Physics 323

Experiment # 3 - Op-Amps I (Negative Feedback)

Introduction

Negative feedback is one of the most important concepts in this course. Operational amplifier circuits use negative feedback to achieve predictable output over a wide range of inputs. We will be using the ubiquitous '741' op-amp.

References: *Electronics 4e* pp. 252-254, 257-267, 275-282, 285-288

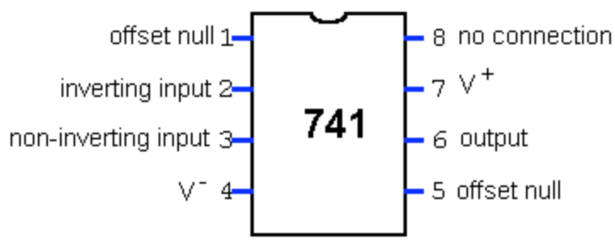
Prelab

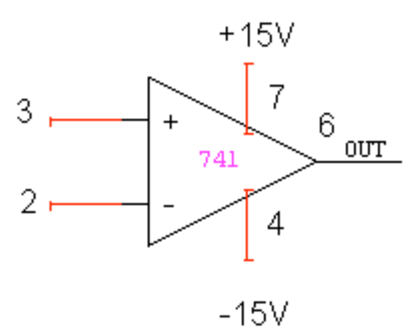
List the output impedance, Z_{out}, the input impedance and, Z_{in}, and the open loop voltage gain, A_{VO}, for an ideal operational amplifier.

Lab

The 741 is an integrated circuit that is composed of various transistors, resistors, and capacitors. (See page 3-257 of the 1982 version of *National Semiconductor Corporation Linear Databook.*) When the power supply connections are made it is designed to act as an ideal differential operational amplifier at low frequencies. In keeping with the top-down approach of our course do not concern yourself with "how" the internal circuitry of the 741 works but instead focus on the 741 as a whole.

It comes in a dual in-line package (DIP or DIL) and should be inserted in the breadboard straddling a "channel". The "notch" (and sometimes a dot) enables us to identify the pin numbers. The figure below on the left gives the pin assignments you need to make the actual connections. The figure below on the right gives the differential amplifier circuit element, repeating the numerical pin assignments.

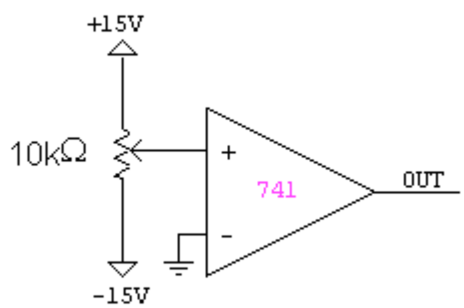




The V+ and V- connections in the figure on the left *are not* the + and – input connections! They are connected to +15 V and -15 V that you provide from the DC power supplies. In most op-amp circuit diagrams the V+ and V- power supply connections are not shown but they are implied (in the same way I assume you have plugged the CRO into the wall!) Sometimes the supply connections are labeled as V_{CC} and V_{EE} for the collector supply voltage and emitter supply voltage (the collector and emitter are parts of the transistors that are internal to the 741). + and – are shown and are the non-inverting and inverting inputs of the differential amplifier. Unfortunately these are often given the labels V+ and V-, especially in formulas. Just pay attention and there should be no confusion. There is a ground connection to each of the supplies (which isn't shown at all) and this becomes the reference ground for the output. We aren't using the "offset null" on pins 1 and 5.

(1) Open-loop gain

To verify the very large open-loop gain examine the behaviour of the following circuit.



You are connecting the middle pin of a 10 kOhm potentiometer to the non-inverting input. The potentiometer acts as a voltage divider between the +15 V and -15 V (which you just get from the power busses). With line triggering you can use the CRO in dual mode to monitor the DC voltage at the non-inverting input and the output simultaneously. (Alternately you could use the DMM to monitor either the input or output voltage.) In principle $V_{OUT}=A(V_{non\text{-}inverting}-V_{inverting})$. Try to get zero output voltage! Can you estimate the voltage on the non-inverting input when the output swings? (This is usually called "going to rail".)

Just try connecting the non-inverting and inverting inputs together to try and get zero output. Op-amps have some small *input offset voltage* so even when the differential inputs are at the same voltage there is some output voltage. The above formula would be modified and the amplifier is of limited use in an open-loop configuration.

(2) Simple amplifiers

Prelab

Design amplifiers with gains of -8 and +14. Use resistors in the range of 1 to 100 kΩ. Remember not all resistors are available! (There is a listing under "Supplies" on the course website.) You should be able to come within 5% of the desired gain. Draw labeled circuit diagrams.

Lab

Build
(a) An inverting amplifier with a gain of -8
(b) A non-inverting amplifier with gain of 14

Verify the operation of the above circuits using a 1 kHz sine wave as input with various input amplitudes between about 20mV and 2V. (In order to reach the small input voltages you will need to use the '-20 dB' attenuation controls on the function generator. One is activated by a button and the other by pulling on the knob that controls amplitude.) Can you observe a chopping distortion of the output? For circuit (b) investigate what happens at an input frequency of 100 kHz. (Use an input signal amplitude that is small enough that the output is not chopped at 1 kHz.) Is there a change in phase as well?

(3) Integrator

Prelab

Draw the circuit for the integrator using the values below. What is the time constant for this integrator?

How would a large resistor in parallel with the capacitor compromise the integrator's performance? (Hint: try and think of how impedances change with frequency in resistors versus capacitors.)

Lab

Build an integrator using a 10 kΩ resistor and a 1 μF capacitor. You may have to prevent the output from "sailing-off" to one of the rails due to the input offset voltage. (It is integrating a constant.) Prevent this by putting a large resistor (~1 MΩ) in parallel with the capacitor.
Examine the behaviour of the circuit with a triangle wave, square wave and a sine wave at f= 100 Hz. Do you get the expected magnitude of the output signal for the square wave? Increase the frequency to see if you get a filtering effect.

(4) Differentiator

Using a 0.01 μF capacitor and a 100 kΩ resistor build a differentiator (swap the positions of the capacitor and the resistor versus the integrator.) Examine its behaviour with triangle and square waves. You should see the differentiating behaviour but also "ringing" in the circuit. What is the frequency of the ringing? To damp the ringing add a 1 kΩ resistor in series with the 0.01 μF capacitor.

Does this improve performance? Any idea why it might?

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