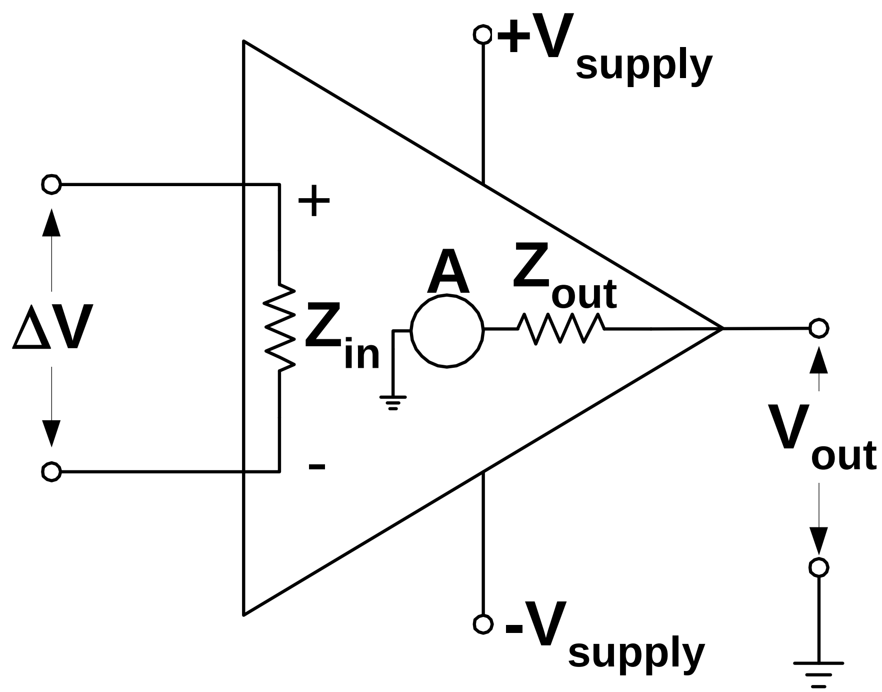
Operational Amplifiers

A brief introduction

Op-Amp Introduction

- Need exists for a circuit element that can perform:
  - Add, subtract, multiply, divide, differentiate, integrate
- Evolved from Analog Computers
- Op-Amp properties
  - Single building block which can be assembled into above functions by adding passive components (R,L,C)
  - Inexpensive (used in high volume)
  - Compact
- Op-Amp analysis
    - Use assumptions of “Ideal Op-Amp” to allow low frequency performance to be approximated
    - Typically have near ideal characteristics but frequency response of an integrator ($G(s) = 1/\tau s$). (Otherwise, the high bandwidth would be impossibly difficult to manage.)

Ideal Op-Amp Assumptions

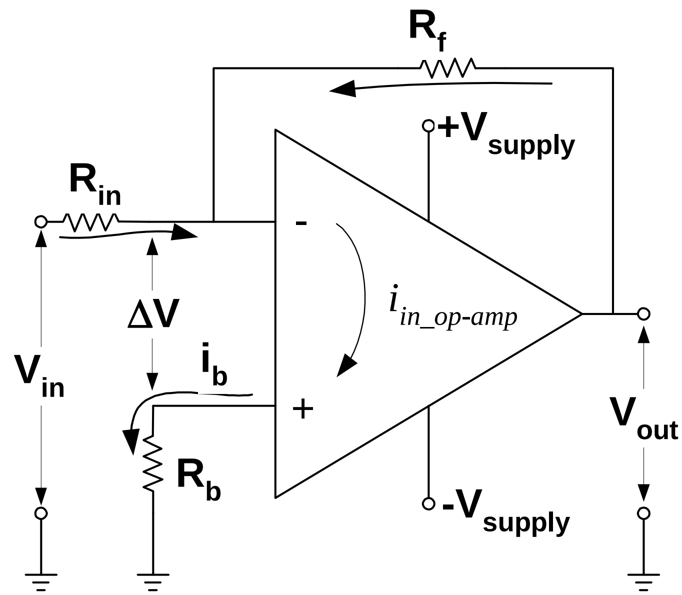


- Differential function
  - $V_{out} = A \bullet \Delta V$
- Infinite
  - Intrinsic gain: $A = \infty$
  - Input impedance: $Z_{in} = \infty$
  - Bandwidth: $V_{out} \neq f(\omega)$
- Zero
  - Input offset voltage: $V_{io} = 0$ for $V_{out} + V_{io} = A \bullet \Delta V$
  - Input impedance: $Z_{out} = 0$

Inverting Amplifier

- Consider the circuit configuration to the right

$$V_{in} = V_{R_{in}} + \Delta V + V_{R_b}$$
$$V_{out} = V_{R_f} + \Delta V + V_{R_b}$$
$$i_{R_{in}} + i_{R_f} = i_{in\_op-amp}$$



- Assuming intrinsic gain of the op-amp is very large for the frequency of interest: $\Delta VA = V_{out}$
  - V_{out} is finite and typically within +15 to -15 V implying ΔV is very small
- Assuming i_b is very small given the intrinsic input impedance is very large, V_b must be very small

Inverting Amplifier

$$V_{in} \cong V_{R_{in}}$$

$$V_{out} \cong V_{R_f}$$

$$i_{R_{in}} = -i_{R_f}$$

$$\frac{V_{R_{in}}}{R_{in}} = -\frac{V_{R_f}}{R_f}$$

$$\frac{V_{in}}{R_{in}} = -\frac{V_{out}}{R_f}$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}}$$

- Amplifier performance is a function of external components only for ideal assumptions
- Input and output impedances of the amplifier can be calculated as approximately:

$$Z_{in} = R_{in} \qquad Z_{out} = \frac{Z_{out\_intrinsic}}{\left(1 + A\frac{R_{in}}{R_{in} + R_f}\right)}$$

- Very good output impedance characteristics

Non-Inverting Amplifier

$$V_{in} = V_{R_{in}} + \Delta V + V_{R_b}$$

$$V_{out} = V_{R_f} + V_{R_b}$$

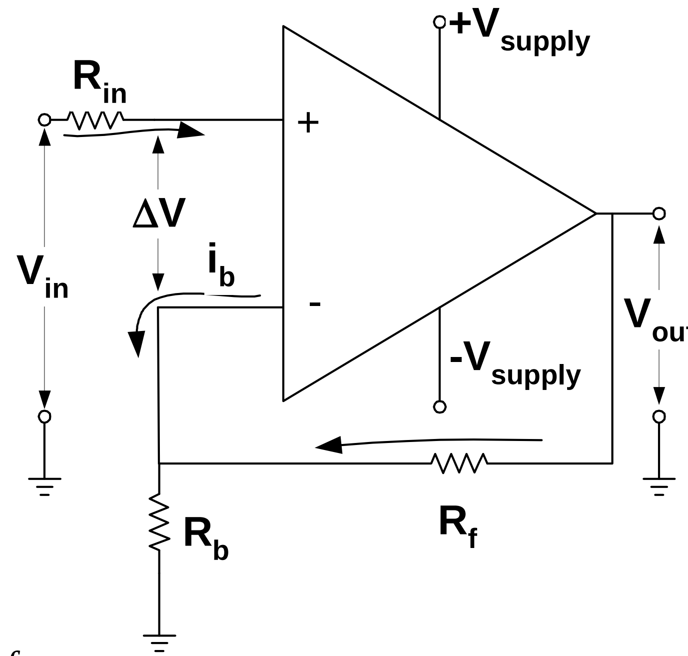
$$i_{R_f} + i_b = i_{R_b}$$

$$V_{in} \cong V_{R_b}$$

$$V_{out} = V_{R_f} + V_{in}$$

$$i_{R_f} \cong i_{R_b} \qquad \frac{V_{R_f}}{R_f} = \frac{V_{R_b}}{R_b} \qquad V_{R_f} = V_{in}\frac{R_f}{R_b}$$

$$V_{out} = V_{in}\frac{R_f}{R_b} + V_{in} = V_{in}\left(1 + \frac{R_f}{R_b}\right)$$



$$\boxed{\frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R_b}\right)}$$

Non-Inverting Amplifier

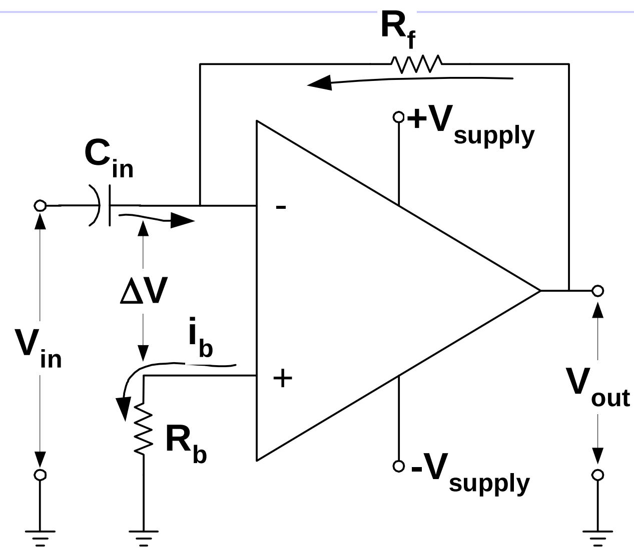
- Input and output impedances can be calculated as approximately:

$$Z_{in} = Z_{in\_intrinsic}\left(1 + A\left(\frac{R_{in}}{R_{in} + R_f}\right)\right)$$

$$Z_{out} = \frac{Z_{out\_intrinsic}}{\left(1 + A\left(\frac{R_{in}}{R_{in} + R_f}\right)\right)}$$

Differentiator

- Consider the circuit configuration to the right



$$V_{in} = V_{C_{in}} + \cancel{\Delta V} + \cancel{V_{R_b}}$$

$$V_{out} = V_{R_f} + \cancel{\Delta V} + \cancel{V_{R_b}}$$

$$i_{C_{in}} + i_{R_f} = \cancel{i_{in\_op-amp}}$$

$$i_{C_{in}} = C_{in} \frac{dV_{C_{in}}}{dt} \qquad i_{C_{in}} = C_{in} \frac{dV_{C_{in}}}{dt} = -i_{R_f} = \frac{V_{R_f}}{R_f}$$

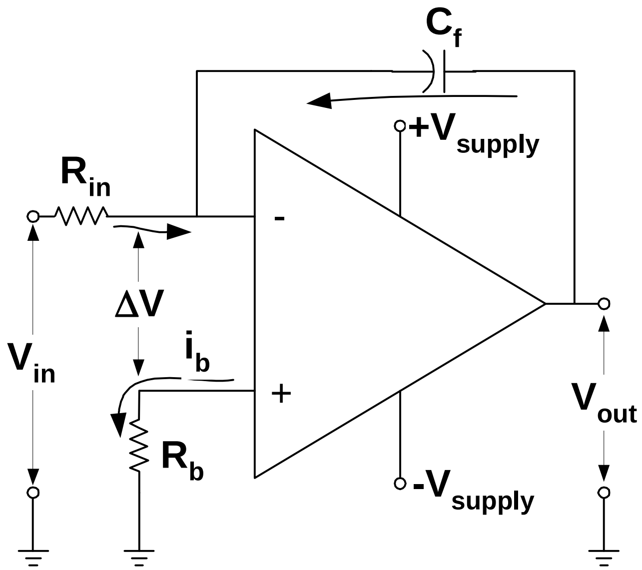
$$i_{R_f} = \frac{V_{R_f}}{R_f}$$

$$C_{in} \frac{dV_{in}}{dt} = \frac{V_{out}}{R_f}$$

$$\boxed{V_{out} = R_f C_{in} \frac{dV_{in}}{dt}}$$

Integrator

- Consider the circuit configuration to the right



$$V_{in} = V_{R_{in}} + \Delta V + V_{R_b}$$

$$V_{out} = V_{C_f} + \Delta V + V_{R_b}$$

$$i_{R_{in}} + i_{C_f} = i_{in\_op-amp}$$

$$i_{C_f} = C_{in} \frac{dV_{C_f}}{dt}$$

$$i_{R_{in}} = \frac{V_{R_{in}}}{R_{in}} = -i_{C_f} = C_f \frac{dV_{C_f}}{dt}$$

$$i_{R_{in}} = \frac{V_{R_{in}}}{R_f}$$

$$\frac{V_{in}}{R_{in}} = C_f \frac{dV_{out}}{dt}$$

$$\int V_{in} dt = R_{in} C_f \int dV_{out}$$

$$\boxed{V_{out} = \frac{1}{R_{in} C_f} \int V_{in} dt}$$

What is the transfer function for this circuit?