Lecture 24

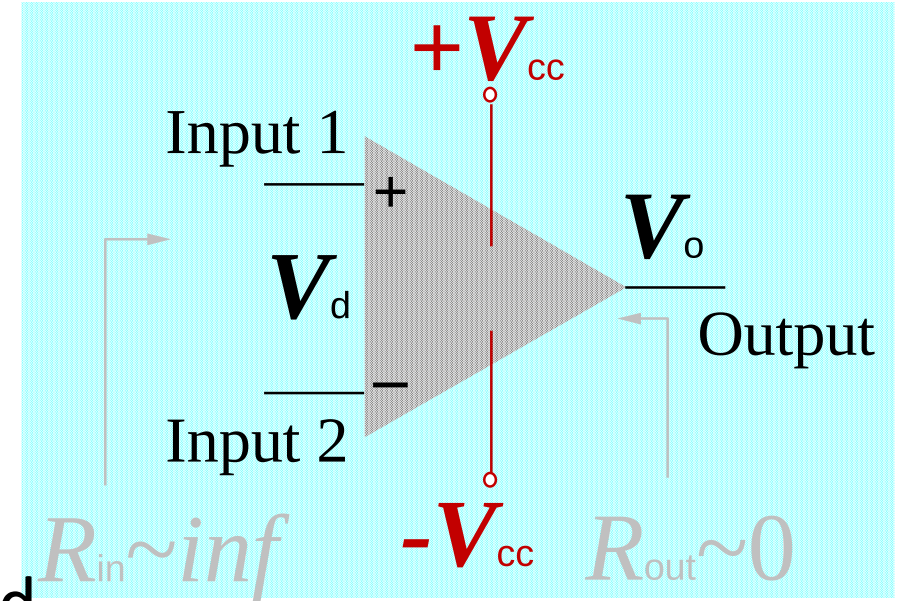
Op- Amp

Op-Amp

- Introduction of Operation Amplifier (Op-Amp)
- Analysis of ideal Op-Amp applications
- Comparison of ideal and non-ideal Op-Amp
- Non-ideal Op-Amp consideration

Operational Amplifier (Op-Amp)

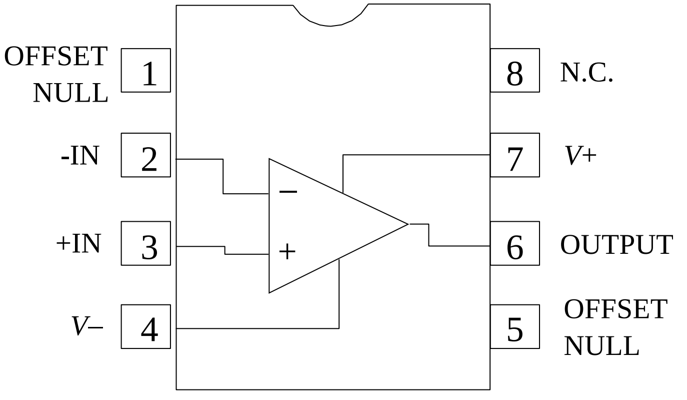
- Very high differential gain
- High input impedance
- Low output impedance
- Provide voltage changes (amplitude and polarity)
- Used in oscillator, filter and instrumentation
- Accumulate a very high gain by multiple stages



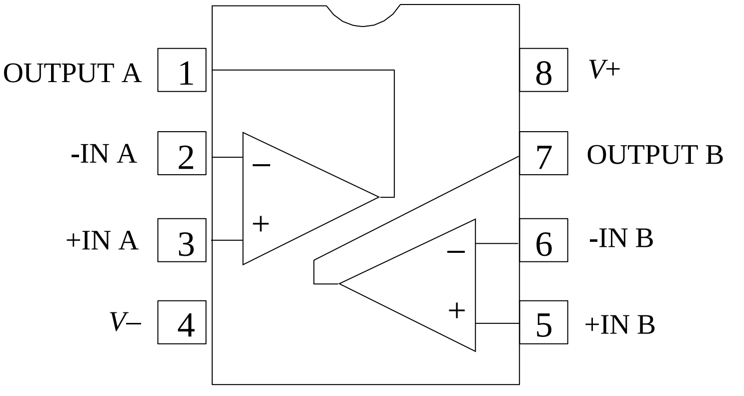
$$V_o = G_d V_d$$

G_d : differential gain normally very large, say 10^5

IC Product

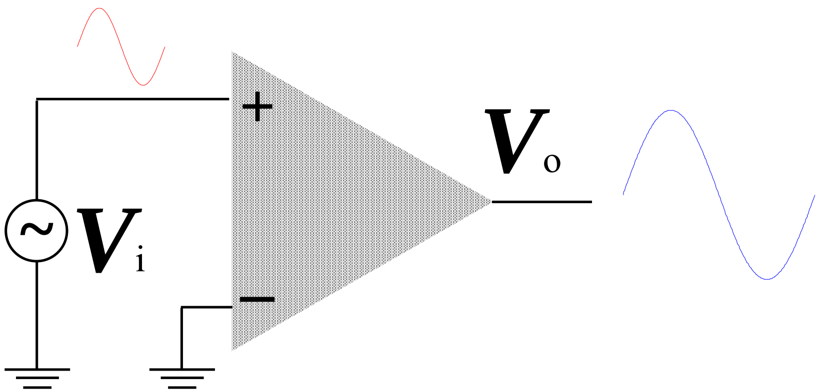


DIP-741

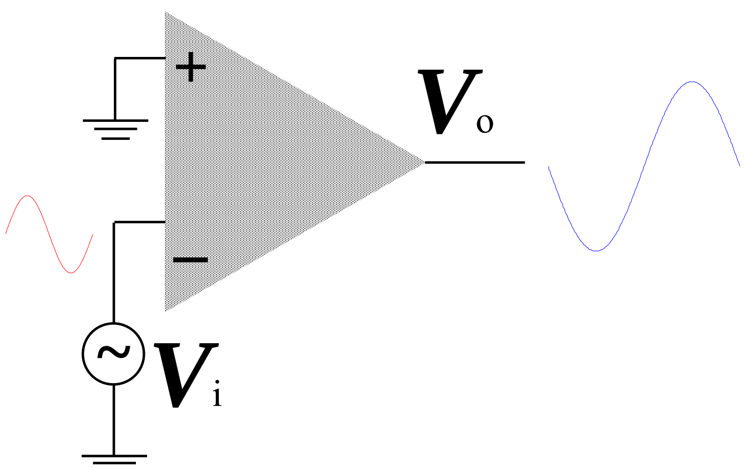


Dual op-amp 1458 device

Single-Ended Input

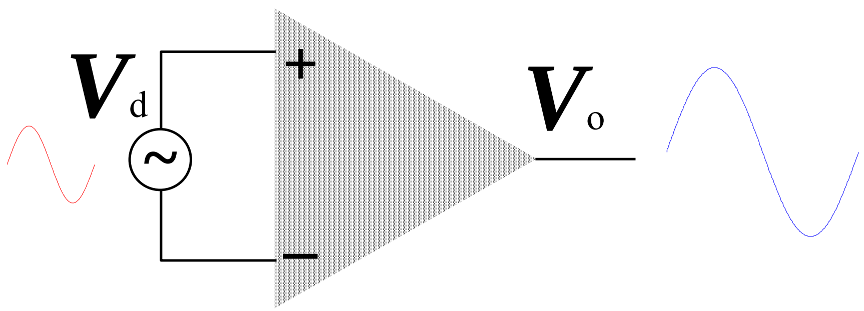


- + terminal : Source
- – terminal : Ground
- 0^o phase change

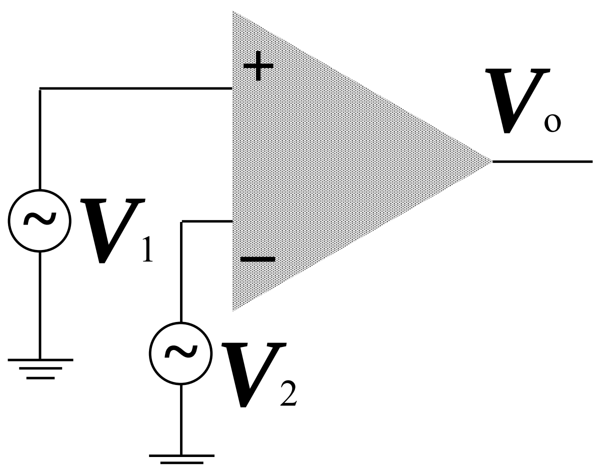


- + terminal : Ground
- – terminal : Source
- 180^o phase change

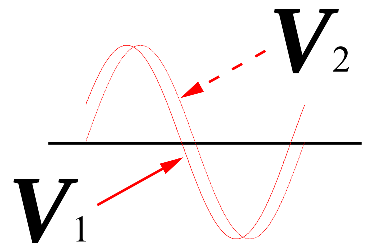
Double-Ended Input



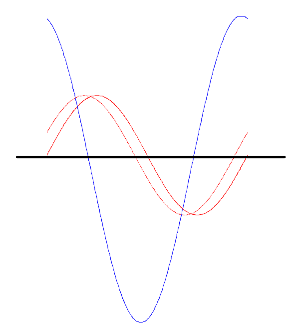
- Differential input
- $$V_d = V_+ - V_-$$
- 0° phase shift change between V_o and V_d



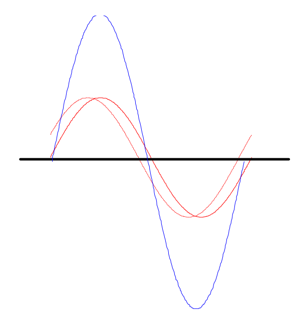
Qu: What V_o should be if,



Ans: (A or B) ?

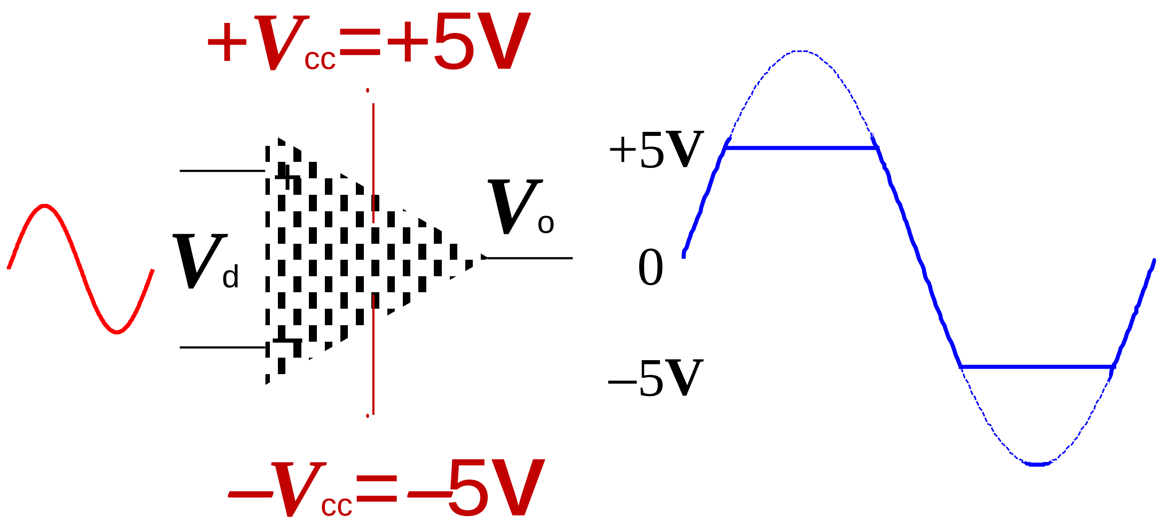


(A)



(B)

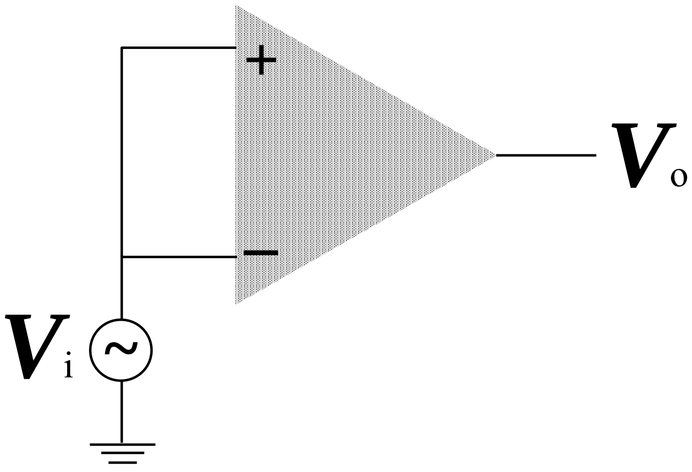
Distortion



The output voltage never excess the DC voltage supply of the Op-Amp

Common-Mode Operation

- Same voltage source is applied at both terminals
- Ideally, two input are equally amplified
- Output voltage is ideally zero due to differential voltage is zero
- Practically, a small output signal can still be measured



Note for differential circuits:
Opposite inputs : highly amplified
Common inputs : slightly amplified

$\Rightarrow$ Common-Mode Rejection

Common-Mode Rejection Ratio (CMRR)

Differential voltage input :

$$V_d = V_+ - V_-$$

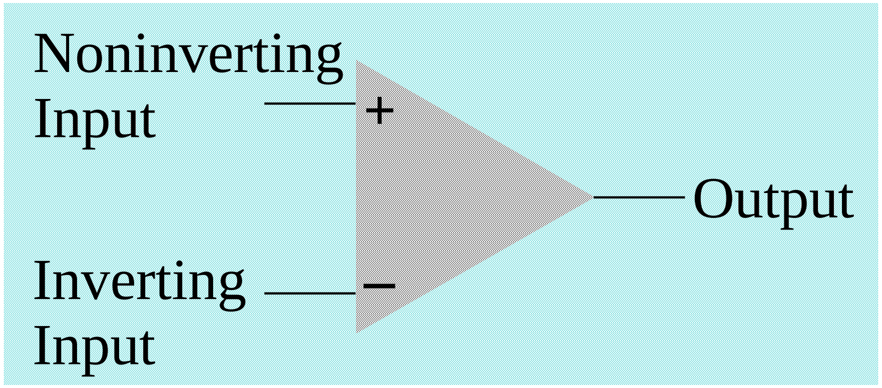
Common voltage input :

$$V_c = \frac{1}{2}(V_+ + V_-)$$

Output voltage :

$$V_o = G_d V_d + G_c V_c$$

G_d : Differential gain
G_c : Common mode gain



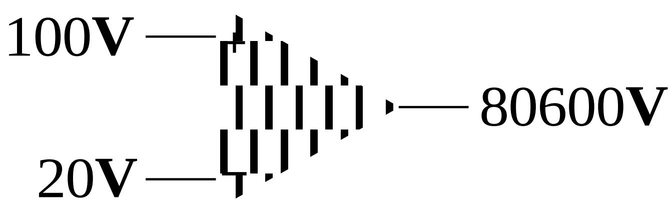
Common-mode rejection ratio:

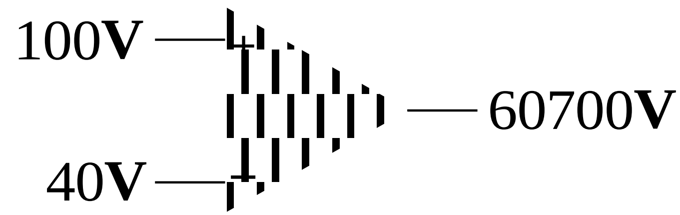
$$\text{CMRR} = \frac{G_d}{G_c} = 20\log_{10}\frac{G_d}{G_c}\ \text{(dB)}$$

Note:
When $G_d >> G_c$ or CMRR $\rightarrow \infty$
$\Rightarrow V_o = G_d V_d$

CMRR Example

What is the CMRR?





Solution :

$$\left.\begin{aligned} V_{d1} &= 100 - 20 = 80\mathbf{V} \\ V_{c1} &= \frac{100+20}{2} = 60\mathbf{V} \end{aligned}\right\} (1) \qquad \left.\begin{aligned} V_{d2} &= 100 - 40 = 60\mathbf{V} \\ V_{c2} &= \frac{100+40}{2} = 70\mathbf{V} \end{aligned}\right\} (2)$$

From (1) $\quad V_o = 80G_d + 60G_c = 80600\mathbf{V}$

From (2) $\quad V_o = 60G_d + 70G_c = 60700\mathbf{V}$

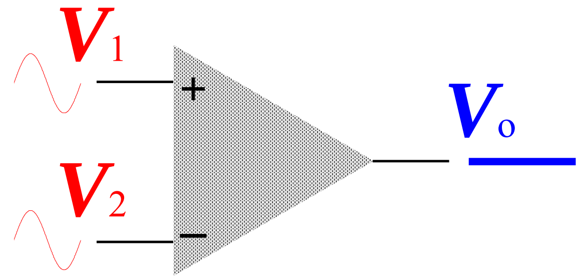
$G_d = 1000$ **and** $G_c = 10$ $\Rightarrow \mathbf{CMRR} = 20\log(1000/10) = 40\mathbf{dB}$

NB: This method is Not work! Why?

Op-Amp Properties

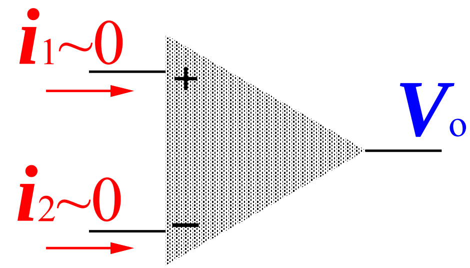
(1) Infinite Open Loop gain

- The gain without feedback
- Equal to differential gain
- Zero common-mode gain
- Pratically, G_d = 20,000 to 200,000



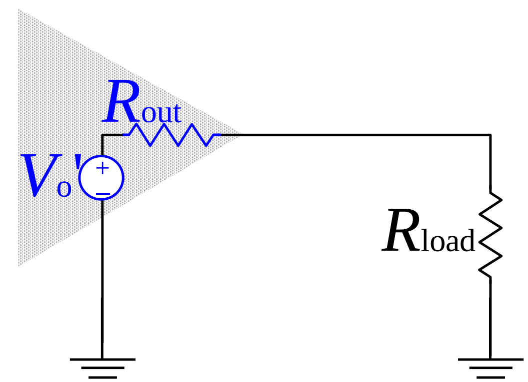
(2) Infinite Input impedance

- Input current i_i ~0A
- T-Ω in high-grade op-amp
- m-A input current in low-grade op-amp



(3) Zero Output Impedance

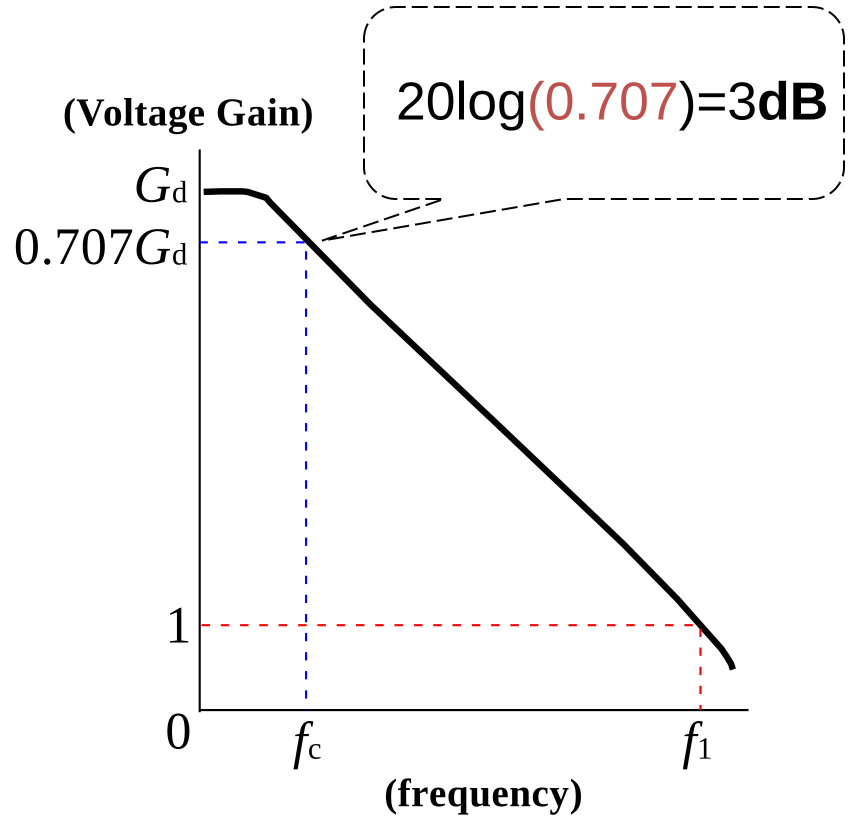
- act as perfect internal voltage source
- No internal resistance
- Output impedance in series with load
- Reducing output voltage to the load
- Practically, R_{out} ~ 20-100 Ω



$$V_{load} = V_o' \frac{R_{load}}{R_{load} + R_{out}}$$

Frequency-Gain Relation

- Ideally, signals are amplified from DC to the highest AC frequency
- Practically, bandwidth is limited
- 741 family op-amp have an limit bandwidth of few KHz.
- Unity Gain frequency f_1: the gain at unity
- Cutoff frequency f_c: the gain drop by 3dB from dc gain G_d



GB Product : $f_1 = G_d\, f_c$

GB Product

Example: Determine the cutoff frequency of an op-amp having a unit gain frequency f_1 = 10 MHz and voltage differential gain G_d = 20**V**/m**V**

Sol:

Since f_1 = 10 MHz

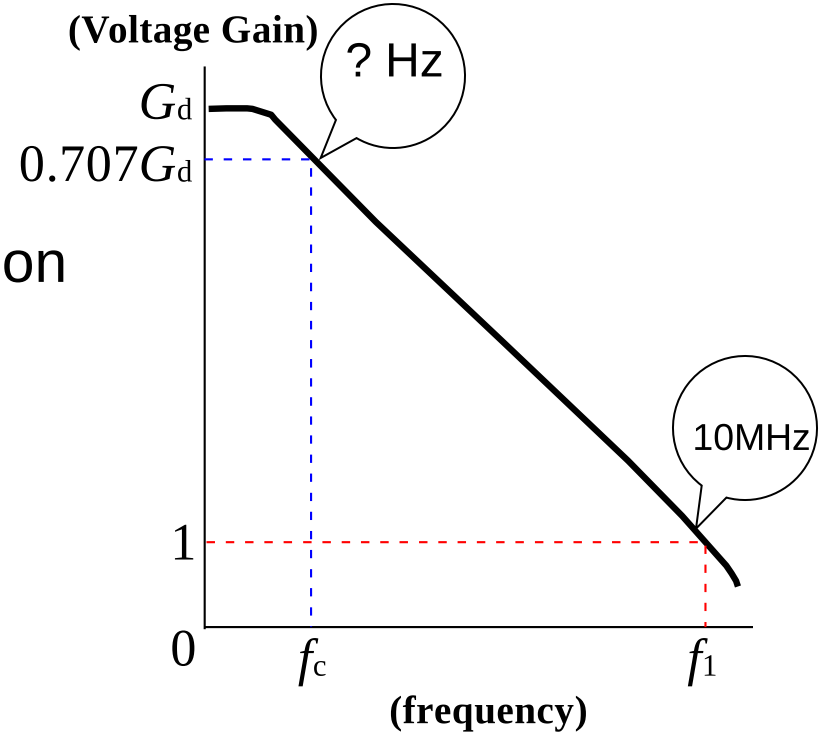
By using GB production equation

$$f_1 = G_d f_c$$

$f_c = f_1 / G_d$ = 10 MHz / 20 V/mV

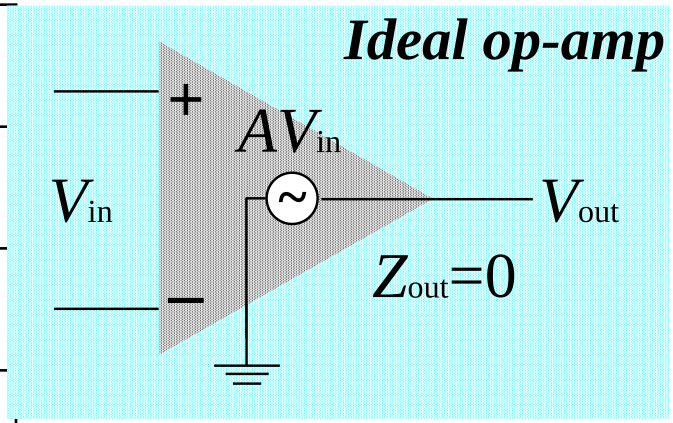
$= 10 \times 10^6 / 20 \times 10^3$

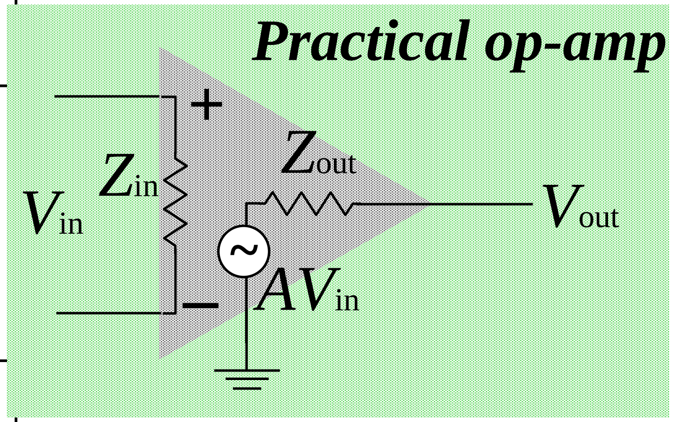
= 500 Hz



Ideal Vs Practical Op-Amp

	Ideal	Practical
Open Loop gain A	$\propto$	10^5
Bandwidth BW	$\propto$	10-100Hz
Input Impedance Z_{in}	$\propto$	>1MΩ
Output Impedance Z_{out}	0 Ω	10-100 Ω
Output Voltage V_{out}	Depends only on $V_d = (V_+ - V_-)$ Differential mode signal	Depends slightly on average input $V_c = (V_+ + V_-)/2$ Common-Mode signal
CMRR	$\propto$	10-100dB





Ideal Op-Amp Applications

Analysis Method :

Two ideal Op-Amp Properties:

(1) The voltage between V_+ and V_- is zero $V_+ = V_-$

(2) The current into both V_+ and V_- termainals is zero

For ideal Op-Amp circuit:

(1) Write the kirchhoff node equation at the noninverting terminal V_+

(2) Write the kirchhoff node eqaution at the inverting terminal V_-

(3) Set $V_+ = V_-$ and solve for the desired closed-loop gain