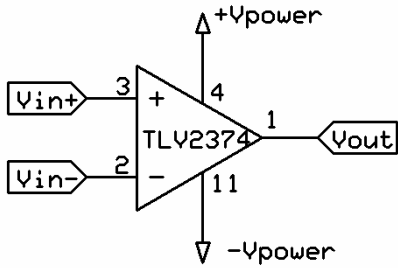
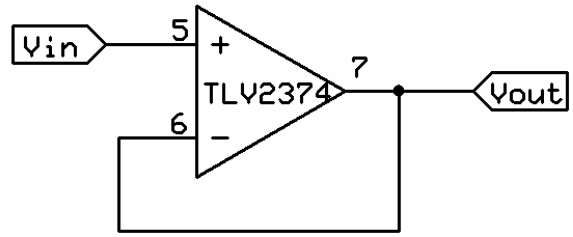


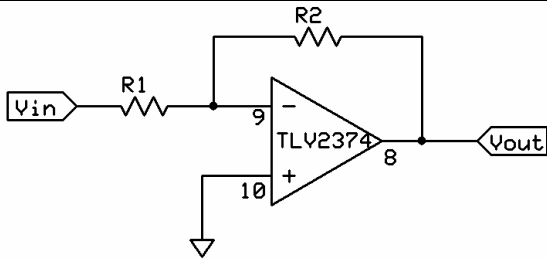
Op-Amps



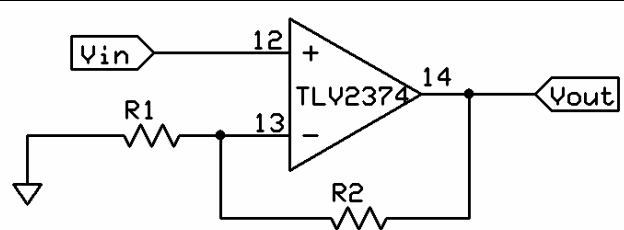
Op-amps are 5 terminal devices
 Inputs and outputs cannot exceed supplies
 Golden rules (valid when feedback is working):
 1. $V_{in+} = V_{in-}$
 2. No current flows at input terminals
 For op-amp circuits using resistors, keep resistors in 10K-100K range, widen to 1K to 500K if needed



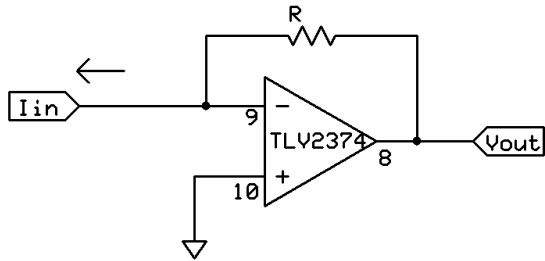
Unity-gain buffer
 $V_{out} = V_{in}$
 Provides low-impedance output. Use where you don't want to draw current from the source



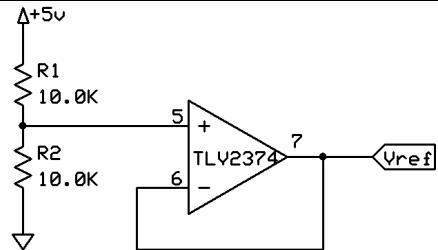
Inverting gain
 $V_{out} = -(R2/R1) * V_{in}$
 Practical max gain ~100



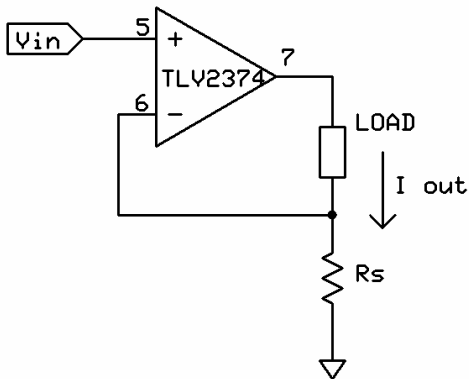
Non-inverting gain
 $V_{out} = (1+R2/R1) * V_{in}$
 Min gain = 1



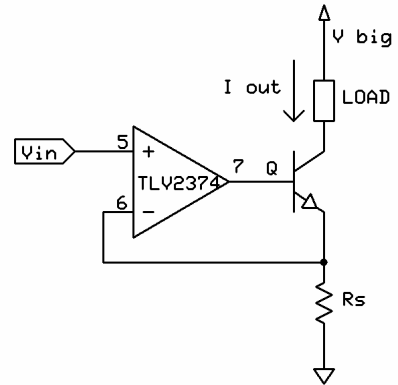
Current to voltage converter
 $V_{out} = I_{in} * R$



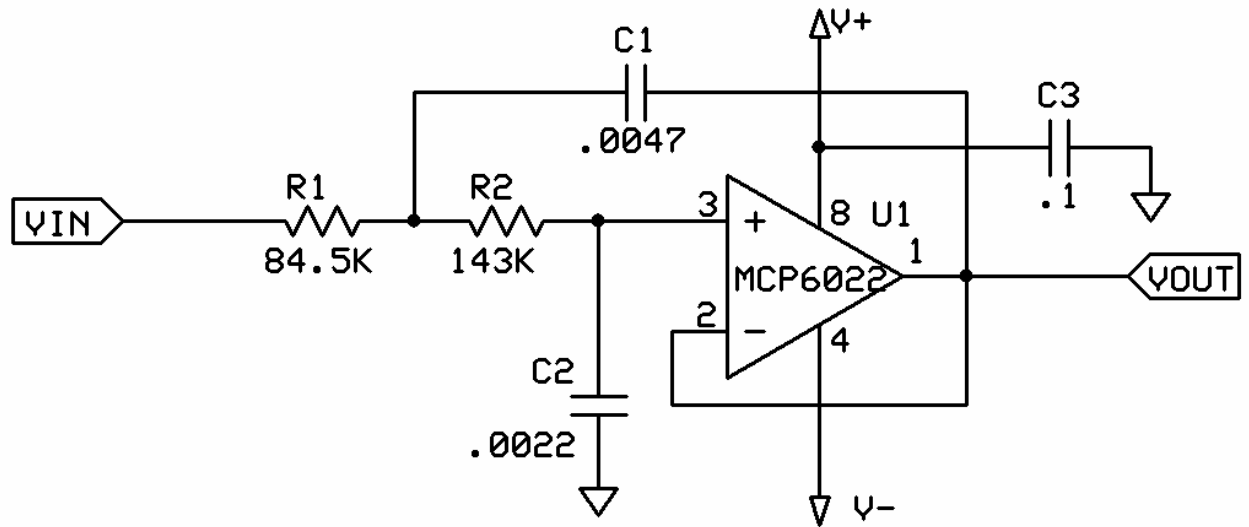
Virtual ground
 For single supply applications
 $V_{out} = 2.5V$



Voltage to current converter
 $I_{out} = V_{in}/R_s$



High-current voltage to current converter
 $I_{out} = V_{in}/R_s$



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>

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