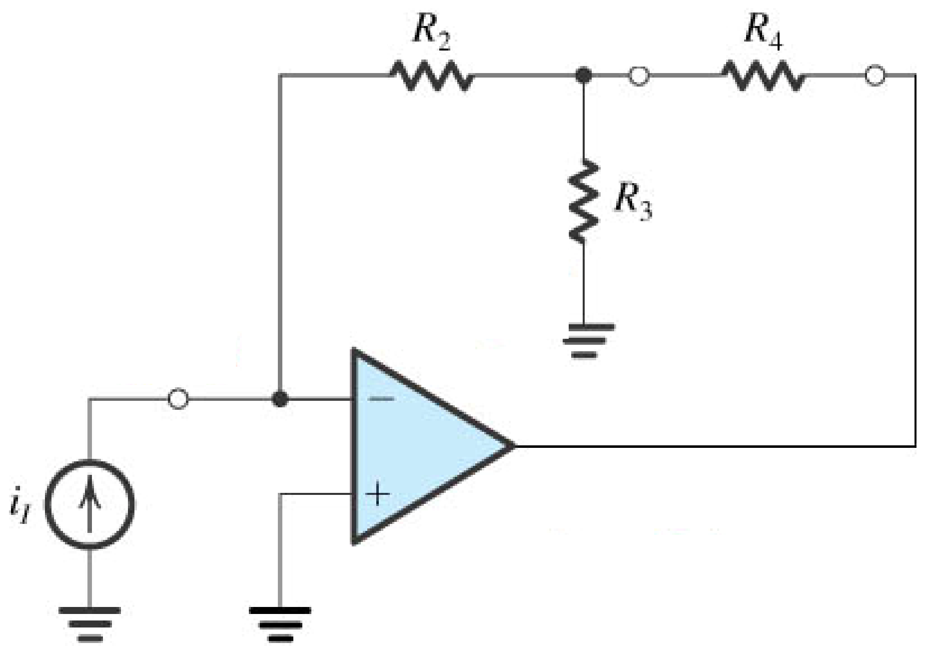
Current amplifier



$$A_i = \frac{i_4}{i_i} = (1 + \frac{R_2}{R_3})$$

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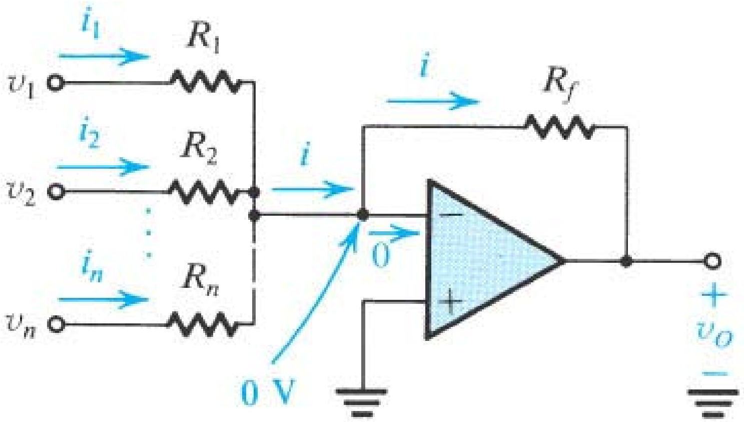
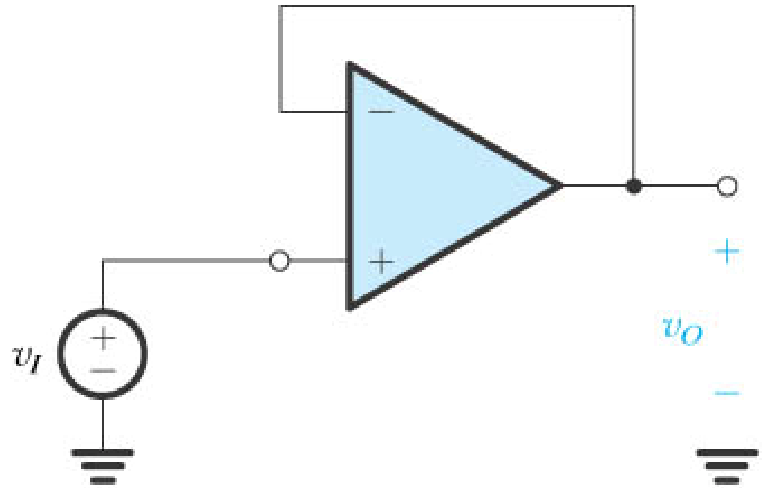


weighted summer (adder)



(a)

voltage buffer

Op amp for many analog signal processing applications

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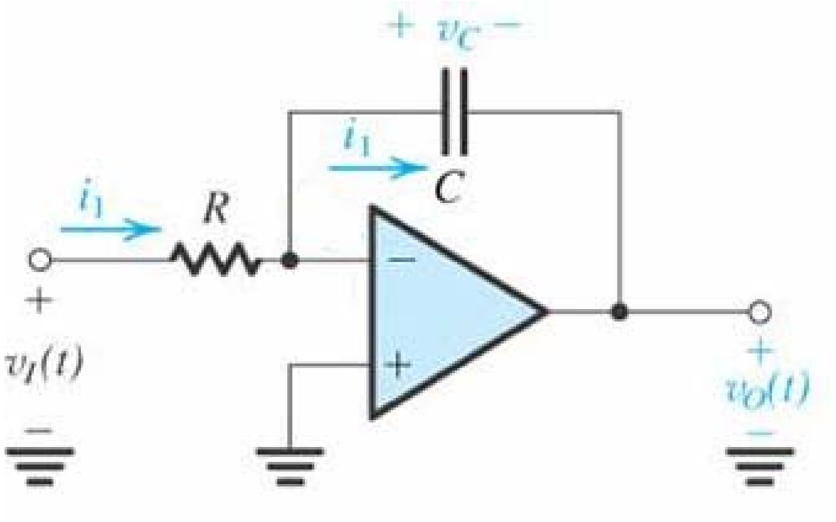

$$C\frac{d\upsilon_O(t)}{dt} = -\frac{v_i(t)}{R}$$

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

Integrator

Op amp for many useful analog signal processing applications!

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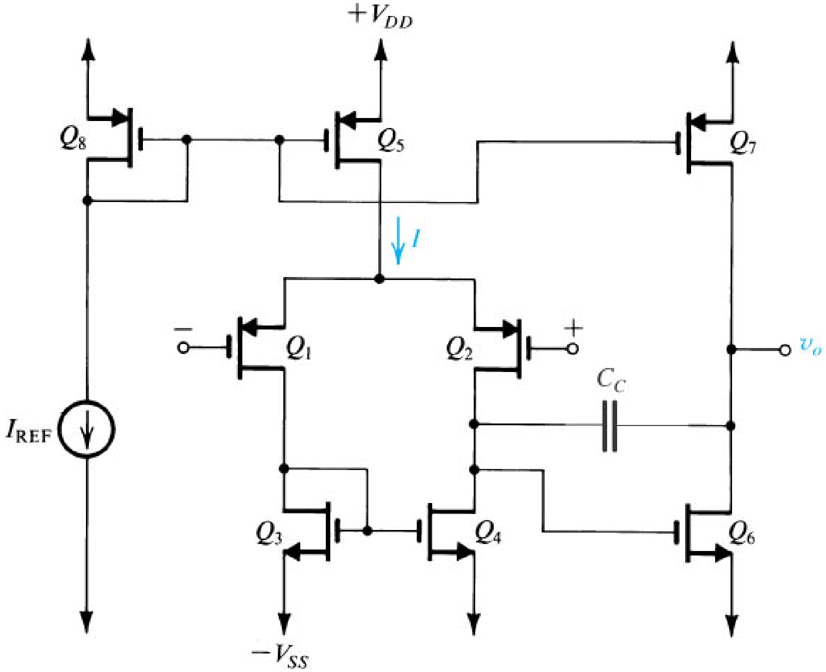
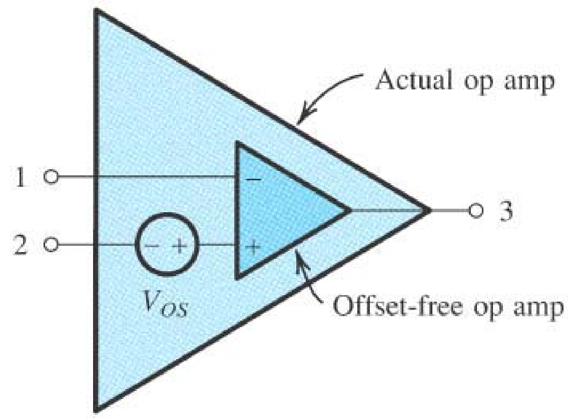
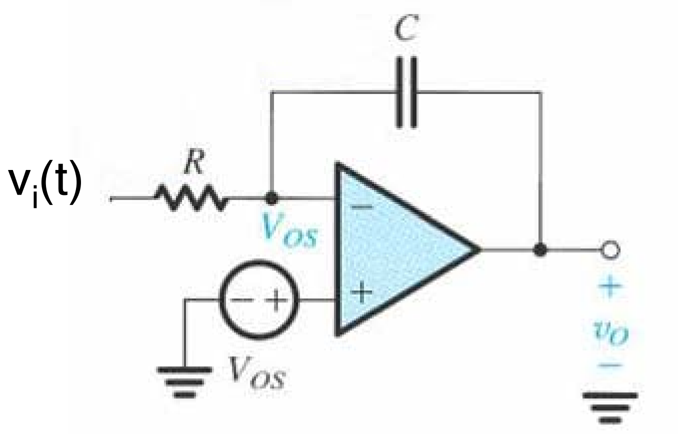
Real Op Amps are not ideal: Input voltage offset

Ideally, $v_o = 0$ if $v^+ = v^-$ But, often, $v_o = 0$ when $v^+ - v^- = V_{os}$ (offset voltage)

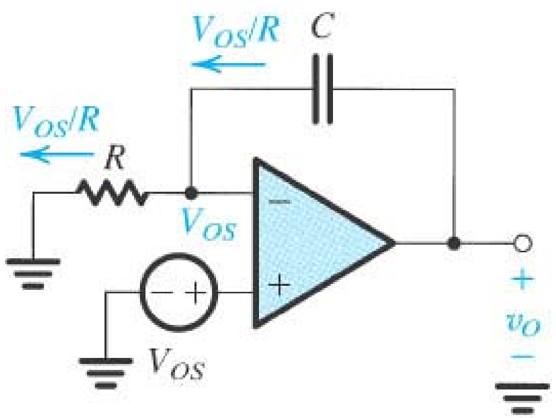




What happens to Op Amp integrator?

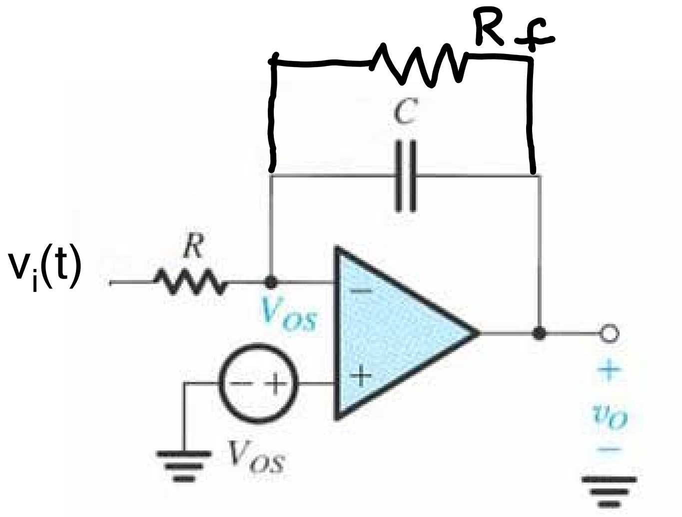


It does not work as an integrator!



$$v_O = V_{OS} + \frac{1}{C}\int_0^t \frac{V_{OS}}{R}dt$$
$$= V_{OS} + \frac{V_{OS}}{CR}t$$

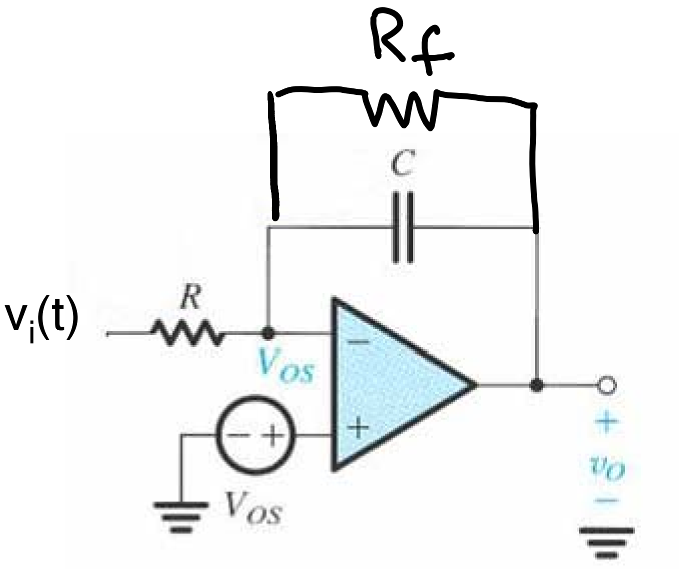
Solution: Lossy Integrator



$$\frac{v_i(t)-V_{OS}}{R}+\frac{v_0(t)-V_{OS}}{R_f}+C\frac{d(\upsilon_O(t)-V_{OS})}{dt}=0$$

$$R_f C\frac{d\upsilon_O(t)}{dt}+v_0(t)=-\frac{R_f}{R}v_i(t)+(1+\frac{R_f}{R})V_{OS}$$

Solution: Lossy Integrator



$$R_f C \frac{d\upsilon_O(t)}{dt} + v_0(t) = -\frac{R_f}{R} v_i(t) + (1 + \frac{R_f}{R}) V_{OS}$$

Use superposition

$$R_f C \frac{d\upsilon_{O1}(t)}{dt} + v_{01}(t) = (1 + \frac{R_f}{R}) V_{OS}$$

$$R_f C \frac{d\upsilon_{O2}(t)}{dt} + v_{02}(t) = -\frac{R_f}{R} v_i(t)$$

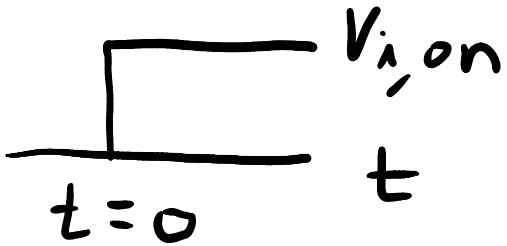
$$\upsilon_O(t) = \upsilon_{O1}(t) + \upsilon_{O2}(t)$$

$$R_f C \frac{d\upsilon_{O1}(t)}{dt} + v_{01}(t) = (1 + \frac{R_f}{R})V_{OS}$$

$$\upsilon_{O1}(t) = v_{o1,0} \exp(-\frac{1}{R_f C} t) + (1 + \frac{R_f}{R})V_{OS} = (1 + \frac{R_f}{R})V_{OS} \quad \text{(Assuming } v_{o1,0} = 0)$$

$$R_f C \frac{d\upsilon_{O2}(t)}{dt} + v_{02}(t) = -\frac{R_f}{R} v_i(t)$$

Assuming $v_i(t)$ is a step function at t= with $V_{i,on}$



$$\upsilon_{O2}(t) = -\frac{R_f}{R} V_{i,on}[1 - \exp(-\frac{t}{R_f C})]$$

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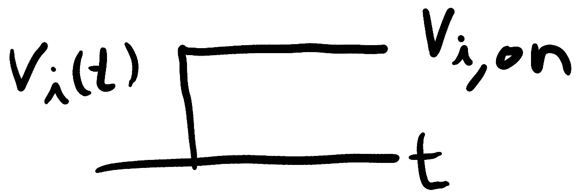
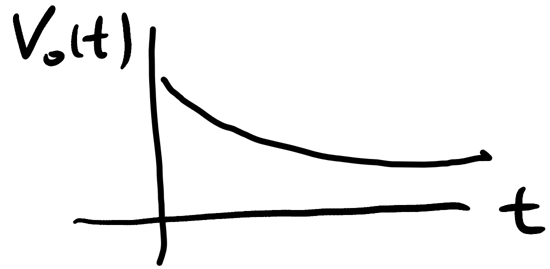
$$\therefore v_O(t) = v_{O1}(t) + v_{O1}(t)$$

$$= (1 + \frac{R_f}{R})V_{OS} - \frac{R_f}{R}V_{i,on}[1 - \exp(-\frac{t}{R_f C})]$$

Is this an integrator?





Yes, if $t \ll R_f C$

➔ $f \gg 1/(R_f C)$