Operational Amplifier Circuits

We have built voltage and current amplifiers using transistors. Circuits of this kind with nice properties (high gain and high input impedance, for example), packaged as integrated circuits (ICs), are called **operational amplifiers** or op amps. They are called ``operational'' amplifiers, because they can be used to perform arithmetic operations (addition, subtraction, multiplication) with signals. In fact, op amps can also be used to integrate (calculate the areas under) and differentiate (calculate the slopes of) signals.

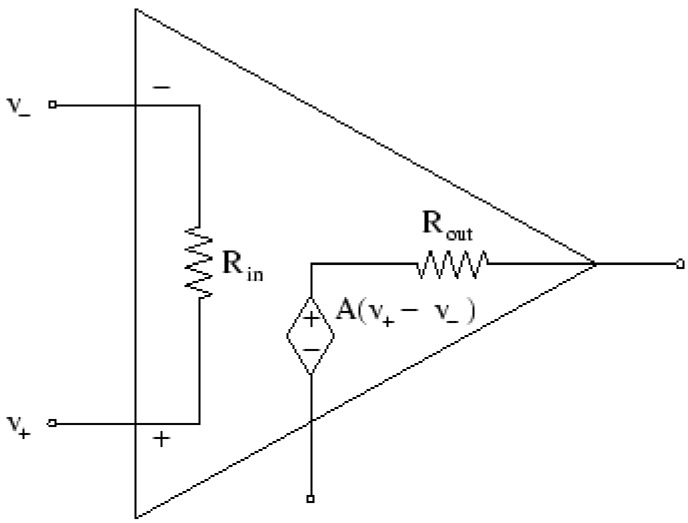

Figure 22: A circuit model of an operational amplifier (op amp) with gain A and input and output resistances R_{in} and R_{out}.

A circuit model of an operational amplifier is shown in Figure 22. The output voltage of the op amp is linearly proportional to the voltage difference between the input terminals $v_+ - v_-$ by a factor of the gain A. However, the output voltage is limited to the range $-V_{CC} \leq v \leq V_{CC}$, where V_{CC} is the supply voltage specified by the designer of the op amp. The range $-V_{CC} \leq v \leq V_{CC}$ is often called the **linear region** of the amplifier, and when the output swings to V_{CC} or $-V_{CC}$, the op amp is said to be **saturated**. The output ranges of the amplifiers we built as part of Lab 3 were similarly limited by the supply voltage.

An ideal op amp has infinite gain ($A = \infty$), infinite input resistance ($R_{in} = \infty$), and zero output resistance ($R_{out} = 0$). You should use these two assumptions to analyze the op amp circuits covered in the assignments below. A consequence of the assumption of infinite gain is that, if the output voltage is within the finite linear region, we must have $v_+ = v_-$. A real op amp has a gain on the range 10^3 - 10^5 (depending on the type), and hence actually maintains a very small difference in input terminal voltages when operating in its linear region. For most applications, we can get away with assuming $v_+ \approx v_-$.

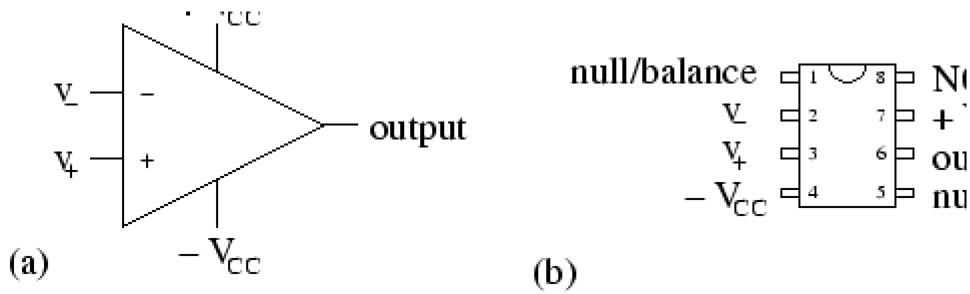

Figure 23: (a) Schematic symbol for an op amp. (b) Connection diagram for the LM741 and LF411 8 pin dual inline packages (DIPs). We will not make use of the null (LM741) / balance (LF411) pins. Pins labeled NC are not connected to the integrated circuit.

We will use two operational amplifiers in our laboratory exercises, the LM741, a general purpose bipolar junction transistor (BJT) based amplifier with a typical input resistance of 2 MΩ, and the LF411, with field effect transistors (FETs) at the inputs giving a much larger input resistance (10^{12} Ω). Detailed data sheets for these devices are available for dowload at the National Semicondictor web site (www.national.com). Of the two, the LF411 comes closest to satisfying our two assumptions associated with ideal op amp behavior. It costs more than the LM741 (a whopping $0.61 vs. $0.23 as of spring 2001). The schematic symbol for an op amp and the connection diagram for the chips, called dual inline packages (DIPs), we will be using are shown in Figure 23.

Assignment

The inverting amplifier (4.1) and Schmitt trigger (4.8) are mandatory for everyone. Of the remaining circuits, choose at least 4. Whether you use a LM741 or LF411 op amp is up to you, but in at least one circuit, compare the two. For all circuits and both kinds of op amp, $V_{CC} = 15$ V.

Inverting Amplifier

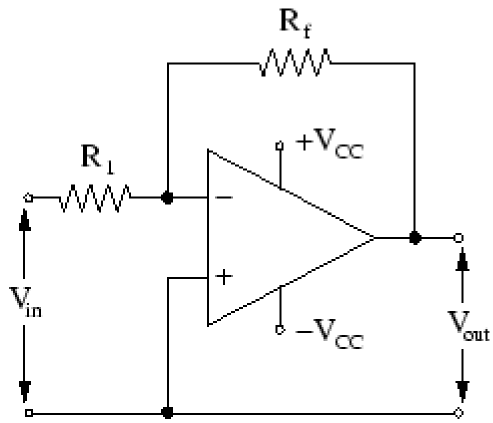

Figure 24: Inverting amplifier circuit.

An inverting amplifier circuit is shown in Figure 24.

1. Show that the gain of the amplifier is

$$A = -\frac{R_f}{R_1}. \tag{18}$$

2.

3. Build the circuit, and check your prediction experimentally for gains of 10 and 100.
4. Measure the bandwidth (the difference between the upper and lower 3 dB points) of the amplifier for each gain. The product of the gain and bandwidth should be constant. Is it?
5. Check the linearity of the amplifier for each gain over its useful frequency range.
6. Measure the input impedance of the amplifier by placing various resistors in series with the source. Explain your result.

Noninverting Amplifier

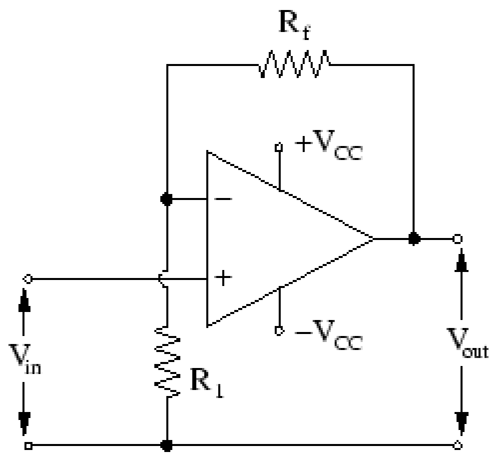

Figure 25: Noninverting amplifier circuit.

A noninverting amplifier circuit is shown in Figure 25.

1. Show that the gain of the amplifier is

$$A = \frac{R_1 + R_f}{R_1}. \tag{19}$$

2.

3. Build the circuit, and check your prediction experimentally for gains of 10 and 100.
4. What is the input impedance of the amplifier?

Voltage Follower

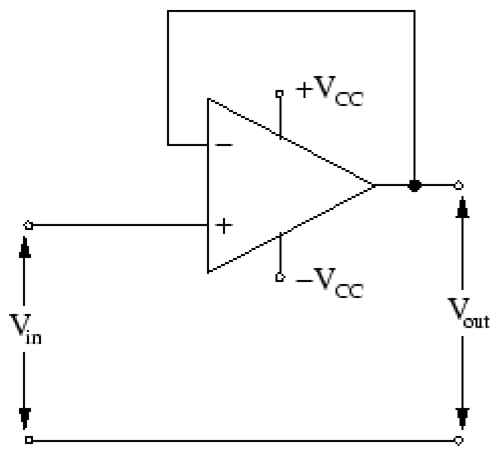

Figure 26: Voltage follower circuit.

A voltage follower circuit is shown in Figure 26.

1. What's the point?
2. What is the input impedance of the amplifier?
3. Build the circuit, and use it to improve the input impedance of an inverting amp.

Differential Amplifier

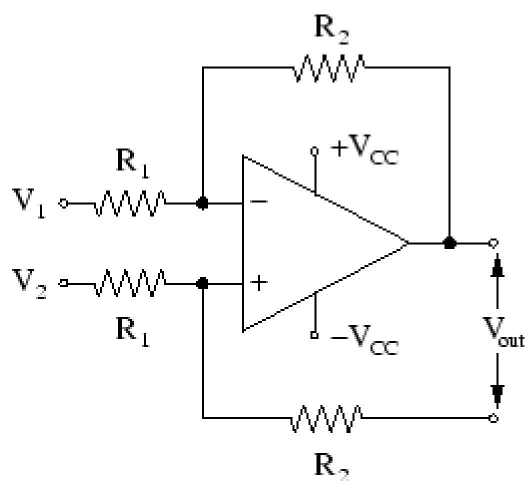

Figure 27: Differential amplifier circuit.

A differential amplifier circuit is shown in Figure 27.

1. Show that the output signal of the amplifier is

$$V_{out} = -\frac{R_2}{R_1}(V_1 - V_2). \tag{20}$$

2.

3. Build the circuit, and check your prediction experimentally for a gain of 10.
4. Measure the input impedance of the amplifier by placing various resistors in series with the source. To measure the impedance of one terminal, drive it with a small signal through a resistor and ground the other. Explain your result.

Summing Amplifier

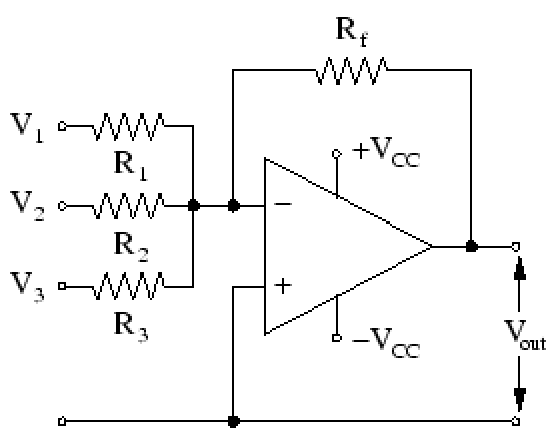

Figure 28: Summing amplifier circuit.

A summing amplifier circuit is shown in Figure 28.

1. Show that the output signal of the amplifier is

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) \tag{21}$$

2.

3. Build the circuit, and check your prediction experimentally for a gain of 10.

4. Measure the input impedance of the amplifier by placing various resistors in series with the source. To measure the impedance of one terminal, drive it with a small signal through a resistor and ground the other. Explain your result.

Integrator

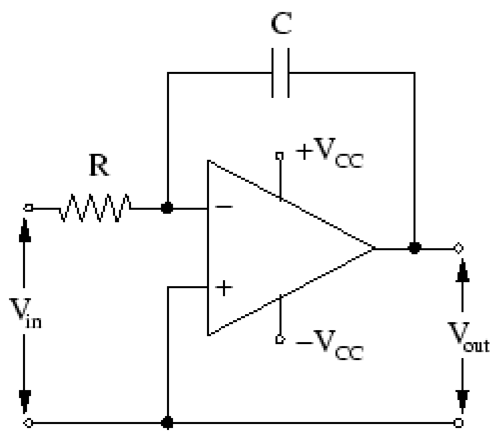

Figure 29: Integrator circuit.

An integrator circuit is shown in Figure 29.

1. Show that the output signal of the amplifier is

$$V_{out} = -\frac{1}{RC}\int V_{in}\,dt. \tag{22}$$

2.

3. Build the circuit with $R = 10$ kΩ, $C = 0.1$ μF and use square and sinusoidal wave forms to test the predicted behavior. Also place a 100 MΩ resistor in parallel with the capacitor. This resistor drains charge to avoid saturation due to very low frequency or DC signals.

Differentiator

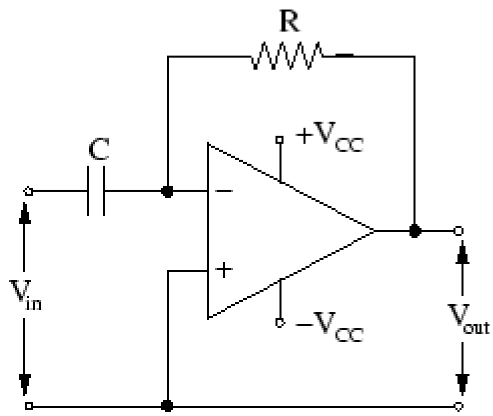

Figure 30: Differentiator circuit.

A differentiator circuit is shown in Figure 30.

1. Show that the output signal of the amplifier is

$$V_{out} = -RC\frac{dV_{in}}{dt}. \tag{23}$$

2.

3. Build the circuit with $R = 10\ \mathrm{k}\Omega$, $C = 0.1\ \mu$F and use triangle and sinusoidal wave forms to test the predicted behavior.

Schmitt Trigger

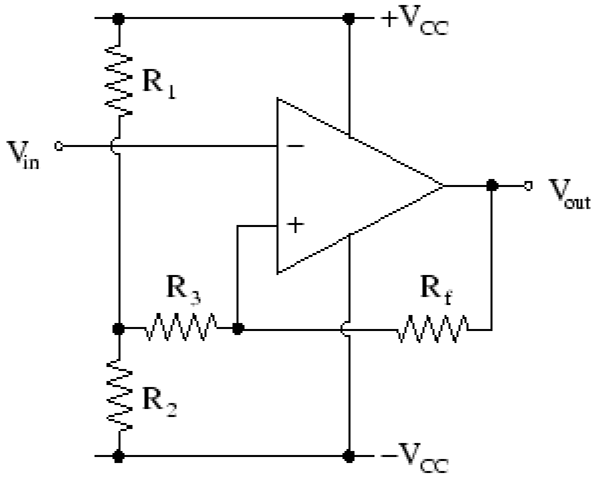

Figure 31: Schmitt trigger circuit. V_{out} and V_{in} are relative to ground, or some reference between $-V_{CC}$ and $+V_{CC}$.

A Schmitt trigger circuit is shown in Figure 31. The analysis is not difficult. It is, however, tedious. The R_1, R_2 voltage divider sets the rough neighborhood of the trigger thresholds. R_3 controls the hysteresis of the switch (the difference between the ``turn on" and ``turn off" thresholds). The feedback resistor R_f should be a factor 10-100 larger than the voltage divider resistors. Otherwise, it drags the thresholds apart.

1. Predict the ``turn on" and ``turn off" thresholds for $R_1 = 1$ kΩ, $R_2 = 2.2$ kΩ, $R_3 = 2.2$ kΩ, and $R_f = 100$ kΩ. Rather than finding a general expression, it's fine to consider this particular case. For the analysis, assume a maximal output voltage swing of ± 13 V. This actually varies with each op amp, but should not be far from the truth.
2. Build the circuit, using the resistance values given above. Measure the input thresholds of the trigger and compare with your predictions.

Source:
**http://webpages.ursinus.edu/lriley/ref/circuits/node5.html#SECTION00058000000000000
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