# Op-Amps

Op-amps are 5 terminal devices

Inputs and outputs cannot exceed supplies

Golden rules (valid when feedback is working):
1. \( V_{in+} = V_{in-} \)
2. No current flows at input terminals

For op-amp circuits using resistors, keep resistors in 10K-100K range, widen to 1K to 500K if needed

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## Inverting Gain

\[ V_{out} = -(\frac{R_2}{R_1}) \cdot V_{in} \]

Practical max gain ~100

## Non-inverting Gain

\[ V_{out} = (1+\frac{R_2}{R_1}) \cdot V_{in} \]

Min gain = 1

## Current to Voltage Converter

\[ V_{out} = I_{in} \cdot R \]

## Voltage to Current Converter

\[ I_{out} = \frac{V_{in}}{R_s} \]

## High-current Voltage to Current Converter

\[ I_{out} = \frac{V_{in}}{R_s} \]
Low pass filter, 450 Hz
2-pole Butterworth
Unity-gain
Sallen-Key configuration
1% resistors, Polypropylene capacitors

Op-amp notes
No 741 types allowed
No +/- 15 V supplies allowed
Use 0.1 bypass capacitor on every chip, lead lengths short.
Use ground plane or ground pour
Keep analog circuits away from digital circuits
Attach analog ground to digital ground at one point on the board
For op-amp types, see [http://www.me.umn.edu/labs/hmd/lab/electronics/ic.html](http://www.me.umn.edu/labs/hmd/lab/electronics/ic.html)

Suggested part numbers:
TLV2374 – generic rail-to-rail
TLC2274 – somewhat lower noise, somewhat faster, +5V max
MCP6024 – fast, +5V max
TLC074 – low noise, good for audio circuits