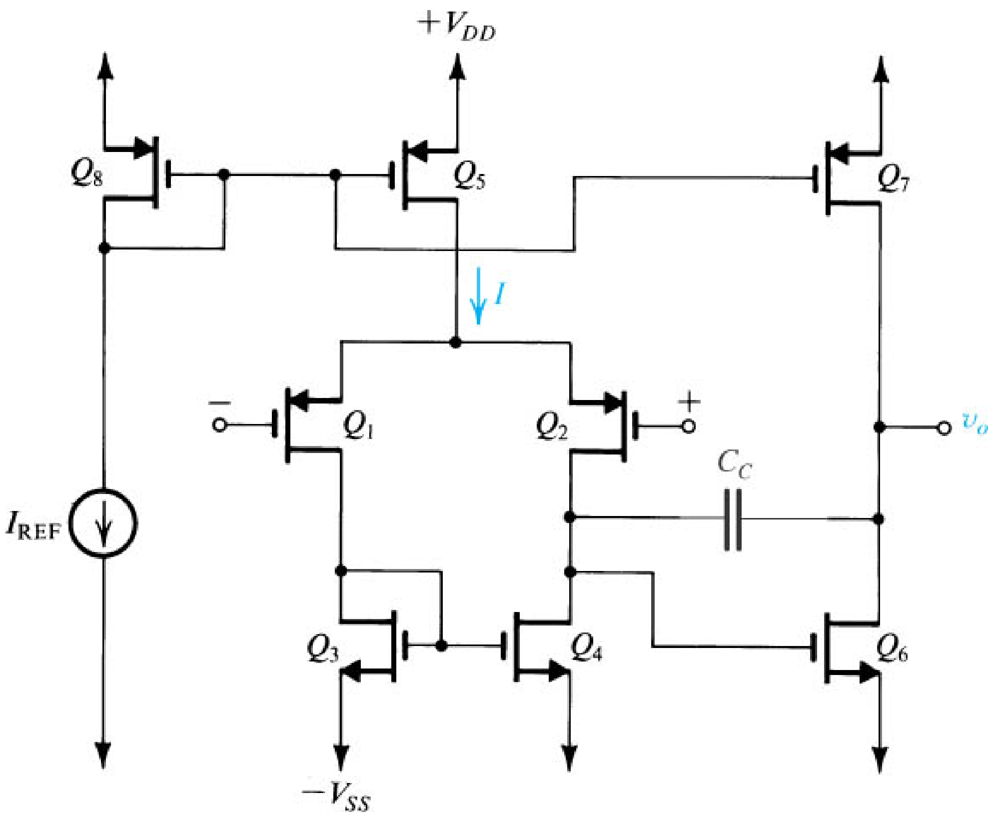
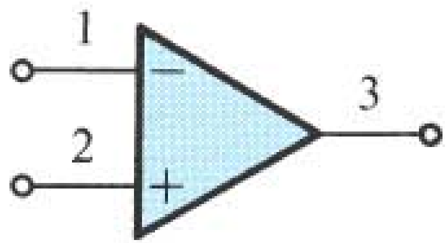
# Lect. 16: Operational Amplifier

(Chap. 8 in Razavi)

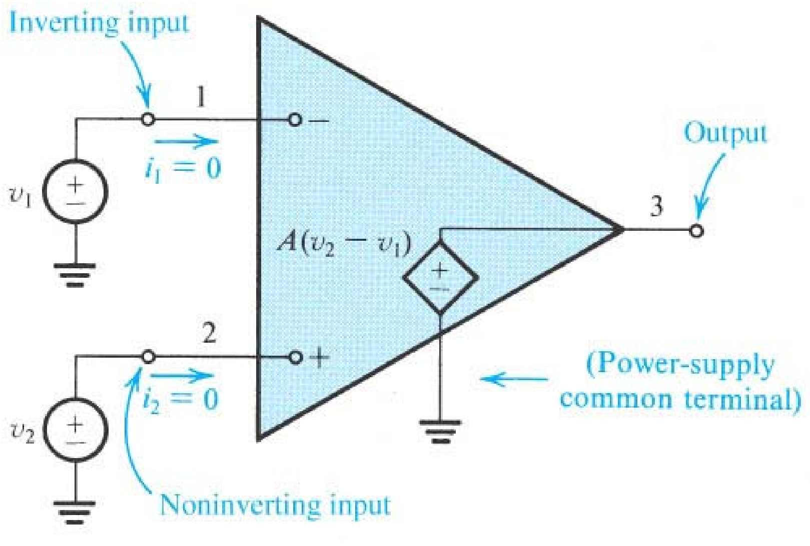



Operational Amplifier (Op Amp)

What is the application for this?

# Lect. 16: Operational Amplifier




Characteristics of an *ideal* op amp

- Ideal amplifier for input voltage difference

$R_{in}$: Infinite

$A_v$: Infinite

$R_{out}$: 0 for voltage output

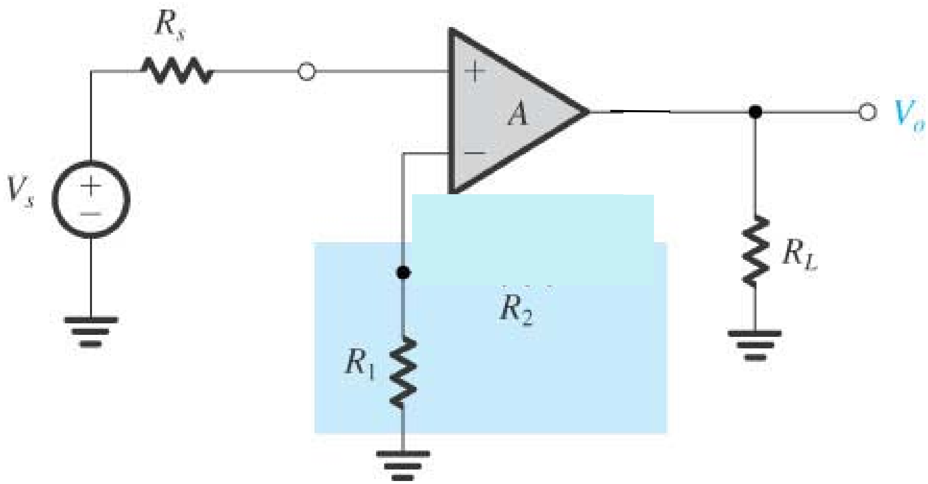
infinite for current output

➔ OTA

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

# Lect. 16: Operational Amplifier

Op amp is very often used with feedback




$V_o = A_v(V_s - 0)$

➔ +/ – supply voltage

With feedback

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

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

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

Remember $A_f = \dfrac{x_o}{x_s} = \dfrac{A}{1 + A\beta} \sim \dfrac{1}{\beta}$

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

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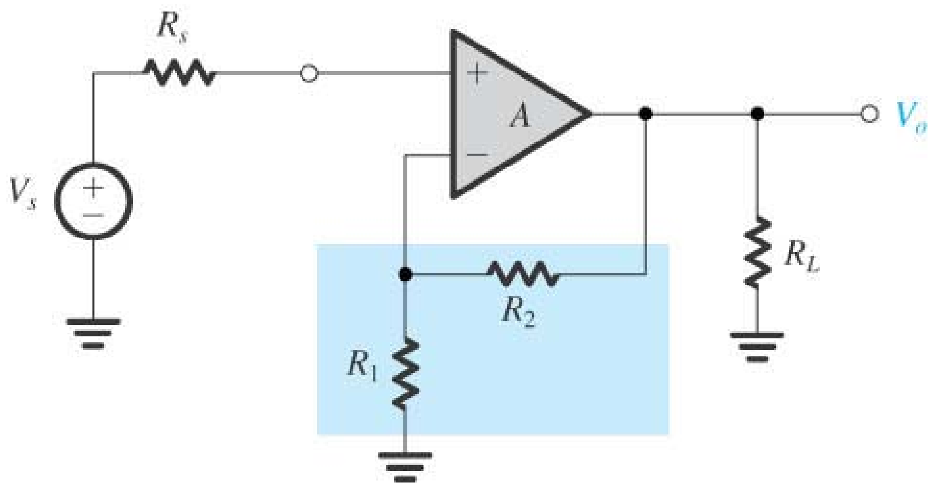



$$\frac{V_o}{V_s} = \frac{R_1 + R_2}{R_1}$$

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

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

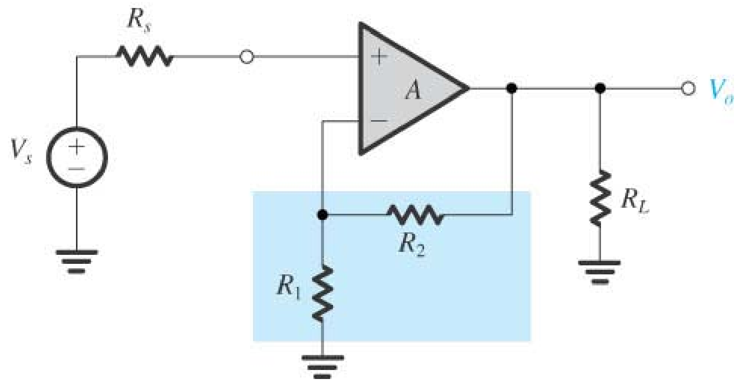
➔ Feedback tries to maintain $V^+ = V^-$

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

Use virtaul short condition for Op-Amp analysis!

# Lect. 16: Operational Amplifier

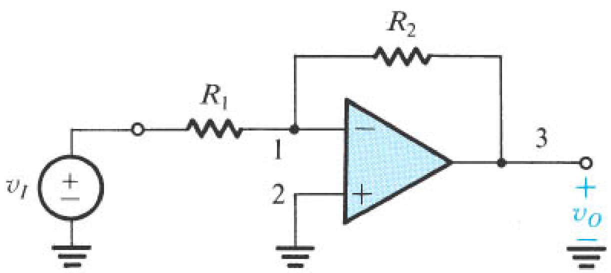
What good is it?




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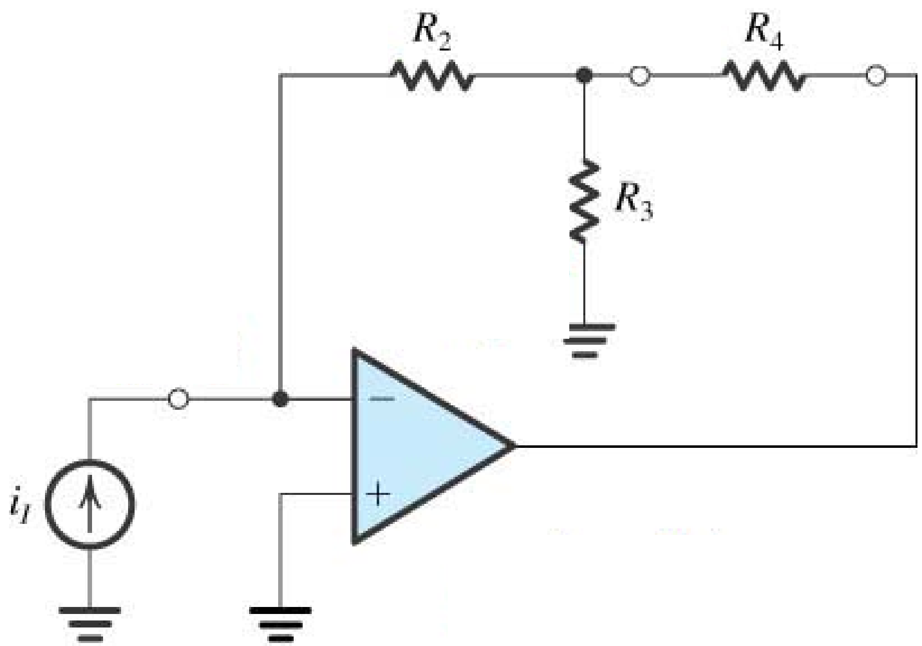
Current amplifier




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

No loading effect!

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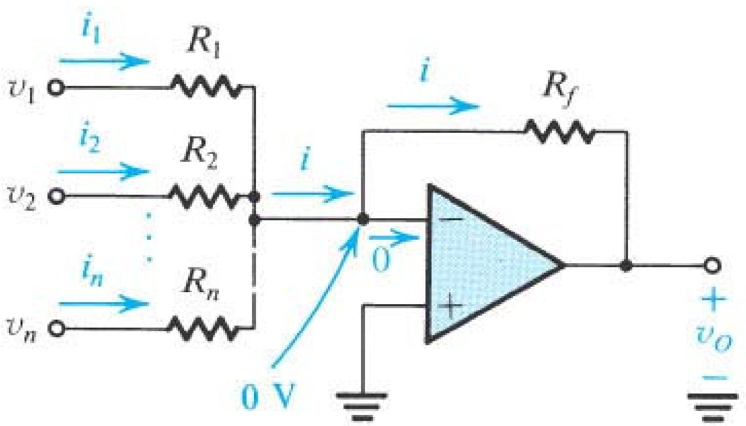
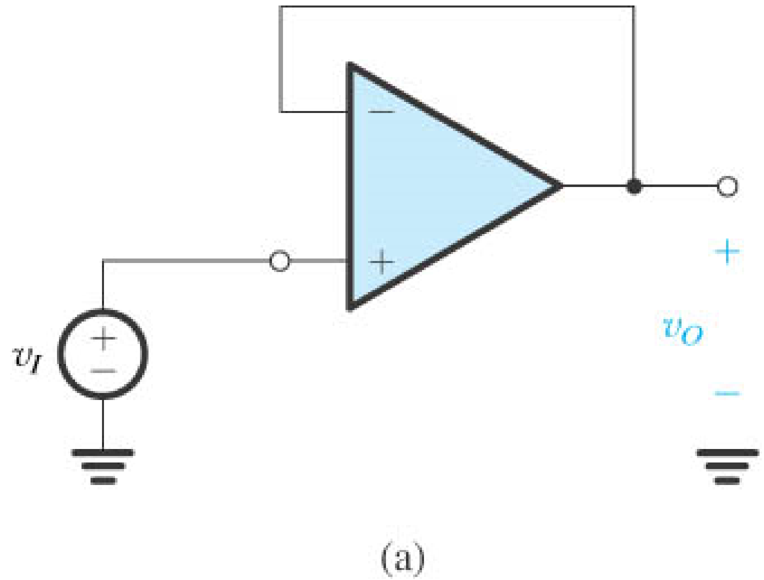



weighted summer (adder)




voltage buffer

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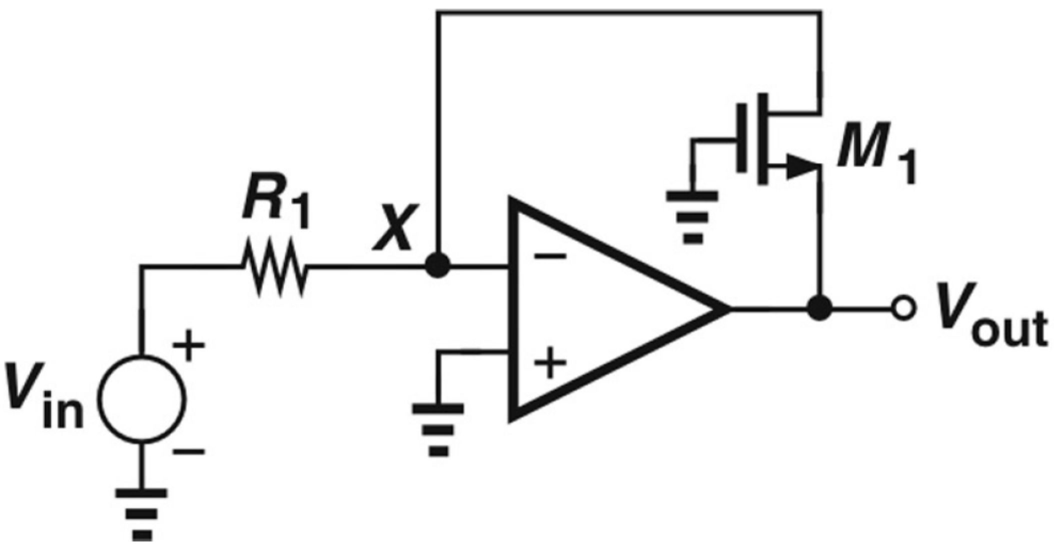
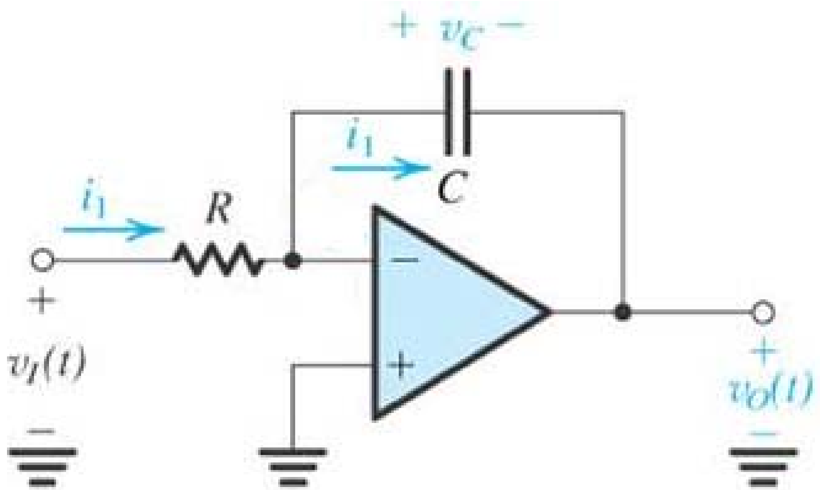





$$C\frac{d\upsilon_O(t)}{dt} = -\frac{v_i(t)}{R}$$

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

➔ Integrator

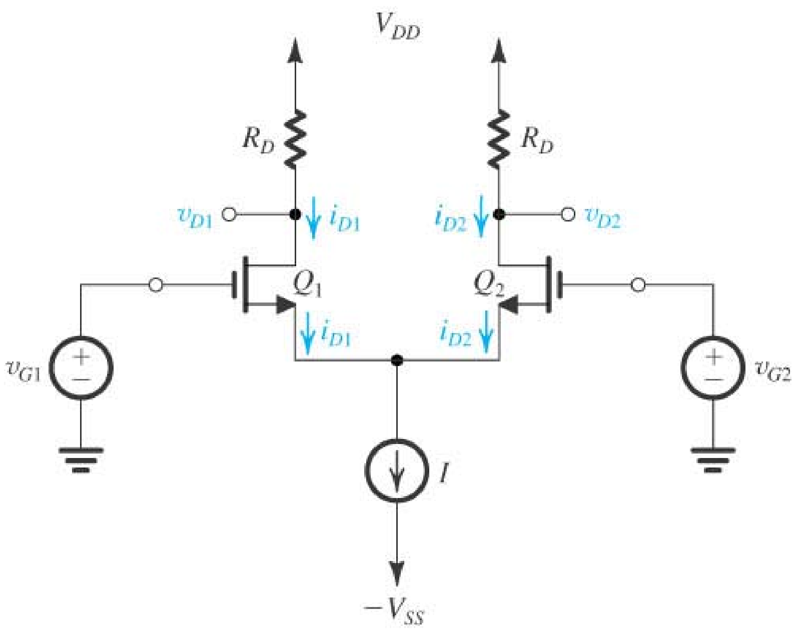
In s-domain?

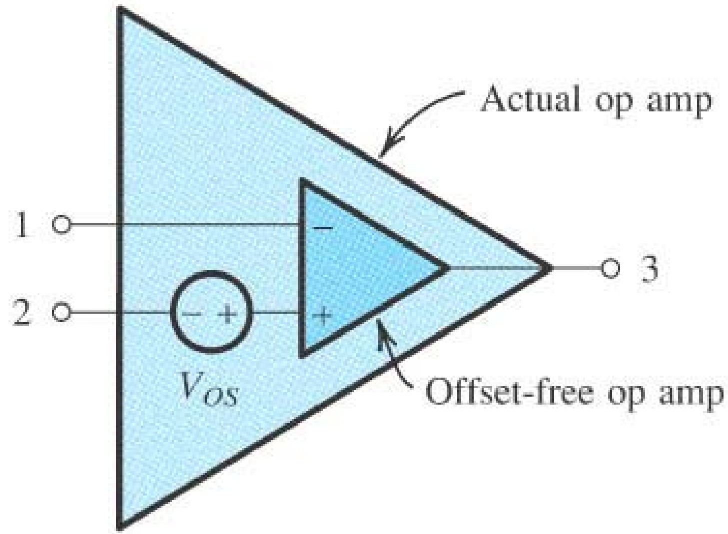
# Lect. 16: Operational Amplifier

In reality, op amps have input offset

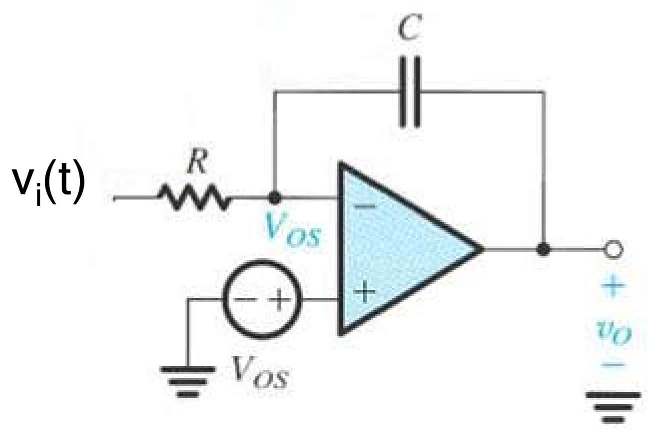
Ideally, $v_o = 0$ if $v^+=v^-$ But, often, $v_o=0$ when $v^+$, $v^-$ have offset voltage $V_{os}$

Caused by mismatched in differential pair

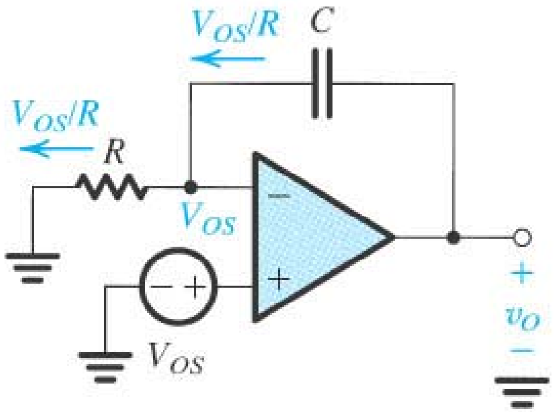


What happens to Op Amp integrator?




Consider zero input

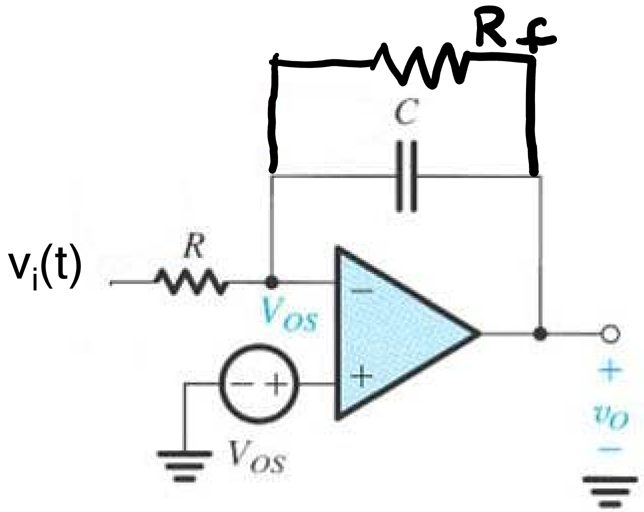



$$v_O = V_{OS} + \frac{1}{C}\int_0^t \frac{V_{OS}}{R}dt$$
$$= V_{OS} + \frac{V_{OS}}{CR}t$$

It does not work as an integrator!

How can you solve this problem?

Solution: Lossy Integrator



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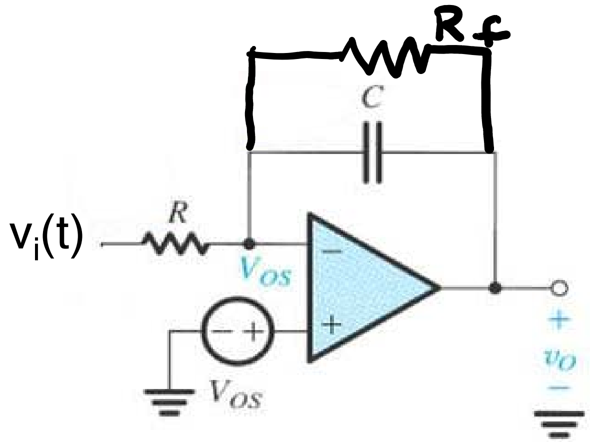
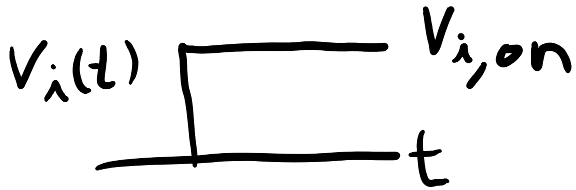
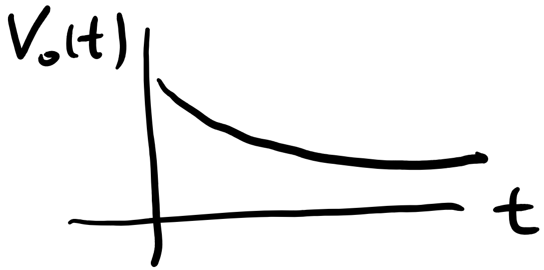



Is this an integrator?




Yes, if $t \ll R_f C$

➔ $f \gg 1/(R_f C)$