Lab 9: Operational amplifiers II (version 1.6)

WARNING: Use electrical test equipment with care! Always double-check connections before applying power. Look for short circuits, which can quickly destroy expensive equipment.

Summary

An introduction to the operational amplifier and basic signal amplification circuits II.

Learning Outcomes

- Understand slew rate and gain-bandwidth product of amplifiers.
- Build an integrating amplifier using op amps.
- Build band-pass filter using op amps.

Lab Goals

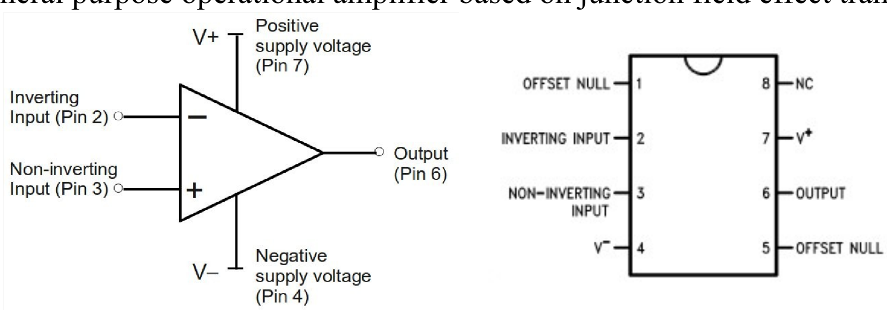
Build and study an inverting amplifier, an integrator, and a bandpass filter.

Experiment/Procedure

In this lab, you will measure the gain-bandwidth product and the slew rate of an amplifier. Then you will build an integrator and a bandpass based on opamps.

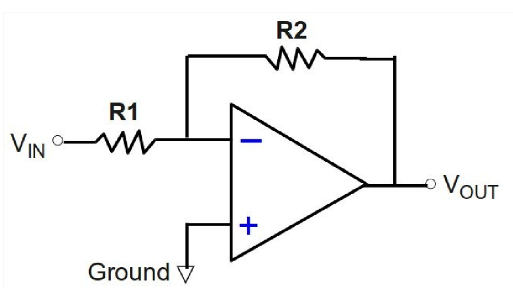
LM741 and LF411 Op-amps

The LF411 is a general purpose operational amplifier based on junction field effect transistors (JFETs).



Gain-bandwidth product

The inverting amplifier (studied in Lab 8) has a gain of $V_{OUT}/V_{IN} = -R2/R1$ (minus sign indicates a π phaseshift).



This formula suggests that any amount of gain can be attained by adjusting the resistor ratio, independently of the operating frequency. This is, however, in acute contrast with real devices. The gain-bandwidth product of an op-amp characterizes its ability to provide the desired gain at a chosen operating frequency. This number is listed on the manufacturer's specification sheet. For example, an op-amp with gain-bandwidth product of 1 MHz can provide a *maximum* gain as shown in the following table:

Frequency	**Maximum gain**
1 MHz	1 (0 dB)
100 kHz	10 (20 dB)
20 kHz	50 (34 dB)
5 kHz	200 (46 dB)

Notice that the gain-bandwidth product is a constant and limits the gain that can be achieved at a given frequency. For example, this op-amp would not be able to amplify more than 10x at 100 kHz.

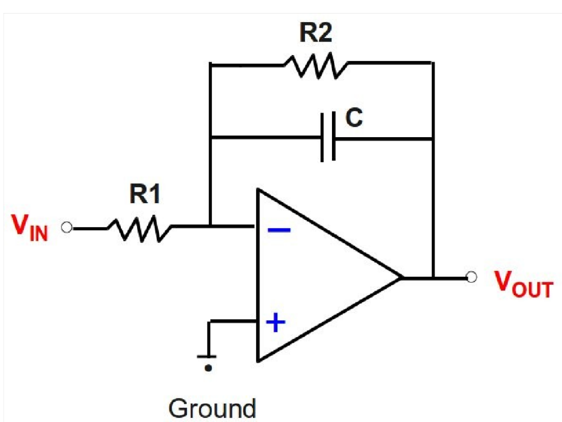
Find the gain-bandwidth product of the LF411. Build the above circuit (with the same parameters as in Lab 8). Investigate the gain of the circuit with a given R1 and R2 (V_{OUT}/V_{IN}) as a function of frequency. Observe how the gain decreases as you increase the frequency (just like in a low-pass filter but *without* any external capacitor present in the circuit). The gain should exhibit a sharp rolloff/reduction from the nominal value of **G=−R2/R1** at sufficiently high frequencies. In the high frequency range, you can determine the gain-bandwidth product of the op-amp at several frequencies. Report your results with plots/tables, compare with expected values, and discuss in your lab notebook.

Slew rate:

Another practical issue with op-amps is that they cannot reach an arbitrary output voltage infinitely fast. This limitation is called slewing. Slewing of an op-amp can be observed using a fast square-wave voltage input V_{IN}. Monitor V_{IN} and V_{OUT} on the scope. Adjust the input voltage (below the supply voltage), frequency, and gain as necessary to cause the output waveform to deviate from an ideal square wave. The slope of the leading edge of the output waveform defines the slew rate, expressed in Volts per μs. Measure the slew and compare with manufacturer data.

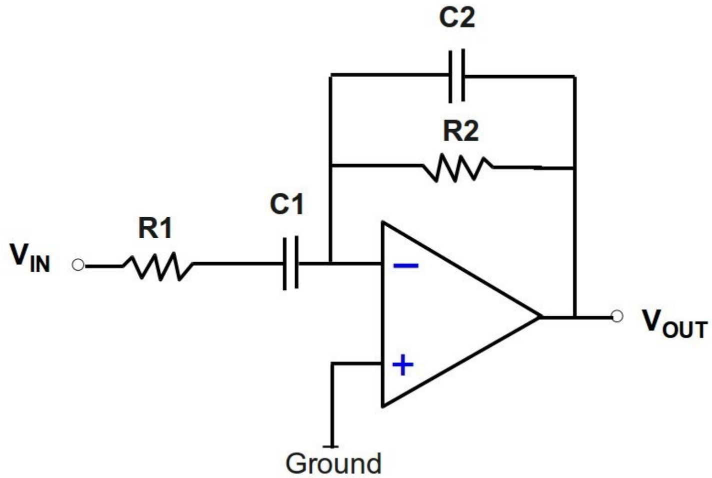
Low-pass filter (integrating amplifier)

Build the following circuit with R1 = R2 ~5 kΩ and C ≈ 10 nF. Input a sine wave in V_{IN} and scan the frequency from 100 Hz to 20 kHz. Confirm that you have low-pass filter behavior. Record data for the response V_{OUT}/V_{IN} (~10 different frequencies or more), and compare with the theoretical model using the response function for this circuit.



Band-pass filter

The band-pass filter combines the characteristics of the low- and high-pass circuits. Modify the low-pass amplifier by building the following circuit with: R1 ≈ 500 Ω, R2 ≈ 5 kΩ, C1 ≈ 100 nF, and C2 ≈ 22 nF (use disc ceramic capacitors if available). Do not stay too far (> 25%) from these specified values or the circuit may not function as a band-pass filter.



Obtain phase and amplitude data to build the Bode plot for frequencies from 100 Hz to 10 kHz (~10 different frequencies). You should see distinctly different behavior in both amplitude and phase compared to the low-pass filter. Obtain the theoretical response function for this circuit. Compare your results with the theoretical model for the specific values and discuss.

Analysis

The required elements of the analysis for the different circuits are already discussed in each part. I
In your lab notebook describe the experimental procedure with diagrams and plots, when necessary, discuss results, analysis, and comparison with theory. Below there are more details about the analysis:

Analyze the data of the low-pass and band-pass amplifiers by providing model curves for the voltage amplitude and phase. Recall that the response function is a complex number (G) that depends on the feedback impedance (Z_F) to the input impedance (Z_{IN}). For an ideal op-amp: $V_{OUT} = -(Z_F/Z_{IN})\ V_{IN}$.

Make four plots (2 for each circuit) showing amplitude (dB) and phase (degrees) as a function of frequency (on a log-10 scale) to compare with your data. Provide your formulas and their derivations for G for both circuits. Explain clearly your reasoning.