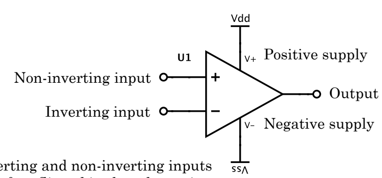
Op Amps and Signal Conditioning

E80 Spring 2015
Erik Spjut

5 wire diagram



Inverting and non-inverting inputs are often flipped in the schematic. Be sure you check.

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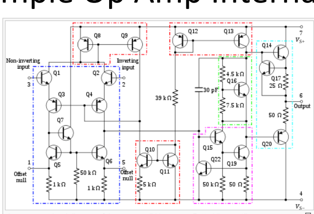
Sample Op Amp Internals

For the curious. Not needed for E80



A component-level diagram of the common 741 op-amp. Dotted lines outline: current mirrors (red); differential amplifier (blue); class A gain stage (magenta); voltage level shifter (green); output stage (cyan).

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Simulink Op Amp Model

For the curious. Not needed for E80

- Rate limited integrator followed by a range limit block.
- Ask Prof. Spjut if you ever need it.

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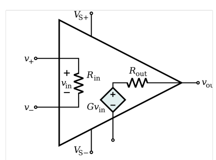
Simplified Real Op Amp Model

For the curious. Not needed for E80

- The internally generated voltage is the gain times the difference of the input voltages.
- The input impedance is very large.
- The output impedance is very small.
- The ideal op amp is derived by assuming the gain approaches ∞, the output impedance approaches 0, and the input impedance approaches ∞.



$$V_{out} = G\left(V_+ - V_-\right)$$

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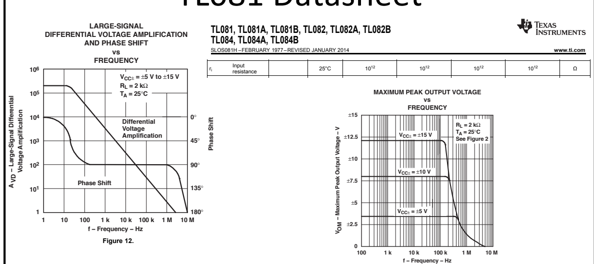
TL081 Datasheet



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Ideal Op Amp Model

- Input impedance: ∞Ω
- Output impedance: 0Ω
- With negative feedback, gain so high that $V_+ = V_-$

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Operational **Amp**lifier

- Can be configured to perform mathematical operations on a signal.
  - Multiply by a constant (change gain)
  - Change sign
  - Add two or more signals
  - Subtract one signal from another
  - Integrate a signal
  - Differentiate a signal
  - Many others

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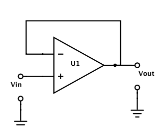
Unity Gain Buffer

- Your go-to circuit. It solves many problems.
- Analyze circuit.
- Draws no current at input (ideal model).
- Provides needed current at output (ideal model).
- Transfers voltage with no circuit loading.



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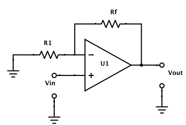
Non-Inverting

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



- High impedance input, great for measuring voltages
- Gains ≥1
- Do you see the voltage divider?
- Analyze circuit.

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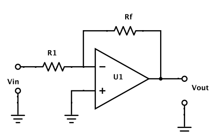
Inverting

$$V_{out} = -\frac{R_f}{R_1} V_{in}$$



- Input impedance is R_1 (ideal model).
- Flips sign (or phase) of input.
- Full gain range
- Analyze circuit.

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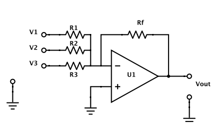
Inverting Summing Amp

$$V_{out} = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right)$$



- How would you sum three signals?
- How would you average three signals?
- What is the input impedance?
- Analyze circuit.
- Non-inverting summer exists.

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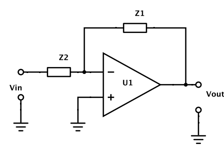
General Impedance Model

$$V_{out} = -\frac{Z_1}{Z_2} V_{in}$$

- Analyze circuit.
- Do you see the voltage divider?
- What is the input impedance?



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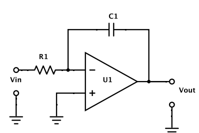
Integrator

$$V_{out} = -\frac{Z_1}{Z_2} V_{in} = -\frac{1/j\omega C_1}{R_1} V_{in} = -\frac{1}{jR_1C_1\omega} V_{in}$$

- What is the time-domain version?
- How do you set initial condition?
- How do you reset?



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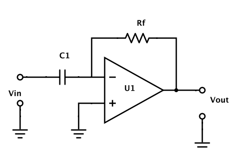
Differentiator

$$V_{out} = -\frac{Z_1}{Z_2} V_{in} = -\frac{R_1}{1/j\omega C_1} V_{in} = -\left(jR_1C_1\omega\right) V_{in}$$



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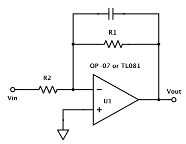
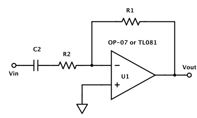
Filters – LP, HP

$$\frac{V_{out}}{V_{in}} = H(j\omega) = -\frac{R_1/R_2}{1 + j\omega R_1 C_1}$$



$$\frac{V_{out}}{V_{in}} = H(j\omega) = -\frac{j\omega R_1 C_2}{1 + j\omega R_2 C_2}$$



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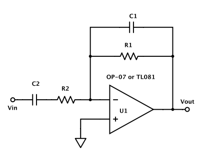
Filters – BP

$$H(j\omega) = \frac{-j\omega R_2 C_1}{\left(1 + j\omega R_1 C_1\right)\left(1 + j\omega R_2 C_2\right)}$$



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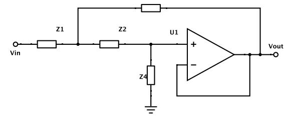
A Step Up – Sallen & Key

$$\frac{V_{out}}{V_{in}} = \frac{Z_3 Z_4}{Z_1 Z_2 + Z_3\left(Z_1 + Z_2\right) + Z_3 Z_4}$$



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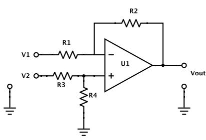
Difference Amplifier

$$V_{out} = \left(\frac{R_4}{R_3 + R_4}\right)\left(\frac{R_1 + R_2}{R_1}\right)V_2 - \left(\frac{R_2}{R_1}\right)V_1$$

If $R_3 = R_1$ and $R_4 = R_2$ then $V_{out} = \frac{R_2}{R_1}\left(V_2 - V_1\right)$



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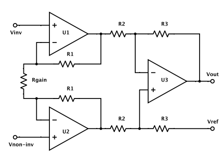
Instrumentation Amplifier

$$V_{out} - V_{ref} = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2}\left(V_{non-inv} - V_{inv}\right)$$

- Set gain with R_{gain}.
- V_{ref} must be a low-impedance source.
- Never make one. Use a commercial one.



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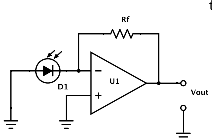
Transimpedance Amp

$$V_{out} = iR_f$$

- If V_{out} has the wrong sign, flip the diode.
- The far side of the photodiode can be tied to V_{bias} instead of ground.



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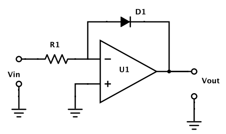
Logarithmic Amp

$$V_{out} = -V_T \ln\left(\frac{V_{in}}{i_s R_1}\right)$$

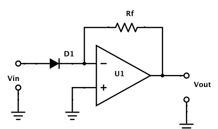
V_T and i_s are diode properties.
- Thermal voltage
- Saturation current



Exponential Amp

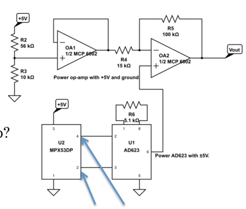
$$V_{out} = -R_1 i_s \exp\left(\frac{V_{in}}{V_T}\right)$$

V_T and i_s are diode properties.
- Thermal voltage
- Saturation current



What Does It Do?

- What does the first voltage divider do?
- Can you find the unity gain buffer?
- Where is the instrumentation amp?
- Can you find the modified difference amp?
- What are G and K?
- Don't use a circuit you don't understand.



$$V_{out} = G(V_2 - V_4) + K$$

LabVIEW File Naming Convention:

- Your file name should be (Last Name)_(First Initial)_A(Assignment Number)_S(Section Number).(vi or llb). For example, if I were Greg Lake in Section 4 and I was turning in Assignment 3, my file would be named Lake_G_A3_S4.llb. **If your file does not have the correct naming convention, it will not be graded.**

Professors have asked that you submit lab reports as PDF files. There are too many Mac/Win formatting battles to submit Word files.

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