Operational Amplifier (Op-Amp)

Dr. M. Shiple

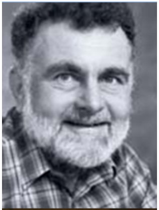
Refer to Electronic circuits ,Adel Sedra , 7th edition

Electronic Circuits (Elec I), 2023

Outline

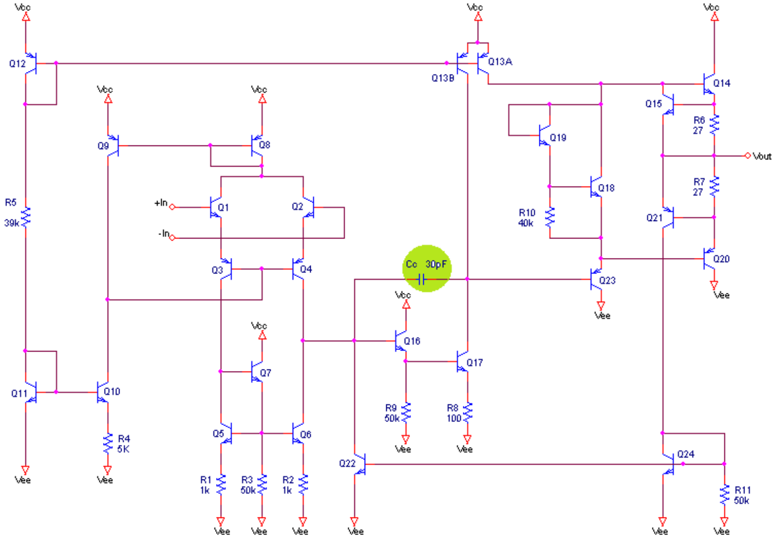
Brief History

Fairchild Lab:

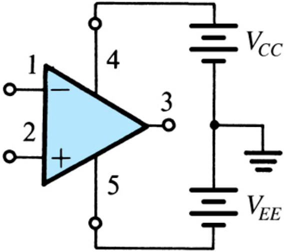


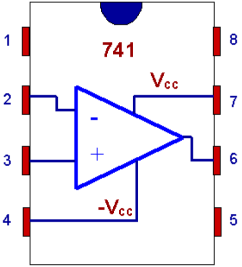
- 1964: **Bob Widlar** designs the first op-amp: the *702*.
  - Open-loop gain over 7000.
  - Using only 9 transistors and cost $300 per op-amp.
- 1965: **He** designs also the *709* $\equiv$ uA741.
  - Open-loop gain around 70,000.
  - lack of short circuit protection.
- 1968: **Dave Fullagar** designs the *741*.
  - Add fixed internal compensation capacitor, that eliminates the external circuitry, unlike its predecessors.
  - Add extra transistors for short circuit protection.
  - Gain around 250,000.

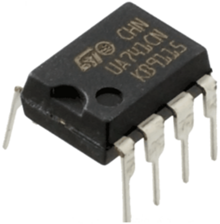
Schematic of UA741 Op Amp



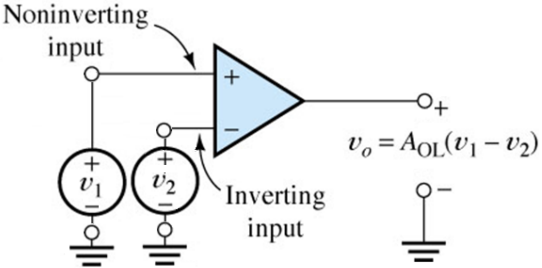
Terminals of Op Amp (2.1.1)





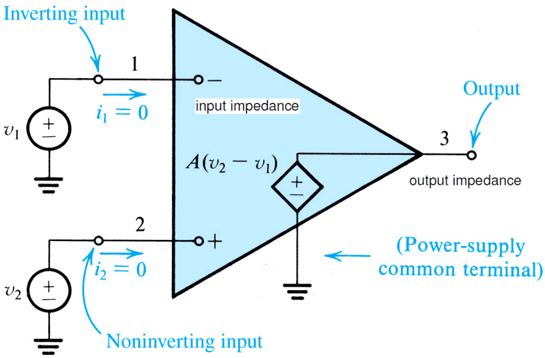


Characteristics of the Ideal Op Amp (2.1.2)

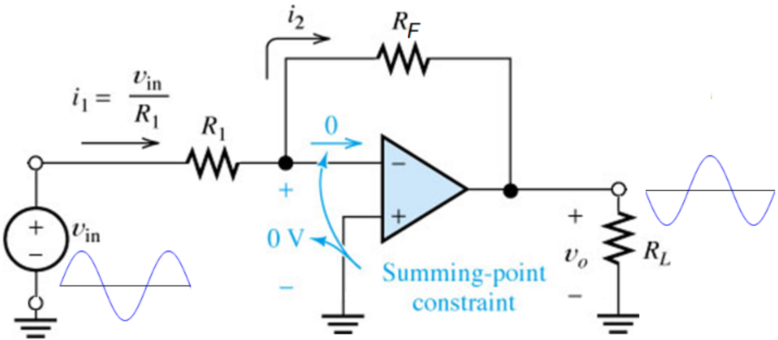


- Ideal gain is defined as $V_3 = A(V_2 - V_1)$
- Ideal input impedance is infinite.
- Ideal output impedance is zero.
- Differential gain;open-loop gain (A) is infinite
- Bandwidth gain is constant from dc to high frequencies

Characteristics of the Ideal Op Amp

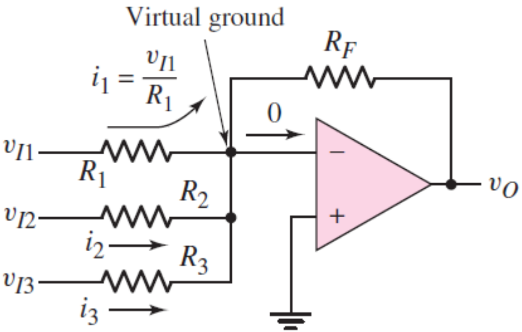


The Inverting Amplifier(2.2)



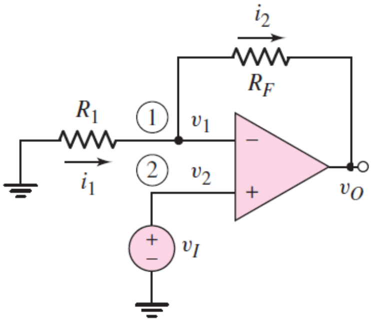
$$V_{out} = -\frac{R_F}{R_1} V_{in}$$

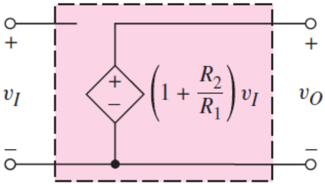
The Weighted Summer (2.2.4)



$$V_{out} = -\frac{R_F}{R_1}V_{I1} - \frac{R_F}{R_2}V_{I2} - \frac{R_F}{R_3}V_{I3}$$

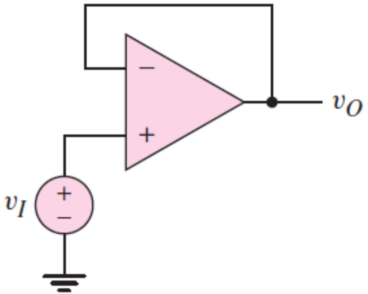
The Non-Invering Configuration(2.3)





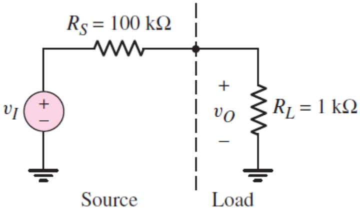
$$G = 1 + \frac{R_F}{R_1}$$

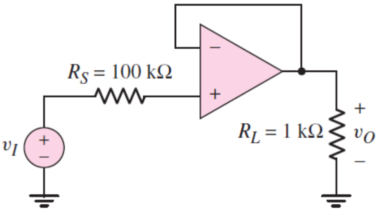
The Voltage Follower (Buffer) (2.3.4)



- unity-gain amplifier.
- impedance transformer.

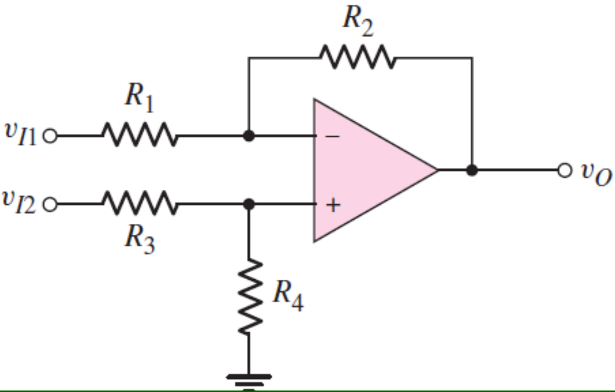
The Voltage Follower (Cont.)





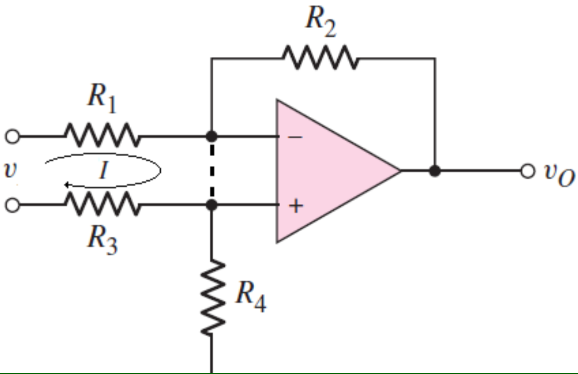
loading problem

Difference Amplifier (2.4)



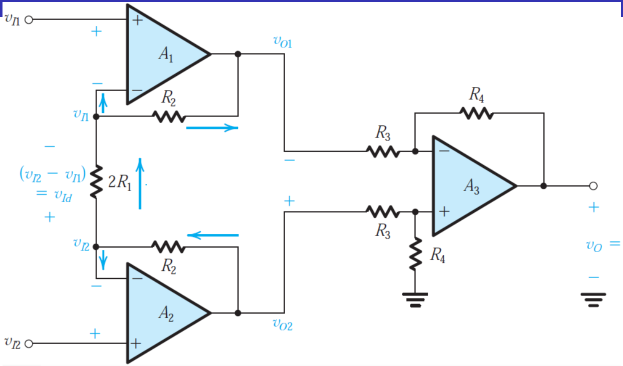
The inverting configuration suffers from a low input resistance. what about the R_F to save the gain!!!

Input Impedance of Difference Amplifier



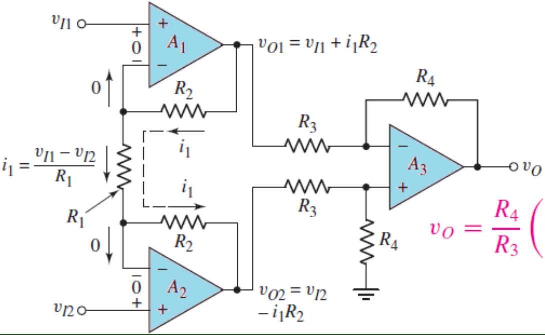
($R_i = 2R$) The difference configuration suffers from a low input resistance. Dilemma of input impedance and high gain !!! To change the gain two resistor should be changed and keep the resistors ratio too.

The Instrumentation Amplifier



- To vary the differential gain Ad, two resistors have to be varied simultaneously (voltage follower).
- The two amplifier channels in the first stage are not perfectly matched.
- The input common-mode signal v_{Icm} is amplified in the first stage.

The Instrumentation Amplifier (2.4.2)

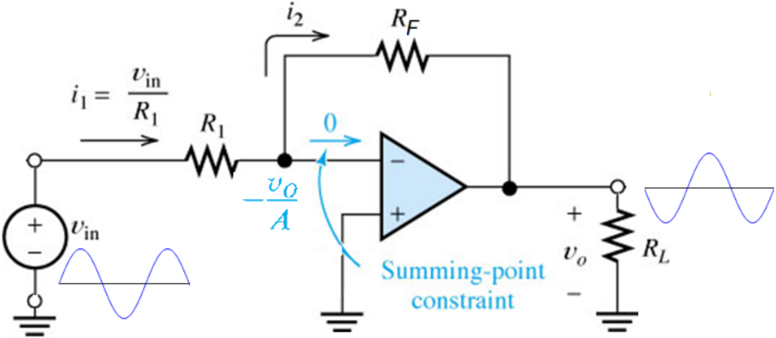


$$v_O = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)(v_{I2} - v_{I1})$$

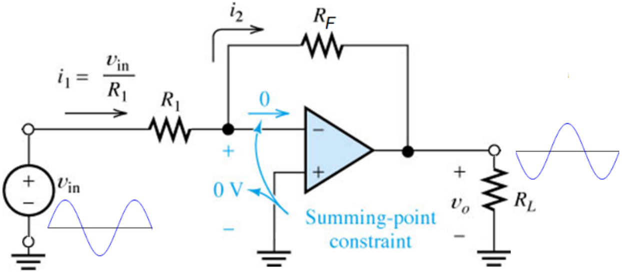
Change just one resistor to tune the gain!!!

The Effect of Finite Gain on Inverting Amplifier

Q: How does the gain expression change if open loop gain (A_{ol}) is not assumed to be infinite?



Input Resistances



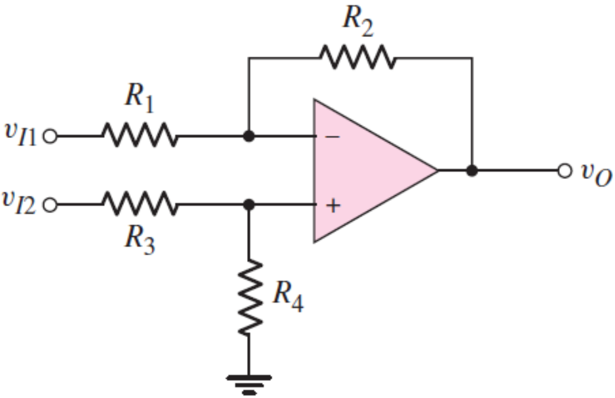
$$R_{in} = \frac{V_{in}}{I_{in}} = \frac{V_{in}}{\frac{V_{in}}{R_1}} = R_1$$

The inverting configuration suffers from a low input resistance. what about the R_F to save the gain!!!

Percent gain error

$$PGE = \frac{G_{ideal} - G_{finite}}{G_{ideal}}$$
$$= \frac{1 + \frac{R_F}{R_1}}{A + 1 + \frac{R_F}{R_1}} \times 100$$

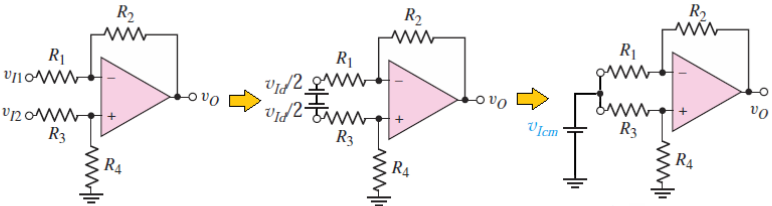
Common-Mode Rejection Ratio (CMRR)



$$v_O = A_d v_{Id} + A_{cm} v_{Icm}$$

$$CMRR = 20 \log \frac{|A_d|}{|A_{cm}|}$$

Common Mode Input Signal



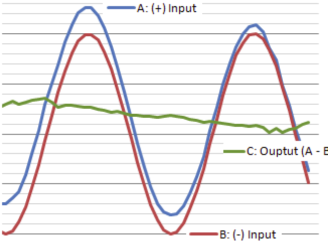
$v_O = A(v_{I2} - v_{I1})$

$v_{Id} = v_{I2} - v_{I1}$

$v_O = A\, v_{Id}$

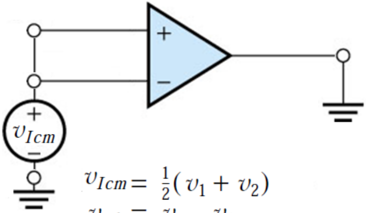
$v_{Icm} = \frac{1}{2}(v_{I1} + v_{I2})$

Difference amplifier is one that responds to the difference between the two signals applied at its input and ideally rejects signals that are common to the two inputs.

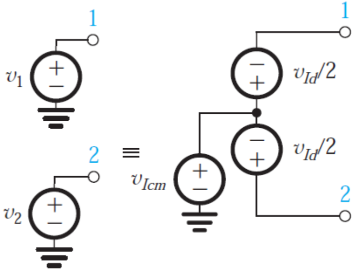


Differential and Common-Mode Signals

- Ideal op amp has zero common-mode gain $\equiv \infty$ common mode rejection.



$$v_{Icm} = \frac{1}{2}(v_1 + v_2)$$
$$v_{Id} = v_2 - v_1$$



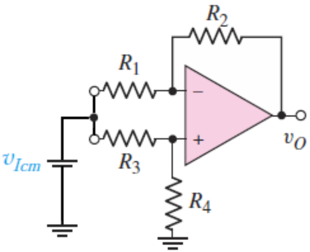
Common Mode Rejection Ratio

By applying superposition:

$$v_o = \frac{R_4}{R_4 + R_3}\left(1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right) v_{cm}$$

$$A_{cm} = \frac{v_o}{v_{cm}} = \frac{R_4}{R_4 + R_3}\left(1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right)$$

$$A_{cm} = \begin{cases} 0, & \frac{R_2}{R_1} = \frac{R_3}{R_4} \\ \frac{R_4}{R_4+R_3}\left(1 - \frac{R_2 R_3}{R_1 R_4}\right) & \text{otherwise} \end{cases}$$



$$v_{Icm} = \frac{1}{2}(v_{I1} + v_{I2})$$

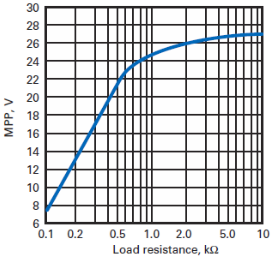
$$v_O = A_d v_{Id} + A_{cm} v_{cm}$$

$$CMRR = 20 log \frac{A_d}{A_{cm}}$$

*cm=common mode

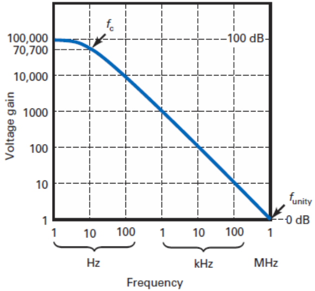
Maximum Peak-to-Peak Output (MPP)

The output cannot swing all the way to the value of the supply voltages because there are small voltage drops in the final stage of the op amp.



Frequency Response

The unity-gain frequency is the frequency at which the voltage gain equals 1.



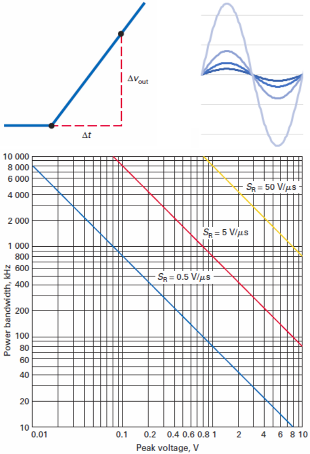
Slew Rate

the charging and discharging of The compensating capacitor. This creates a speed limit on how fast the output of the op amp can change. $S_R = \frac{\Delta V_{out}}{\Delta t}$

Power Bandwidth

where f_{max} is the highest frequency that can be amplified without slew-rate distortion

$S_{Rate} = S_{Signal} = 2\pi f V_p$



741 packaging