Operational amplifiers

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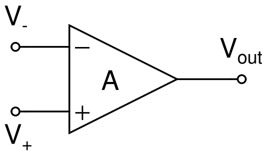
Operational amplifiers (Op-Amp)

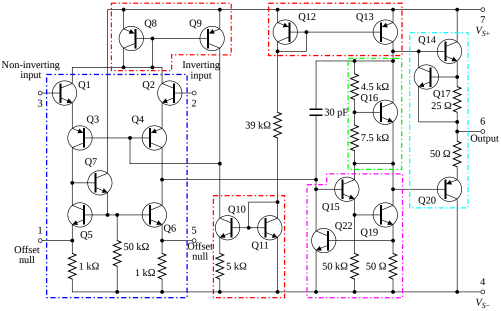


- $V_{out} = A(V_+ - V_-)$ thus sometimes called differential amplifiers
- A is open loop gain
  - A is frequency dependent
  - $A = 10^5 \dots 10^6$ at DC
  - $A \to 0$ at high frequency (roll off)
    this limits operational bandwidth (typically in MHz ... GHz range)
- input impedances are high $10^6 \dots 10^{14}\ \Omega$
- output impedances are low $0.1 \dots 10\ \Omega$
  - however output current usually limited to 10 mA
- **it is super easy to design with them**

If Op-Amps are so great why did we learn transistors?

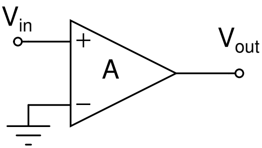
- sometimes one transistor is enough and op-amps are more expensive
- op-amps are made of transistors so to understand their limits we need to know how transistors behave
- op-amps require bipolar power supply
- remember that op-amps cannot source a lot of current/power while transistors can (recall our transistor controlled switch for a bulb)

LM741 (introduced in 1968) internal schematic



So, combine op-amps and transistors for a power circuits. Otherwise do your circuit with op-amps.

Very very bad amplifier !!!



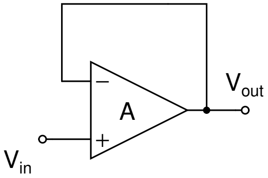
Gain

$$V_{out} = AV_{in}$$

But *A* depends on everything

- temperature
- power supply voltage
- input voltage
- frequency
- . . . and so on

Follower or Buffer



$$V_{out} = \frac{A}{A+1} V_{in}$$

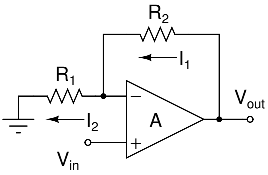
Gain and impedances of ideal Op-Amp ($A \gg 1$)

$$G_{ideal} = 1$$

$$Z_{in} = \infty, Z_{out} = 0$$

notice that with negative feedback $V_+ \approx V_-$

Non-inverting amplifier



$$V_{out} = \left(1 + \frac{R_2}{R1}\right) V_{in} \frac{A}{A + (1 + \frac{R_2}{R_1})}$$

Gain and impedances of ideal Op-Amp ($A \gg 1$)

$$G_{ideal} = 1 + \frac{R_2}{R_1}$$

$$Z_{in} = \infty, Z_{out} = 0$$

notice that with negative feedback $V_+ \approx V_-$

Op-amps golden rules

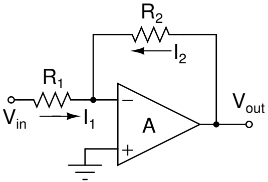
If negative feedback is applied and $A(f) \gg 1$ (open circuit gain at the frequency of interest)

- there is no current into the inputs
- $V_- = V_+$

Gain of non ideal Op-Amp ($A \not\gg 1$)

$$G = G_{ideal}||A = \frac{G_{ideal}A}{G_{ideal} + A}$$

Inverting amplifier



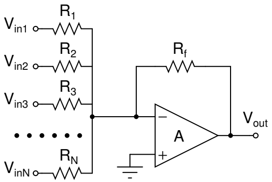
Gain and impedances of ideal Op-Amp ($A \gg 1$)

$$G_{ideal} = -\frac{R_2}{R_1}$$

$$Z_{in} = R_1, Z_{out} = 0$$

notice that with negative feedback $V_+ \approx V_-$

Summing inverting amplifier

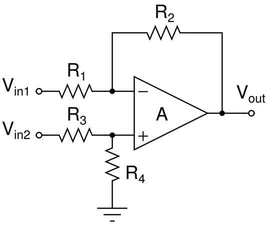


for ideal Op-Amp ($A \gg 1$)

$$V_{out} = -\left(\frac{V_{in1}}{R_1} + \frac{V_{in2}}{R_2} + \frac{V_{in3}}{R_3} + \cdots + \frac{V_{inN}}{R_N} \right) R_f$$

$$Z_{inN} = R_N, Z_{out} = 0$$

Differential amplifier



for ideal Op-Amp ($A \gg 1$)

$$V_{out} = \frac{R_4}{R_1}\frac{R_1 + R_2}{R_3 + R_4} V_{in2} - \frac{R_2}{R_1} V_{in1}$$

$$Z_{out} = 0$$