Physics 3150, Laboratory 7
Op Amp Circuits
March 7 and 9, 2016

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Last revised by Ed Eyler, March 3, 2016

Purpose:

1. To understand the operation of op-amps in negative feedback circuits.
2. To explore a few useful and interesting op-amp circuits, including some of the most common configurations.
3. To observe the effects of a few of the limitations of real op amps, specifically the input bias current and the output slew rate limit.

References:

Chapter 6 of Eggleston. For additional material see Chapter 6 of Meyer, and for a wealth of detail see Chapters 4, 5, and 6 of Horowitz and Hill (3rd Edition).

Equipment:

1. Signal generator.
2. Oscilloscope.
3. Breadboard with power supplies and hookup wire.
4. A selection of 1/4W resistors, trimmer potentiometers, and small capacitors.
5. Coaxial cables with BNC connectors and banana plug adaptors.
6. LF411 op-amps. A data sheet is available on the course web page.
7. Silicon PIN photodiodes suitable for use in photoconductive mode, such as the inexpensive but capable PDB-C156 from Photonic Detectors.
8. 2N3904 and 2N3906 transistors.

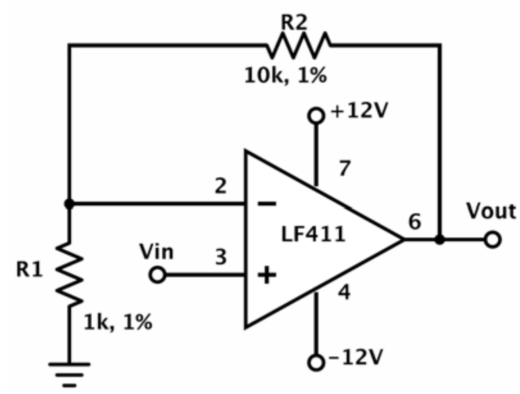
For all of the op amp labs, you can use ±12V or ±15V supplies interchangeably, so long as you remember that the maximum output swing will be altered correspondingly. Note that the power connections to chips like the LF411 are often implied and not indicated explicitly — here, they are shown only in the schematic diagram for Part I.

It's assumed that you are already familiar with the basic inverting amplifier configuration, since it appeared as part of Lab 6.

I. Non-inverting Amplifier

Build the amplifier circuit shown in the sketch, using $R_1 = 1\ k\Omega$ and $R_2 = 10\ k\Omega$. Note that the power supply pins are shown here, but are frequently omitted in schematic diagrams.

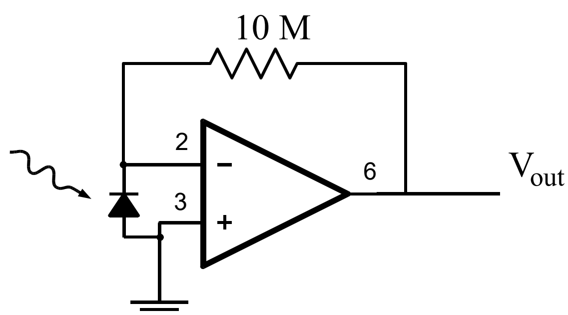
1) Measure the gain for various dc voltages, and compare it to what you expect.
2) Apply a fairly large 10 kHz square wave to V_{in}, perhaps about 750 mV peak-to-peak, but not so large that it saturates the output voltage. Look at both the input and output on the oscilloscope using an expanded time base, and note that the output is slower to turn on or off, with an initially linear slope that's called the large-signal *slew rate* of the op amp. Measure the approximate slope in V/μs and compare it to the output characteristics listed in the LF411 data sheet, available on the course web page.



3) What might you expect for the input impedance of this amplifier? Place a 1 MΩ resistor in series with the input. You won't be able to measure the input impedance, but you will be able to measure the input capacitance, C_{in}. Find the frequency of the 3-db point and use this to find C_{in}.

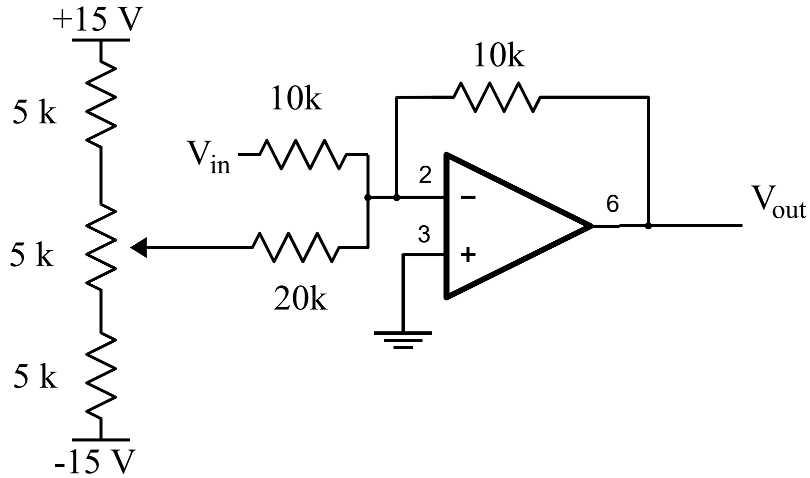
II. A "transimpedance" amplifier for photodiodes and other current sources

Build a circuit that converts a photodiode current to an output voltage: Use a silicon "PIN" photodiode, such as type PDB-C156 from Photonic Detectors, Inc. The data sheet is posted on the Physics 3150 web page.



1) Block and unblock the photodiode with your hand and watch the output voltage. If there is enough light that the op amp saturates at its maximum dc output voltage, replace the 10 MΩ resistor with a 1 MΩ resistor and try again.
2) With the photodiode unblocked, the output signal will probably be slightly modulated at one or more frequencies. What frequency or frequencies are present? Why is this?
3) Disconnect the photodiode and restore the 10 MΩ feedback resistor if you switched it out. A very small output voltage can still be measured with a DMM. This is due to a combination of the *input bias current* and the *input offset voltage* at the inverting input. To separate them, replace the feedback resistor with a 100 kΩ resistor. The output is now a direct measurement of the offset voltage, since the bias current now produces too little voltage across the resistor to be measurable. By comparing the two measurements, calculate the approximate input bias current. Is it consistent with the bias current listed on the LF411 data sheet?

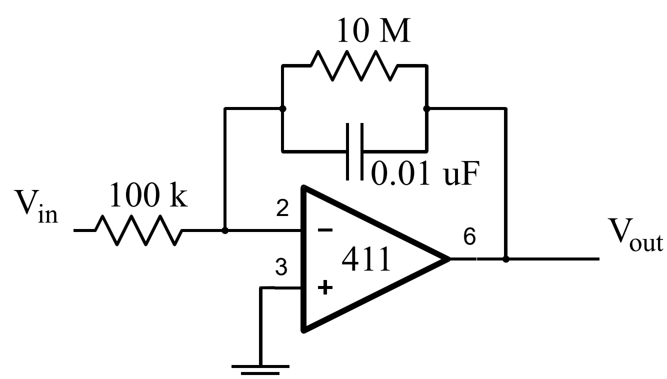
III. Summing amplifier



This is an *extremely* common configuration for op amps in general, especially for scientific instrumentation. In this particular case, the variable resistor provides a variable DC offset.

1) Measure the ac gain on a 1 kHz sine wave applied to V_{in}. Is the gain what you expect?
2) Apply a dc voltage from the voltage divider to the 20 k resistor. What effect does this have on the output? Measure the dc gain by varying the applied voltage using the 5kΩ potentiometer, and compare with the gain calculated from the resistor values.

IV. Integrator



Build the following integrator circuit:

1) Drive the circuit with a 1 kHz sine wave. Record the input amplitude and the output amplitude. Also, measure the phase shift between the input and the output.
2) Drive the circuit with a square wave and a triangle wave and describe the output.
3) Introduce a small dc offset on the input wave. Can you see why the 10 MΩ resistor in parallel with the capacitor is needed? Try removing it and see what happens.

Questions for Part IV:

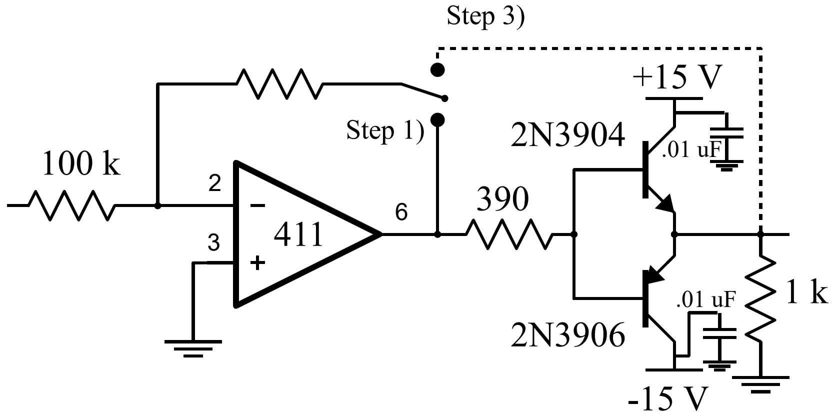
1) Show in detail what the relationship should be between the input and output. Do your

measurements agree?

2) Explain carefully what the phase shift should be. In particular, does the output lead or lag the input? Does this agree with your measurement?
3) Qualitatively explain the output waveforms for the square and triangle waves.
4) Provide a likely explanation for the behavior you saw when the 10 MΩ resistor was removed.

V. (If time permits) High-power Push-pull "buffer"

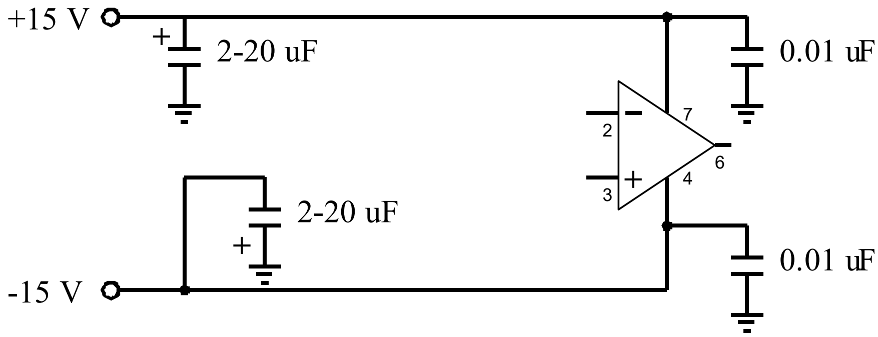
If you still have some time left, build the following circuit, with a feedback resistor in the range 100kΩ–500kΩ, depending on the gain you prefer to use.



1) After reading the "Important notes" below, build the circuit and drive it with a sine wave with an audio frequency (around 400-500 Hz) and several volts in amplitude. Look at the output of the op amp and the output of the transistors. Describe (or photograph!) what you see. The output of the transistor pair shows typical "crossover" distortion.
2) Listen to the output on a speaker. Note that the speaker cannot handle more than about 2 $V_{p\text{-}p}$. How "pure" a tone do you get?
3) Connect the right side of the feedback resistor to the output side of the transistors (dotted line in the circuit diagram). Does the tone sound better? Also, look at the output on the oscilloscope and see how the signal has changed.

Important notes:

(1) This circuit has no output protection. In a practical application, elaborations would often be added to provide better protection against shorts or thermal instability
(2) There's a fairly good chance that your circuit will spontaneously oscillate at high frequencies, particularly when the load is purely resistive. This is an example of unwanted *positive feedback*, in this case via the ground and power supply lines. It's a very common problem. Voltage drops develop on the ground wiring because of its finite resistance, causing time-varying signals on the positive op amp input on pin 3. The problem can be alleviated by slowing down the circuit, by adding a small capacitor in parallel with the feedback resistor, but it's not always acceptable to always have to intentionally degrade the performance of your designs.



Bypass capacitors: best used both on entry to a circuit board and near the individual op-amp chips.

A better solution is to use *bypass capacitors*, as indicated in the figure. You can think of them as small "temporary batteries" that supply the power needed for fast changes of the output, so the currents on the ground and power supply lines will change more slowly and with much smaller peak excursions. A good rule of thumb is to use at least one pair of high-value electrolytic capacitors, a few μF or more, for each circuit card, and additionally to use a pair of 0.01 μF ceramic capacitors located physically adjacent to each integrated circuit. In the present case, since we are using low-frequency circuits, the electrolytics alone will probably suffice.

Questions for Part V (if it was part of the lab for you):

1) In the original circuit, explain the difference between the op amp output and the transistors' output.
2) Why did the tone sound the way it did?
3) Why did moving the feedback point change the results?