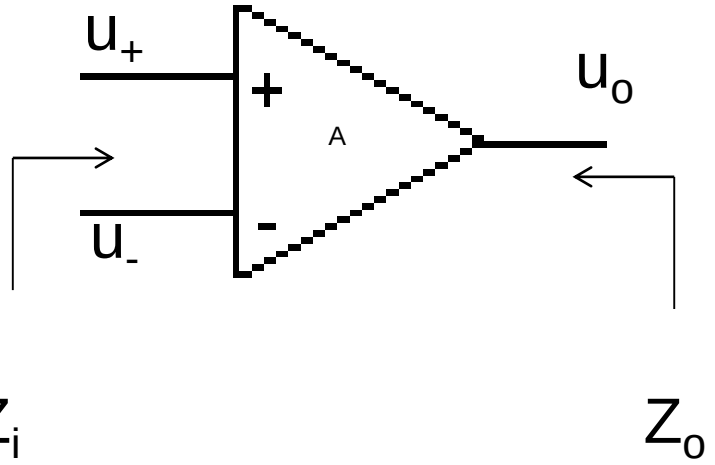
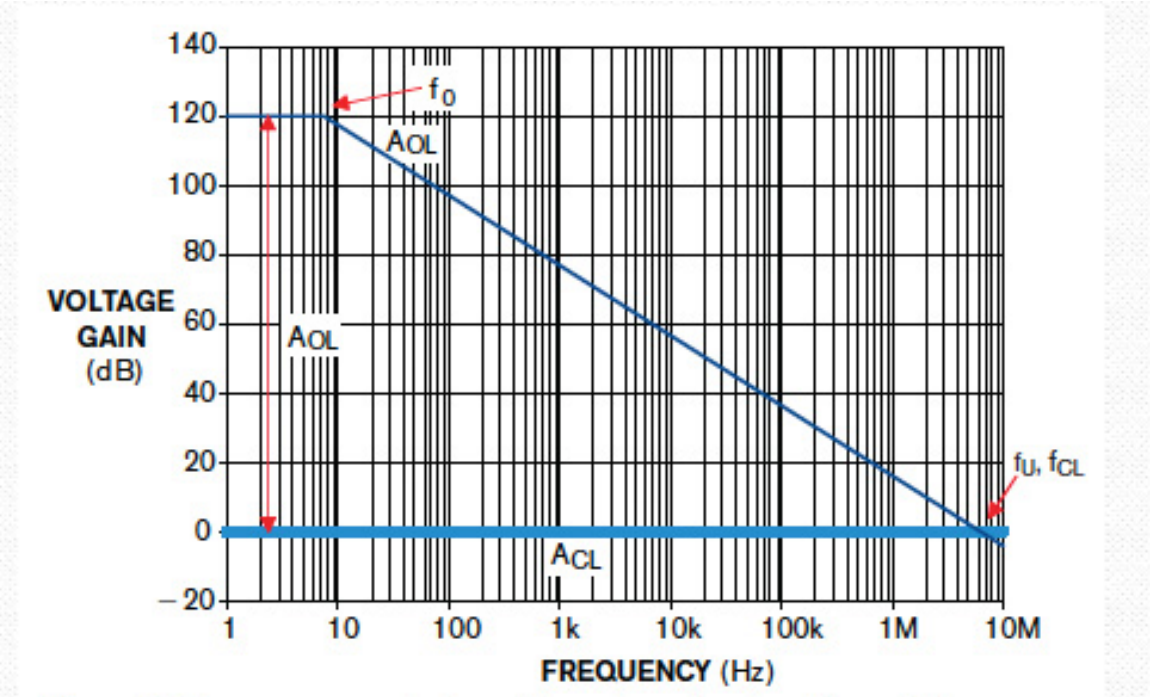
Operational Amplifier

- $A >> \ (=A_{OL} >>)$
- $Z_i >>$
- $Z_o <<$
- $u_o = A(u_+ - u_-)$
- If $A >> u_+ = u_-$, virtual short-circuit



Typical Open Loop Gain



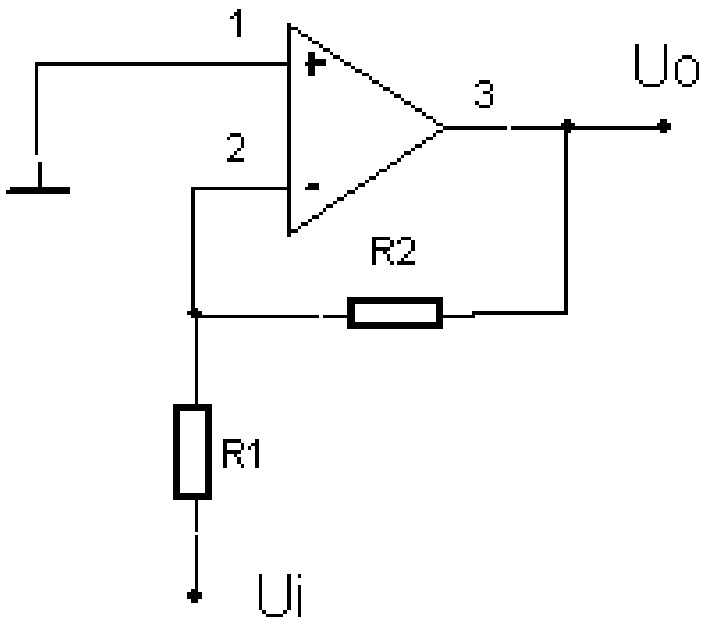
Inverting Configuration

$u_+ = 0$

$u_- = u_o R_1/(R_1+R_2)+u_i R_2/(R_1+R_2)$

If A>>, then $u_+ = u_-$

$u_o = -u_i R_2/R_1$



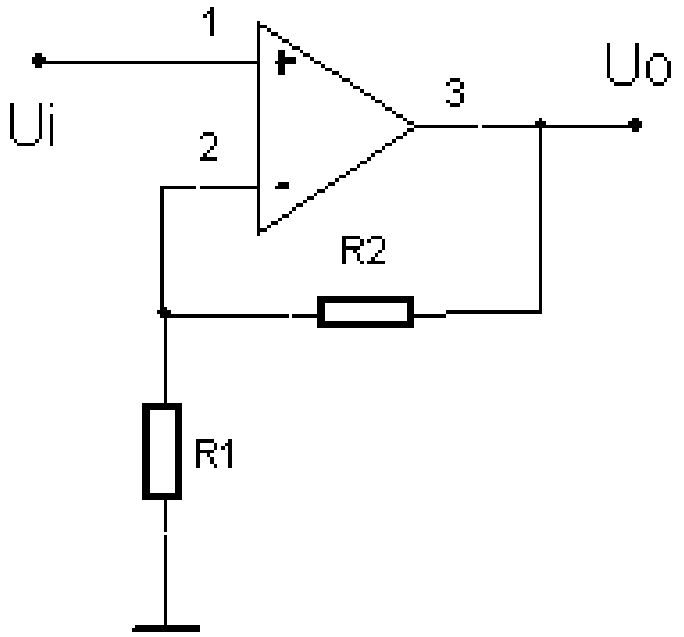
Non-inverting Configuration

$u_+ = u_i$

$u_- = u_o R_1/(R_1+R_2)$

If A>>, then $u_+ = u_-$

$u_o=(R_1+R_2)u_i/R_1$

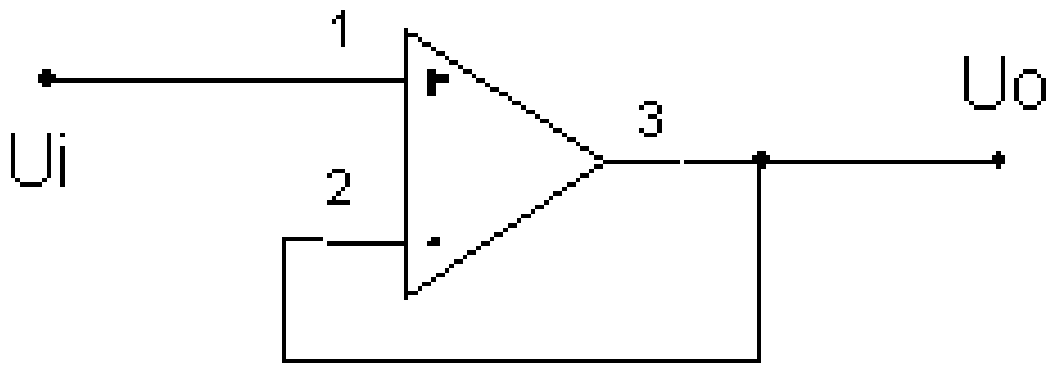


Buffer Amplifier

$u_+ = u_i$

$u_- = u_o$

If A>>, then $u_o = u_i$



Differential Amplifier

$U_+ = U_1 R_4/(R_3+R_4)$

$U_- = U_2 R_2//(R_1+R_2) + U_o R_1//(R_1+R_2)$

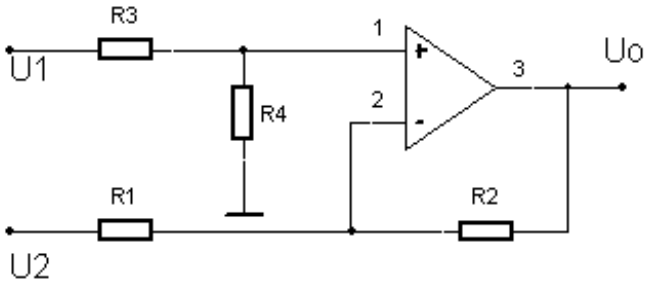
If A>>, then $u_+ = u_-$

If $R_1=R_3$ and $R_2=R_4$, then

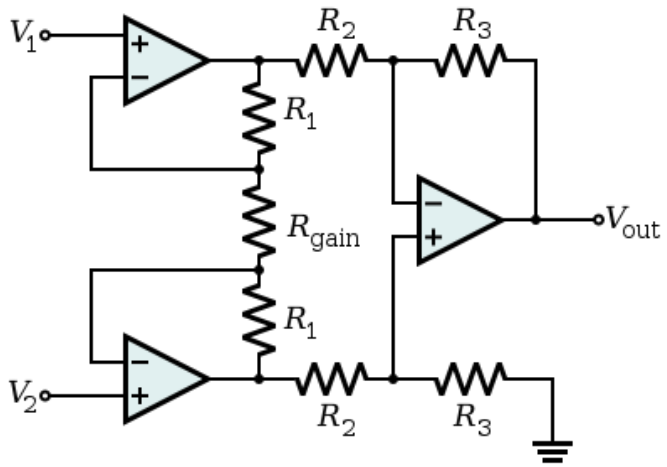
$u_o = (U_1-U_2)R_2/R_1$

If all the resistors are equal, then

$u_o = U_1-U_2$



Instrumentation Amplifier



$$\frac{V_{out}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}$$

$u_{o1}R_3/(R_2+R_3)+u_oR_2/(R_2+R_3) = u_{o2}R_3/(R_2+R_3)$

$\Rightarrow u_o = (u_{o2} - u_{o1})R_3/R_2 \Rightarrow u_{o1} - u_{o2} = - u_oR_2/R_3$

$I_{Rgain} = (u_1-u_2)/R_{gain}$

$u_2 - u_{o2} = R_1\ I_{Rgain} = R_1(u_1-u_2)/R_{gain}$

$u_{o1} - u_1 = R_1\ I_{Rgain} = R_1(u_1-u_2)/R_{gain}$

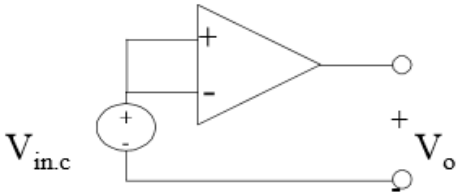
$\Rightarrow u_{o1} - u_{o2} = (2R_1/R_{gain}+1)(u_1-u_2)$

$\Rightarrow u_o = (u_2 - u_1)\ (2R_1/R_{gain}+1)R_3/R_2$

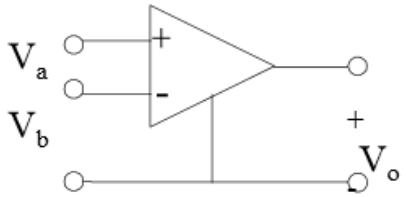
CMRR (Common Mode Rejection Ratio)

- **The CMRR measure how much the op-amp can suppress common-mode signals at its input**

- **Common-mode input voltage $V_{in.c}$= $\frac{(Va + Vb)}{2}$**
  Differential-mode input voltage $V_{in,d}=V_a-V_b$
  Differential gain $A_d= V_o/ V_{in,d}$
  Common-mode gain $A_c= V_o/ V_{in,c}$
  CMRR= (A_d/A_c) or $20 \log_{10} (A_d/A_c)$ in dB (Typically 60~80dB)



Common-mode input



Differential-mode input