ELEG 309 Laboratory 1

OPERATIONAL-AMPLIFIER BASICS and BEYOND

February 14, 2000

1 Objectives

The primary objective of this experiment is to familiarize you with basic properties and applications of the integrated-circuit operational amplifier, the op-amp, one of the most versatile building blocks currently available to elcctronic-circuit designers. The emphasis will be primarily on the nearly ideal, on what is easily and conveniently done.

2 Components and Instrumentation

Your concentration will be on the 741-type op amp provided, one per IC, in an 8-pin dual-in-line (DIP) package whose schematic connection diagram and packaging are shown in Fig. 1. For power, you will use two supplies, +10 V and -10 V, or ±10 V for short. As well, you need a variety of resistors and capacitors, with emphasis on ones simply specified: 1kΩ, 10kΩ, 100kΩ, 1MΩ, 10MΩ and 0.1μF, 0.01μF, 1nF, and the like. Note that it is important to bypass the two power supplies directly on your prototyping board, using, for each supply, a parallel combination of a 100μF tantalum or electrolytic capacitors, and a or 0.1μF low-inductance ceramic capacitor. For measurement, you will use a digital multimeter (DMM) with ohms scales, a two-channel oscilloscope, and a waveform generator.

3 Reading

Sections 2.1 through 2.6 of the Text are related directly to this Experiment. While not all issues discussed there are explored here uniformly, broad familiarity with them will allow you to identify areas for concentrated reading as the need arises. The order of coverage here closely follows that in the Text.

4 Preparation

As the name implies, Preparation is intended to help familiarize you with the experimental work to follow. Ideally, by raising questions about the specific circuits you will later explore, it will help you in thinking about the experiments you will perform, and the results you will obtain, *as you proceed.* Note the emphasis! An experiment can (and should)

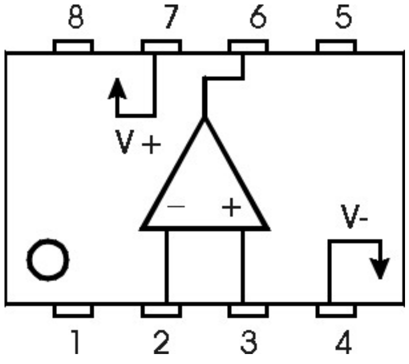

Figure 1: Op-Amp Package and Pin Connections

be a process of active discovery, one in which thinking and doing are conjoined; in short, a process of ”hypothesis and test”. Otherwise, treated procedurally, without the mind ”in gear”, so to speak, blind laboratory measurement is work for slaves, not for the master you wish to become!

For you convenience, the Preparation directions will be numbered to correspond to sections of the Explorations following. You will note that, in general, quite a lot of Preparation work is specified. Sometimes, depending on your other assignments, will not have enough time to do it all. However, it is presented to pique your interest, and to inform you of some aspect of the direction in which the practical exploration will go. Of course, you can prepare by simulating some of the Explorations with PSPICE, or using “Electronics Workbench.” Unless otherwise specified, in what follows, assume all op amps to be ideal.

4.1 The Inverting Amplifier

4.1.1 DC Voltages and Gain

- For the inverting amplifier circuit to the right of node B in Fig. 2, what is the expected closed-loop gain (as measured from node B to, node D)? What is the input resistance to the right of node B?
- For the test adapter shown to the left of node B, and employing resistors R_a and R_b, what voltage is produced at node B, for a node A input of +10V? –10V? Ignore the loading effect of R_1.

4.1.2 Quick Changes of Gain

Design an op-amp circuit with an input resistance of 1kΩ and a gain of -5 V/V. What are the values of R_1 and R_2 you have chosen?

4.1.3 AC Gain and Overload

For the situation described 5.1.3, with R_a reduced to 100Ω, calculate the gain from node A to node D.

4.1.4 Virtual Ground

- Consider the basic inverting op-amp circuit shown at the right of Fig. 2, with a 91 mV peak signal applied at node B. For an ideal op-amp, what signals would you measure at nodes C, D ?
- For an op-amp with an open-loop gain of 1000 V/V and the same output at node D as found above, what would the voltage at node C become? In this situation, for what value of resistor shunted from node C to ground does the current in R_2 (and thus the voltage at node D) reduce by 10%?

4.1.5 Output Resistance

An op-amp circuit whose output is 1.0 V peak with no load reduces by 15 mV when it is loaded by a 100Ω resistor. Estimate the output resistance of the circuit.

4.2 The Non-inverting Amplifier

4.2.1 DC Voltages and Gain

Using an ideal op-amp, design a non-inverting amplifier with gain of +11 V/V having low currents in the associated resistor network, but with no resistor larger than 10kΩ.

4.2.2 Quick Changes of Gain

What is the gain of the circuit in Fig. 3, from node B to node D, with R_1 shunted by a resistor of equal value? With R_2 shunted likewise? With R_2 shorted?

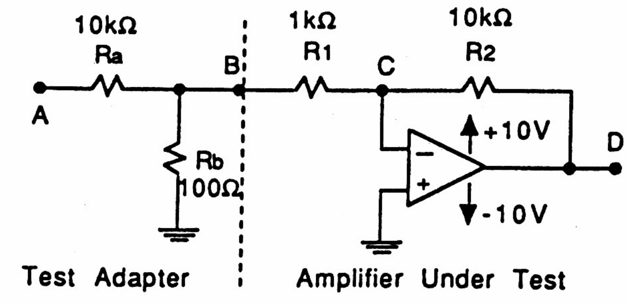

Figure 2: Basic Inverting Amplifier with Input Attenuator.

4.2.3 AC Gain and Input Resistance

- For an ideal op-amp (having very high gain) in the unity-gain non-inverting amplifier topology, what is the voltage between the + and – input terminals for normal operation? For a 1 kΩ resistor shunting the ± terminals what input current would flow at node B for ±l V signals at the output? What is the corresponding input resistance?
- Repeat the previous item under the condition that the op-amp has an open-loop gain of only 100 V/V.

4.3 A General-purpose Amplifier Topology

4.3.1 Individual Inputs, Difference Gains

Calculate the expected gains for individual inputs A, D, F to output C, of the circuit shown in Fig. 4.

4.3.2 Common-Monde Gains

For what two inputs of the circuit described in 5.3.1, are the gains equal in magnitude?

5 Explorations

5.1 The Inverting Amplifier

5.1.1 DC Voltages and Gain

- **Goal:** To explore the basics of inverting-amplifier operation, and the occurence of virtual ground.
- **Setup:** Note that R_a and R_b form a so-called input attenuator, which allows you to provide relatively small signals at the amplifier input (node B).
  - Assemble the circuit as shown in Figure 2.
  - Adjust the supplies to ±10 V using your DVM.
- **Measurement:** [Use your DVM to measure nodes B, C, D in turn.]
  - Node A -open (or grounded); Measure B, C, D.
  - Node A connected to +10 V; Measure B, C, D.
  - Node A connected to –10 V; Measure B, C, D.
- **Tabulation:** V_A, V_B, V_C for $V_A = 0$ V, 10 V, –10 V.
- **Analysis:** Consider the location of virtual ground. Calculate two estimates of the voltage gain, v_D/v_B.

5.1.2 Quick Changes of Gain

- **Goal:** To practice component shunting as a measurement technique, thereby identifying the role of each element in a circuit.
- **Setup:** Use the circuit as shown in Figure 2, with node A connected to +10 V.
- **Measurement:** [Continue to measure node D with your DVM.]
  - Shunt resistor R_2 by one of equal value to reduce the gain by a factor of 2; Measure D, B.
  - Shunt resistor R_1 by one of equal value to raise the gain by a factor of 2; Measure D, B.
  - Open the connection of R_1 to node B, and add a resistor in series with R_1, of equal value, joined to R_1 at a new node to be called X. Measure nodes D, B, X, C.
- **Tabulation:** R_1, R_2, V_D with V_A, V_B, V_X.
- **Analysis:** Consider the technique introduced above and associated measurements as a way to verify the input resistance of the basic circuit to the right of node B of the unmodified circuit in Figure 2. Calculate the input resistance R_{in} at node B.

5.1.3 AC Gain and Overload

- **Goal:** To explore both linear and non-linear amplifier operation.
- **Setup:** Use the circuit as shown in Figure 2, except with $R_a = 1\text{k}\Omega$ and node A connected to a waveform generator.
- **Measurement:** [Use your two-channel oscilloscope externally triggered from the generator, with one probe on node A and the other on nodes B, C, D in turn.]
  - Adjust the waveform at A for 2 Vpeak (at 1 kHz); Measure B, C, D. Note the peak values and relative phase of the signals.
  - Short-circuit resistor R_a; Measure B, C, D. Note the relationship between the signals at B, C, D, using both probes. Prepare a labelled sketch.
- **Tabulation:** $R_a, v_{bp}, v_{cp}, v_{dp}, v_{Bp}, v_{Cp}, v_{Dp}$
- **Analysis:** Consider the effect of attempting to create signals larger than the amplifier's linear output range. Identify the limiting levels at output and input. Note and explain the changes in voltage at node C, when feedback ceases to operate.

5.1.4 *Output Resistance

- **Goal:** To characterize the low output resistance of a feedback amplifier.
- **Setup:** Establish a setup as in 5.1.3 above (with $R_a = 1\text{k}\Omega$).
- **Measurement:**
  - While displaying node D on your screen, adjust the generator to provide an output of 0.1 V peak. Now, load node D to ground with resistors chosen small enough to lower the output by a barely noticeable amount (1% or so). Expand the channel vertical scale to make this peak-change measurement more convenient. Estimate the output voltage change with load.
  - Use your DVM to measure the load-resistor value.
- **Tabulation:** $v_{d0}, R_L, v_{d1}, \delta v_d$
- **Analysis:** Consider an estimate of the output resistance whose effect you are observing. This output resistance is low because of feedback.

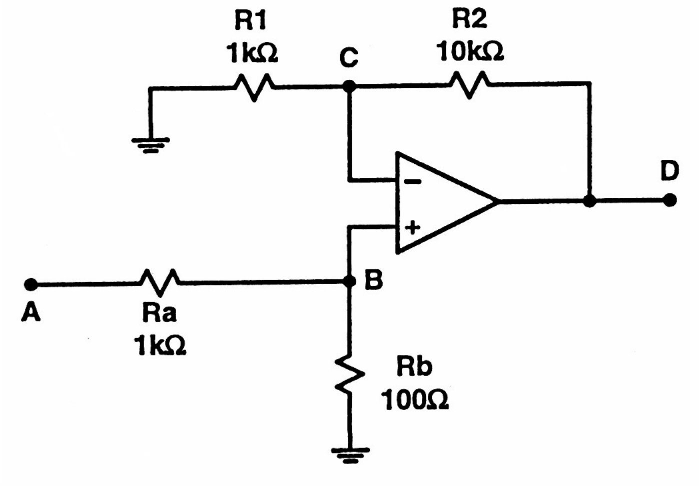

Figure 3: Basic Non-Inverting Amplifier with Input Attenuator.

5.2 The Non-Inverting Amplifier

5.2.1 DC Voltages and Gain

- **Goal:** To explore the basics of non-inverting op-amp operation, and the behaviour of a virtual short circuit.
- **Setup:** Assemble the circuit shown in Figure 3. Adjust the supplies to ±10 V using your DVM.
- **Measurement:** [Use your DVM to measure nodes B, C, D in turn.]
  - Node A open (or grounded); Measure B, C, D.
  - Node B connected to +10 V; Measure B, C, D.
  - Node A connected to -10 V; Measure B, C, D.
- **Tabulation:** v_A, v_B, v_C, v_D for V_A =0 V, 10 V, –10 V.
- **Analysis:** Consider the idea of a virtual short-circuit. Calculate two estimates of voltage gain v_D/v_B.

5.2.2 Quick Changes of Gain

- **Goal:** To become more familiar with shunting as an exploratory technique in electronics, and thereby extend your understanding of the non-inverting amplifier.
- **Setup:** As in 5.2.1 with A connected to +10 V.
- **Measurement:** [Continue to measure node D with your DVM when making the change; then measure node B, C.]
  - Shunt R_2 with a resistor of equal value. Measure B, C, D.
  - Shunt R_1 with a resistor of equal value. Measure B, C, D.
  - Short-circuit R_2. Measure B, D.
- **Tabulation:** v_B, v_C, v_D, R_2, R_1 for various compunations of R_1, R_2.
- **Analysis:** Consider the gain in each case.

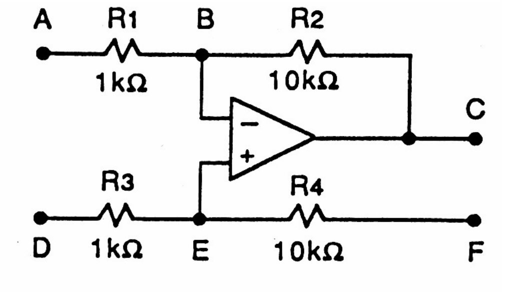

Figure 4: Multi-Purpose Amplifier Tolpology

5.2.3 AC Gain and Input Resistance

- **Goal:** To evaluate the voltage gain and input resistance of a non-inverting op-amp circuit.
- **Setup:** As in 5.2.1 with A connected to a sine wave at 1 kHz having 5 V peak amplitude.
- **Measurement:**
  - With your oscilloscope, measure the peak amplitude of signals at B, C, D.
  - Shunt the op-amp input terminals with a resistor $R_x = 1$ kΩ. Measure B, C, D.
  - Insert a resistor $R_s = 100$ kΩ in series with B and the op-amp +ve input terminal (with the 1 kΩ shunt still in place). Measure B, C, D.
  - Short R_2 and measure again.
- **Tabulation:** $R_2, v_a, v_b, v_c, v_d, R_x, R_s$ for $R_2 = 10$ kΩ or 0 Ω, $R_x = \infty$ or 1 kΩ, and $R_s = 0\Omega$ or 100 kΩ, appropriately.
- **Analysis:** Consider the gains in each case. Estimate the input resistance (with the 1 kΩ shunt on the input) for $R_2 = 10$ kΩ and zero.

5.3 General-Purpose Amplifier Topology

5.3.1 Individual Inputs, Difference Gains

- **Goal:** To investigate the properties and potential application of a special three-input amplifier which facilitates difference measurements.
- **Setup:** Assemble the circuit shown in Figure 4, initially with A, D, F grounded. Adjust the supplies to ±10 V using your DVM.
- **Measurement:**
  - Now, using a sinewave generator, generate a 50 mV peak signal at 1 kHz.
  - Connect the 50 mV signal in turn to one of A, D, F, separately (the other two remaining grounded), and measure C [and B, E, if you have time].
- **Tabulation:** $v_A, v_B, v_C, v_D, v_E, v_F$.
- **Analysis:** Consider all three values of voltage gain from the inputs (A, D, F), to output (C), namely $v_c/v_a, v_c/v_d, v_c/v_f$ and the application of superposition to find the output in terms of the three inputs acting together.

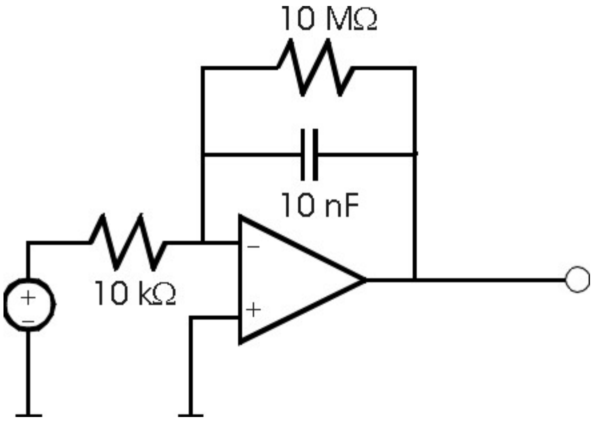

Figure 5: Integrating amplifier

5.3.2 *Common-Mode Gain

- **Goal:** To illustrate that common-mode signals can be amplified quite differently, and, in one case, hardly at all!
- **Setup:** As in 5.3.1 above.
- **Measurement:**
  - Connect the generator to provide a 5 V peak signal to both A, D with F at ground.
  - Connect the 5 V signal to all of A, D, F. Measure the voltages at C, B, E.
- **Tabulation:** $v_A, v_B, v_C, v_D, v_E, v_F$ for two cases $v_A = v_D = v_{AD}$ with $v_F = 0$ and $v_A = v_D = v_F = v_{ADF}$.
- **Analysis:** Consider the common-mode voltage gains from input to output. Find v_C/v_{AD} and v_C/v_{ADF}. To which of these cases does the idea of ”common-mode rejection” apply?

5.4 Integrator

- **Goal:** To study the response of an integrating amplifier.
- **Setup:** Build a circuit as in Fig. 5.
- **Measurement:** Observe the output waveforms and phase you get for sine, square and triangular wave inputs of modest amplitude in the 1–2 kHz range. Remove the 1 MΩ resistor shunting the integrating capacitor. Repeat your observations.
- **Analysis:** Observe carefully the shapes of the waveforms. Do they agree with what you expect from an integrator? What happens to the circuit when you remove the 1 MΩ resistor? Why?