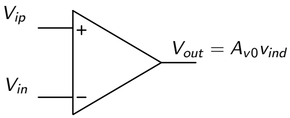
EE 101: Basic Electronics

Opamp and its applications

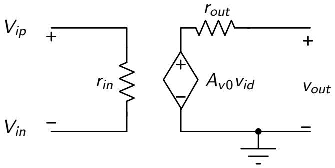
Nagarjuna Nallam

Department of EEE, IIT Guwahati, India

An opamp



An opamp



Equivalent model of an opamp

Differential input $V_{id} = V_{ip} - V_{in}$

Common-mode input $V_{ic} = \frac{V_{ip}+V_{in}}{2}$

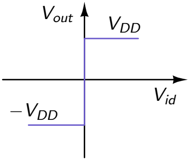
For an ideal opamp

$\boxed{r_{in} = \infty}$

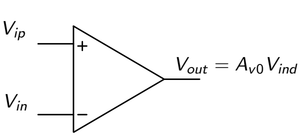
$\boxed{r_{out} = 0}$

$\boxed{A_{v0} \to \infty}$

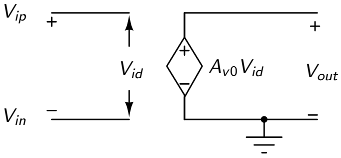
$\boxed{\text{Freq. Range is } 0 \to \infty}$



An ideal opamp



An ideal opamp

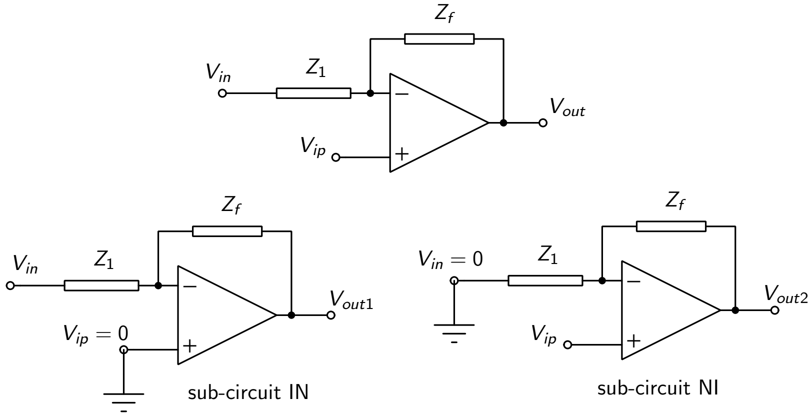


Macro model of an ideal opamp

Notes on ideal opamp:

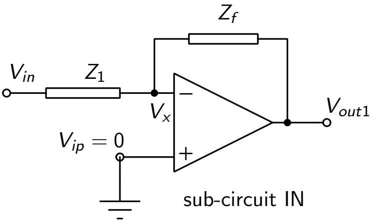
1. Amplifies even differential DC signals (voltages)
2. Rejects all common-mode signals including DC voltages

An opamp circuit



Superposition: $V_{out} = V_{out1} + V_{out2}$

Sub-circuit IN: Inverting Amplifier



Let us assume the gain of the opamp $= A_v$

$$V_{out1} = A_v \times (0 - V_x) = -A_v V_x$$

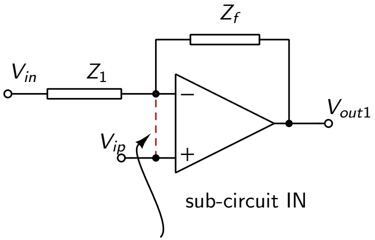
$$\boxed{\text{As } A_v \to \infty, V_x \to 0}$$

No current flows into the opamp.

$$\frac{V_{in} - V_x}{Z_1} = \frac{V_x - V_{out1}}{Z_f}$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{Z_f}{Z_1}}$$

Negative feedback: Virtual Short with no current



Virtual short for voltages (no current flows)

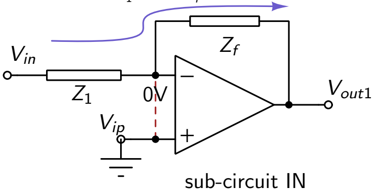
$\Downarrow$

Only if the opamp is in negative feedback

and $A_v \to \infty$

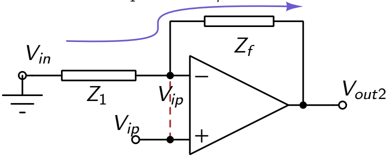
Analysis of inverting amplifier

$$\frac{V_{in}}{Z_1} = \frac{-V_{out1}}{Z_f}$$



Analysis of non-inverting amplifier

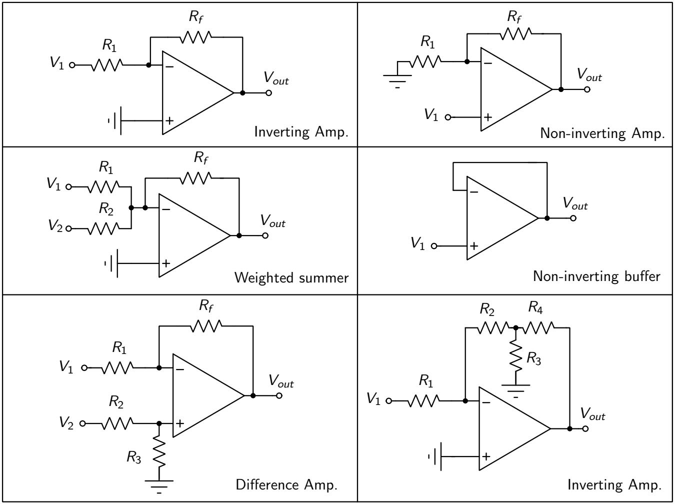
$$\frac{-V_{ip}}{Z_1} = \frac{V_{ip}-V_{out1}}{Z_f}$$



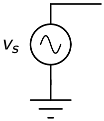
sub-circuit NI

Voltage gain $\frac{V_{out2}}{V_{ip}} = 1 + \frac{Z_f}{Z_1}$

Opamp applications - 1



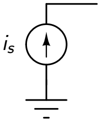
Opamp applications - 2



Given a voltage signal,

how to convert it into a

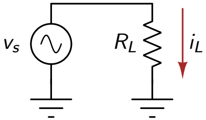
current signal?



Given a current signal,

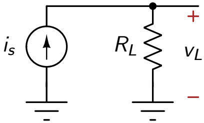
how to convert it into a

voltage signal?



$i_L = \frac{v_s}{R_L}$

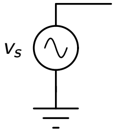
Larger the R_L, smaller is the i_L.

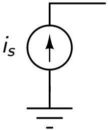


$v_L = i_L R_L$

Smaller the R_L, smaller is the v_L.

Opamp applications - 2





Given a voltage signal,

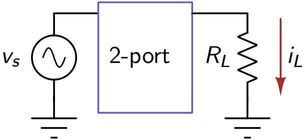
how to convert it into a

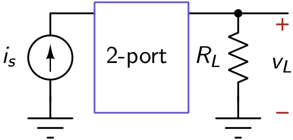
current signal?

Given a current signal,

how to convert it into a

voltage signal?



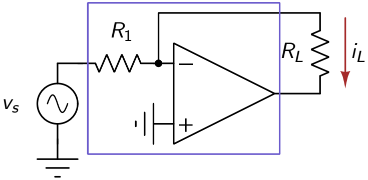


i_L should be independent of R_L

v_L should be independent of R_L

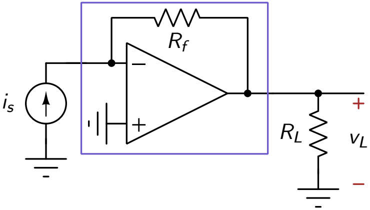
Opamp applications - 2

V-I Converter



$i_L = \frac{-v_s}{R_1}$ is independent of R_L

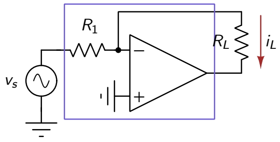
I-V Converter



$v_L = -i_s R_f$ is independent of R_L

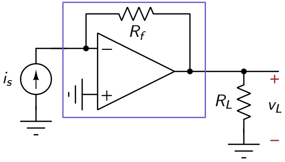
Opamp applications - 2

V-I Converter



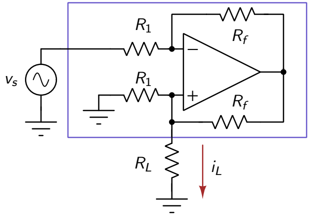
$i_L = \frac{-v_s}{R_1}$ is independent of R_L

I-V Converter



$v_L = -i_s R_f$ is independent of R_L

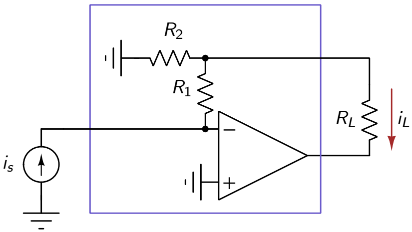
V-I Converter for grounded loads



$i_L = \frac{v_s}{R_1}$

Current Amplifier

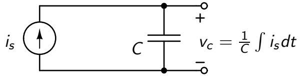
I-I Converter



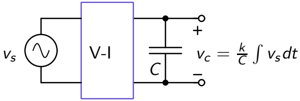
$$i_L = i_s + i_s \frac{R_1}{R_2} = (1 + \frac{R_1}{R_2}) i_s$$

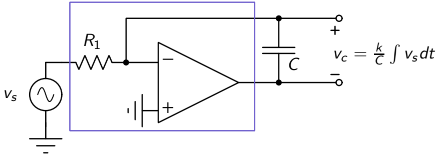
A current amplifier: load current is independent of R_L.

Integrator



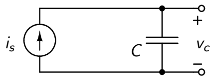
Analog Voltage Integration:





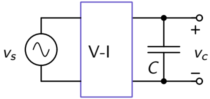
$$v_c = \frac{1}{R_1 C} \int v_s dt$$

Differentiator

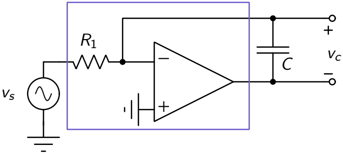


$$v_c = \frac{1}{C}\int i_s dt$$

Analog Voltage Integration:



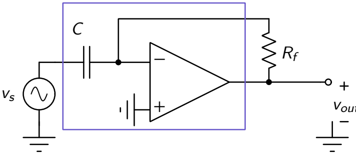
$$v_c = \frac{k}{C}\int v_s dt$$



$$v_c = \frac{k}{C}\int v_s dt$$

$$v_c = \frac{1}{R_1 C}\int v_s dt$$

Analog Voltage Differentiation:

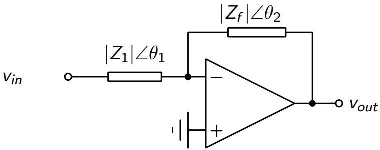


$$-v_s = \frac{1}{R_f C}\int v_{out} dt$$

$$v_{out} = -R_f C \frac{dv_s}{dt}$$

Opamp applications - 2

Phase shifter:



$$v_{out} = |\frac{Z_f}{Z_1}|\angle(\theta_2 - \theta_1)v_{in}$$

Opamp applications - Summary

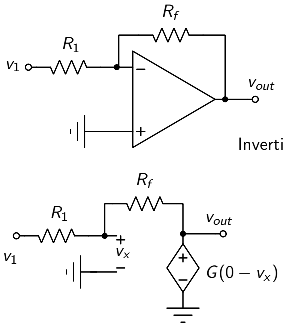
1. Inverting and Non-inverting Amplifiers, Voltage buffer
2. Voltage Summer, Voltage subtractor
3. V-I converter or Transconductor or Voltage Controlled Current Source
4. I-V converter or Transresistor or Current Controlled Voltage Source
5. I-I converter or Current amplifier or Current Controlled Current Source
6. Voltage integrator
7. Voltage differentiator
8. Phase shifter

Further Learning ...

[1] A. Sedra and K. C. Smith, “Microelectronic Circuits,” 6th Ed., Oxford university press, 2011.

Backup slides

Opamp applications - 1



Inverting Amp.

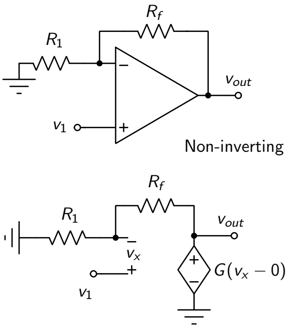
$v_{out} = -Gv_x$; $\frac{v_1 - v_x}{R_1} = \frac{v_1 - v_{out}}{R_1 + R_f}$

$$\frac{v_1 + \frac{v_{out}}{G}}{R_1} = \frac{v_1 - v_{out}}{R_1 + R_f}$$

$$v_{out} = v_1 \frac{-R_f/R_1}{1 + \frac{R_1 + R_f}{GR_1}}$$

As $G \to \infty$,

$$\frac{v_{out}}{v_1} = \frac{-R_f}{R_1}$$



Non-inverting Amp.

$v_{out} = Gv_x$; $\frac{v_1 - v_x}{R_1} = \frac{v_{out}}{R_1 + R_f}$

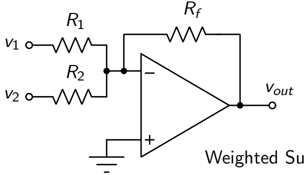
$$\frac{v_1 - \frac{v_{out}}{G}}{R_1} = \frac{v_{out}}{R_1 + R_f}$$

$$v_{out} = v_1 \frac{(R_f + R_1)/R_1}{1 + \frac{R_1 + R_f}{GR_1}}$$

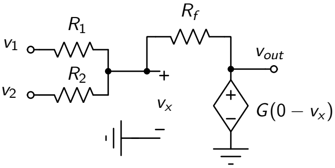
As $G \to \infty$,

$$\frac{v_{out}}{v_1} = 1 + \frac{R_f}{R_1}$$

Opamp applications - 1

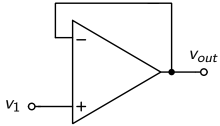


Weighted Summer

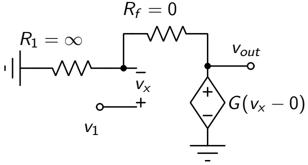


As $G \to \infty$,

$$v_{out} = -[\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2]$$



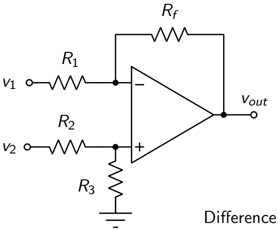
Non-inverting buffer



As $G \to \infty$,

$$v_{out} = v_1$$

Opamp applications - 1

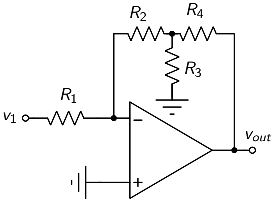


Difference Amp.

$v_{out} = \frac{R_3}{R_2+R_3}\frac{R_1+R_f}{R_1}v_2 - \frac{R_f}{R_1}v_1$

If $\frac{R_3}{R_2} = \frac{R_f}{R_1}$,

$v_{out} = \frac{R_f}{R_1}(v_2 - v_1)$



Inverting Amp.

?