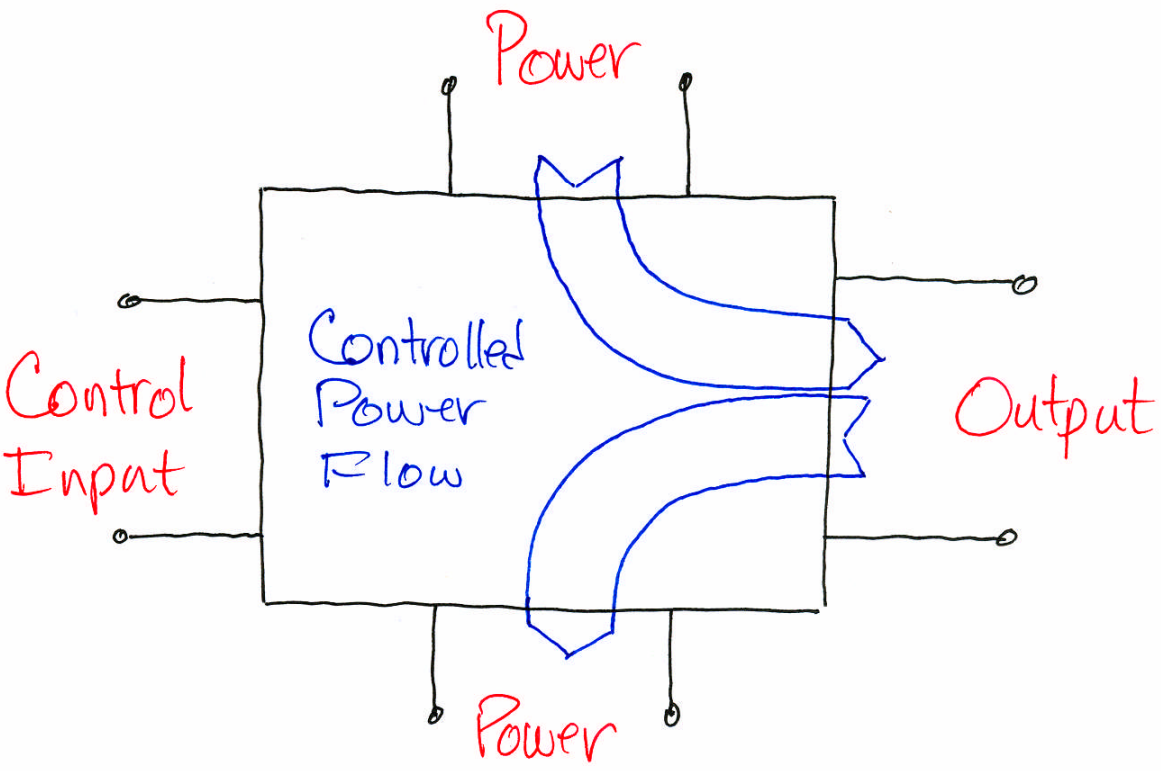
6.002 - Lecture 19

Operational Amplifiers

- Operational Amplifiers (Op Amps)
- Ideal Op Amp
- Non-idealities
- Op-Amp-Based Amplifiers

Amplifiers



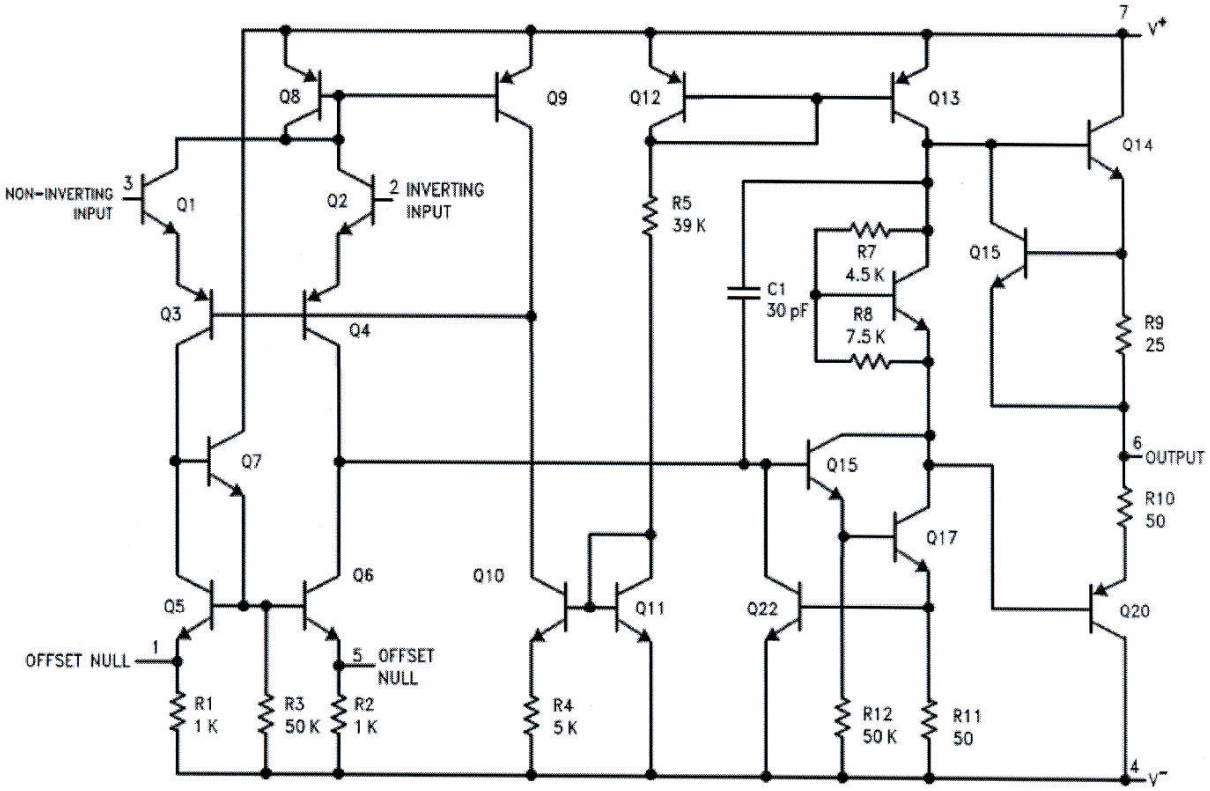
- Amplifier is a three- or four-port device.
- Provides voltage, current and/or power gain.
- Fundamental building block in analog signal processing systems such as: audio and video, communications, instrumentation and control, and so on.

Amplifier Wish List

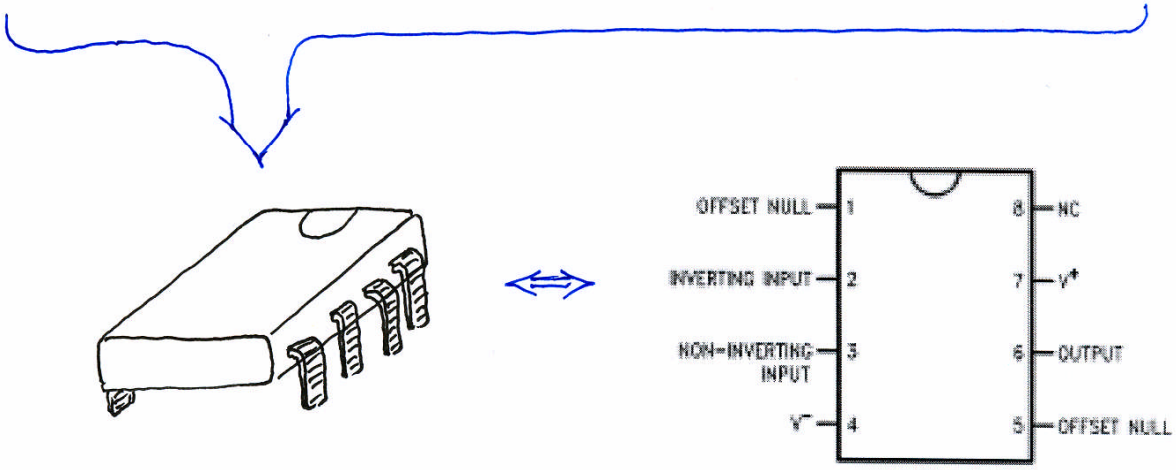
- High voltage, current and/or power gain
- Linear operation
- Wide bandwidth $\longleftrightarrow$ fast operation
- Low noise
- High power handling capability
- Low loss
- Wide temperature operating range
- Differential input
- Single small package

Op amps provide many of these features.

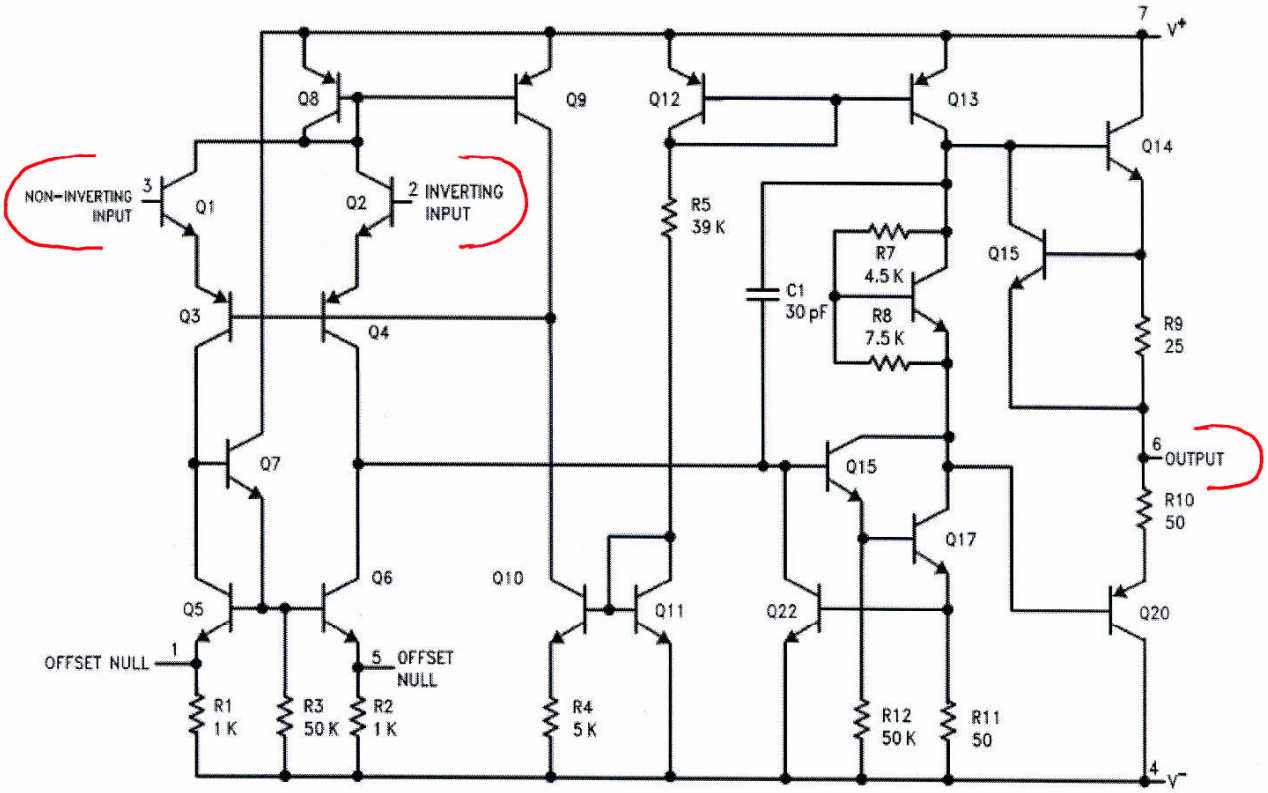
Operational Amplifier



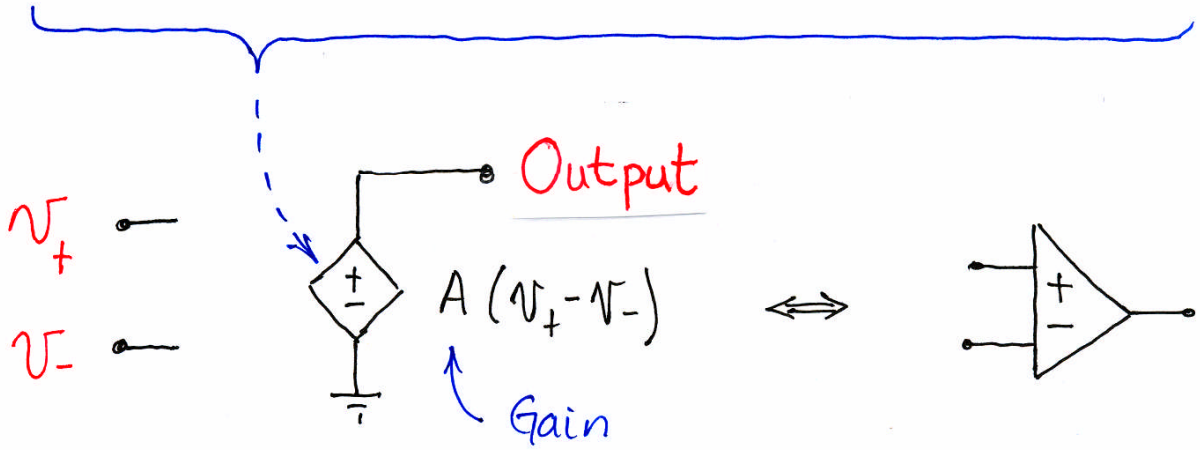
National Semiconductor LM741 Operational Amplifier



Simple Op-Amp Model

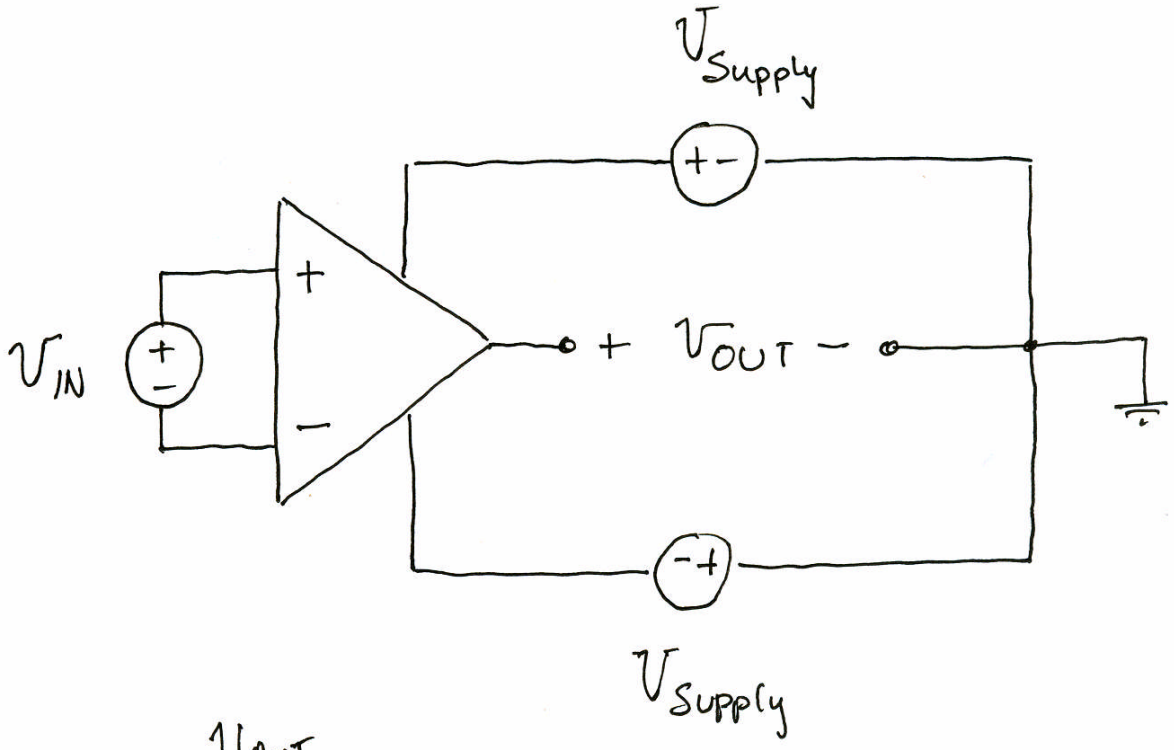


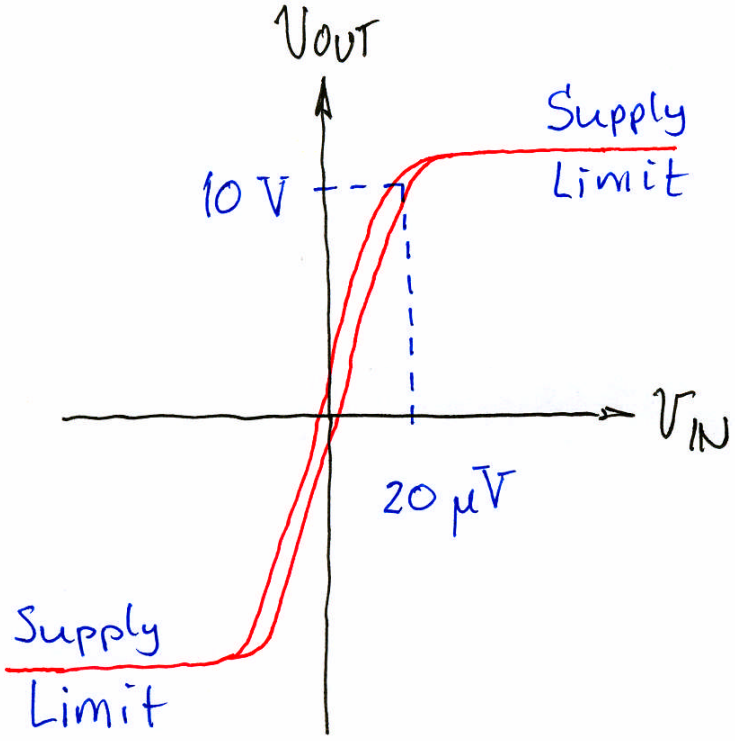
National Semiconductor LM741 Operational Amplifier



Power supply terminals not shown

Op - Amp Behavior





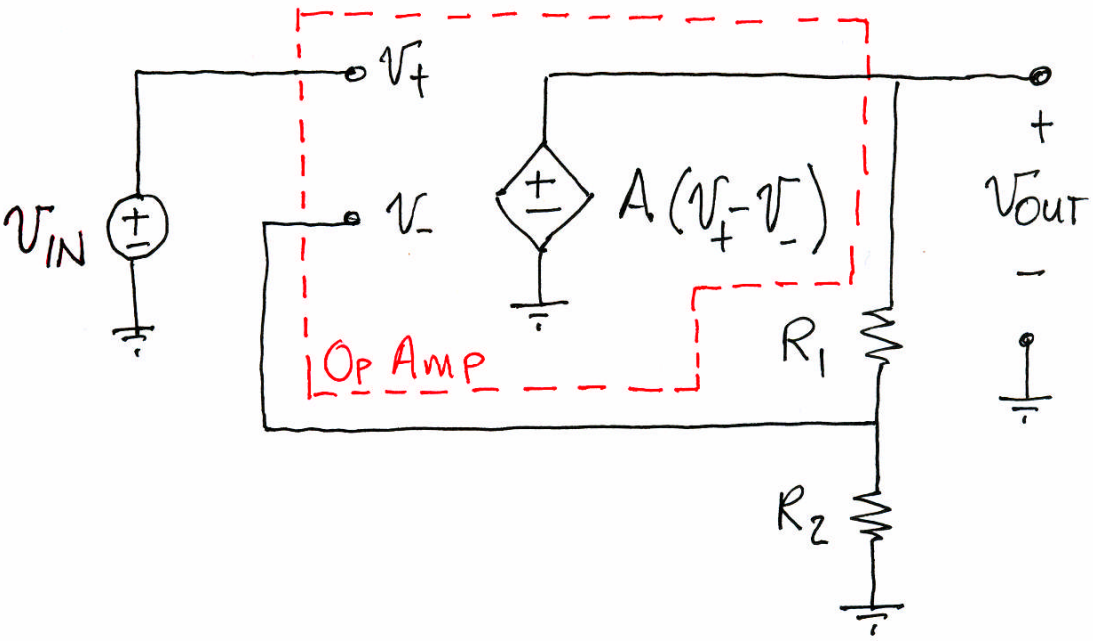
Voltage Gain ≈ $5 \cdot 10^5$

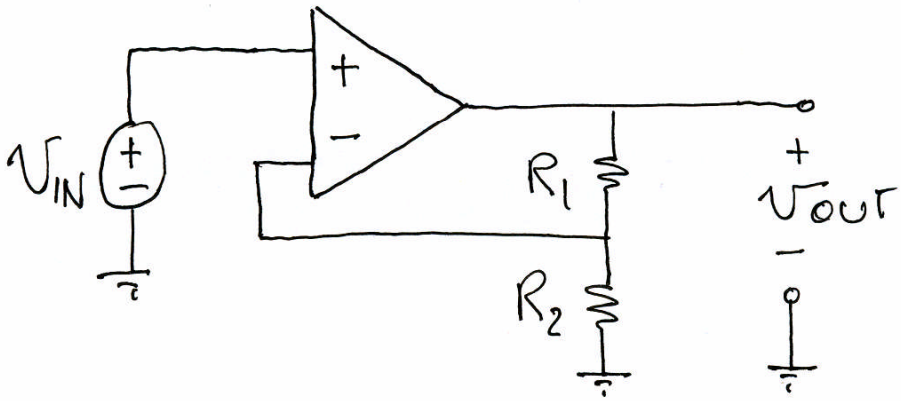
Non - Linear

Temperature Dependent

A Practical Amplifier

Use negative feedback to trade gain for more ideal performance.





Power supply connections not shown.

Analysis I

Node Method: $\dfrac{V_-}{R_2} + \dfrac{V_- - A(V_+ - V_-)}{R_1} = 0$ ($V_+ = V_{IN}$)

$$V_- = \frac{A R_2}{R_1 + (A+1) R_2} V_{IN}$$

$$V_{out} = A(V_+ - V_-) \quad (V_+ = V_{IN})$$

$$= \frac{A \cdot G}{A + G} V_{IN} \qquad G \equiv \frac{R_1 + R_2}{R_2}$$

If $A \gg G$ then $V_{OUT} = G\, V_{IN}$

Dependent only on resistors.

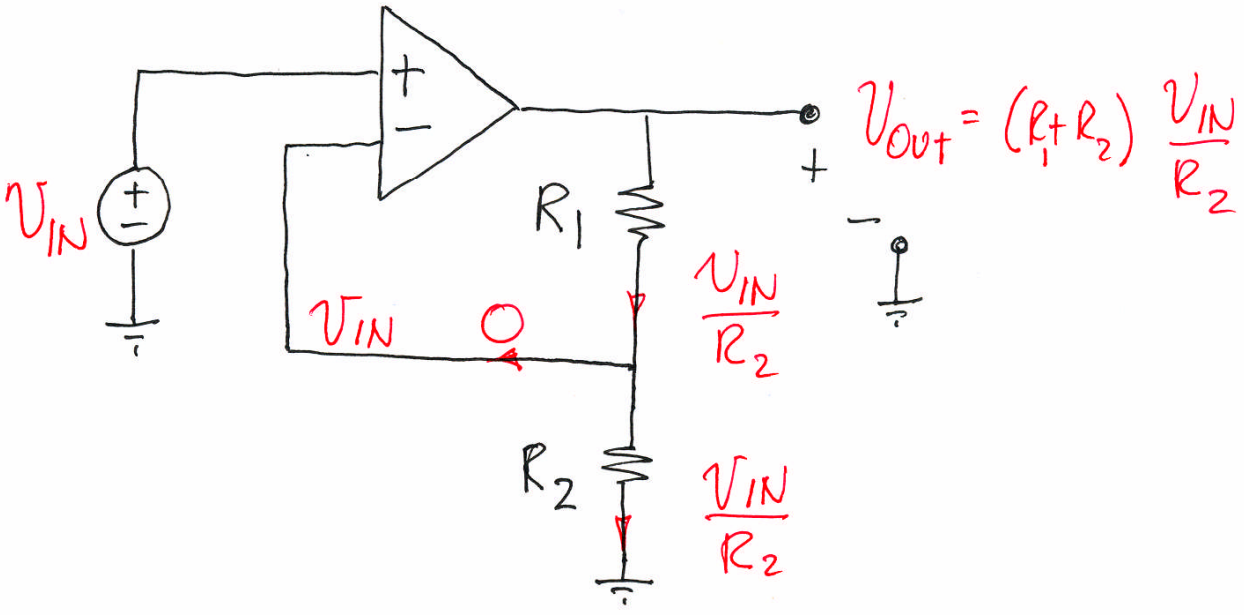
Analysis II

Assume $A \gg G$

$$v_+ - v_- = \frac{V_{OUT}}{A} \approx \frac{G\, V_{IN}}{A}$$

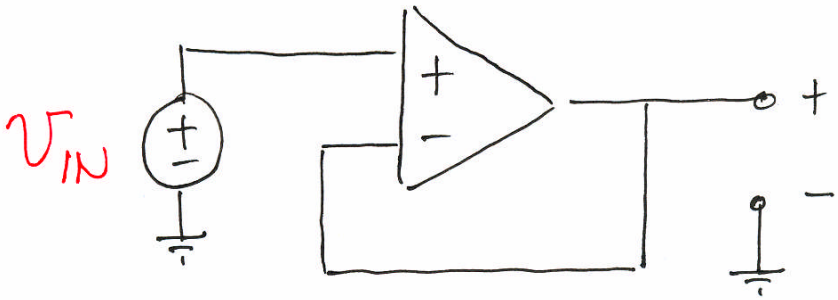
$$v_+ - v_- \ll V_{OUT}, V_{IN}$$

$$v_+ \approx v_-$$

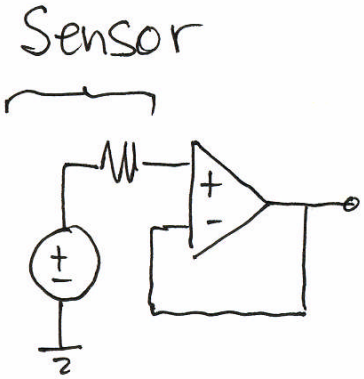


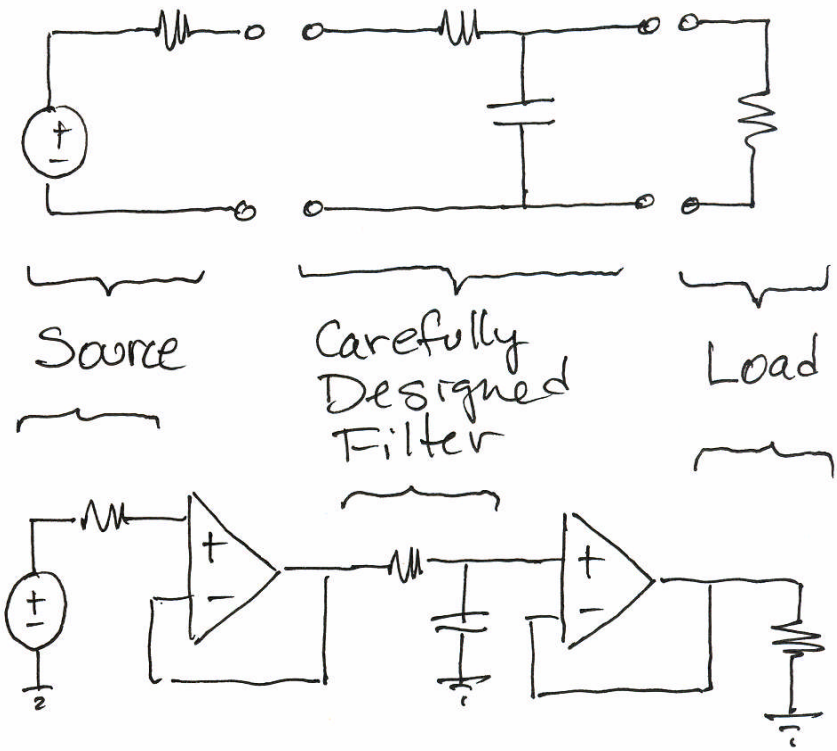
Buffer

$R_1 \to 0$ (Short) $\qquad$ $R_2 \to \infty$ (Open)



Voltage Gain = 1 $\qquad$ Current Gain = ∞ $\qquad$ Power Gain = ∞





Non-idealities

- Finite, non-linear and non-differential gain.
- Finite bandwidth
- Temperature dependence
- Non-zero output resistance
- Finite input resistance
- Input offsets and noise