

*Laboratory 2: Characterization of the LMC6482 Op Amp*  
**Laboratory Exercises**

## INTRODUCTION

### Objectives

In this lab, we will measure the parameters of an actual LMC6482 op amp. The measurement of these parameters will provide insight into the limitations of real-world op-amps in various circuit applications.

### Summary of Procedures

Using a LMC6482 op amp, measure the following parameters:

- (i) DC open loop gain
- (ii) Input offset voltage
- (iii) Dominant pole frequency
- (iv) Unity gain bandwidth
- (v) Slew rate

### Materials Required

- AD2 USB Oscilloscope
- BNC Adapter Board
- LMC6482 Op Amp
- Oscilloscope Probes
- BNC Cable
- Digital Multimeter
- Breadboard
- Assorted Resistors and Capacitors

## PROCEDURE

### 1. Closed-Loop Characteristics

This part of the lab will use the AD2 USB Oscilloscope to measure the closed-loop characteristics of the LMC6482 op amp. Keep in mind that there are two op amps within each LMC6482 chip, and take care to consistently use the same one for each circuit below, as you will later analyze several of these measurements together to characterize a single op amp. The pinout

for the LMC6482 can be found in the part datasheet on the course website. Unless otherwise stated, use the BNC adapter board for all measurements.

- Using one of the op amps in the LMC6482, build a unity gain buffer on your proto-board. Use the Analog Discovery 2 voltage supplies to create  $\pm 5$  V rails. Ground the input and measure the output voltage with your DMM set to the mV scale.
- Connect the input of the amplifier to one of the arbitrary waveform generator outputs using a BNC cable (not an oscilloscope probe). Connect one oscilloscope probe to the input of the amplifier and the other oscilloscope probe to the output of the amplifier. Remember to compensate your probes and set the proper attenuation in Waveforms. Carefully measure the 3-dB frequency of the amplifier.
- Connect the input of the amplifier to a 10 V<sub>pp</sub>, 10-kHz square wave. Use the response of the amplifier to this input to estimate the slew rate of the op amp.
- Reconnect the amplifier as a noninverting amplifier with a gain of 11. Recall that the feedback network of this amplifier has a gain of 1/11, therefore, the loop gain will reach unity when the op amp has gain 11, not 10. Carefully measure the 3-dB frequency of the amplifier.
- Reconnect the amplifier as a non-inverting amplifier with a gain of 101. Carefully measure the 3-dB frequency of this amplifier.

## 2. Open-Loop Characteristics

As you saw in the prelab, when you use an op amp without feedback (i.e., in an open-loop configuration), it becomes critical that you properly bias the input to account for offset voltage and input bias current. Additionally, directly measuring voltage gains on the order of  $10^6$  V/V requires instruments capable of accurately sourcing and measuring signals that differ by six orders of magnitude. Usually, we employ a specialized tool called a Semiconductor Parameter Analyzer for open-loop measurements (the model we have in the 125 Cory lab is the HP 4155B). However, even the HP 4155B requires us to leverage clever circuit design to get accurate measurements by

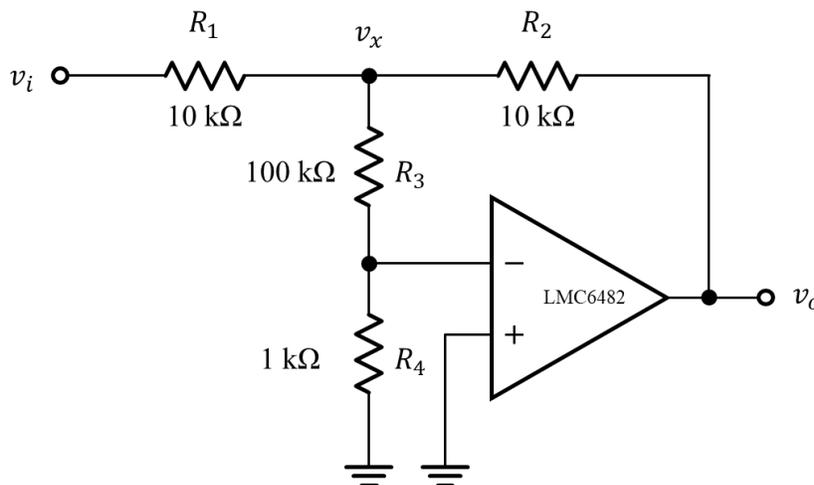


Figure L2.1

first attenuating the input signal with a known voltage divider ratio, and then calculating the final gain  $v_o/v_i$  by dividing the applied input signal by the voltage divider ratio to get  $v_i$ . Since we do not have access to the HP 4155B this semester, we will use an alternative solution that is generally not as accurate but at least gets us in the ballpark.

This part of the lab will push the capabilities of the Analog Discovery 2 to measure the open-loop response of the LMC6482. Because the voltage supplies on the Analog Discovery 2 do not allow for fine enough tuning to compensate for offset voltage, we will use the circuit in Figure L2.1 to estimate the open-loop characteristics of the LMC6482. Construct this circuit on your breadboard using the same op amp that you used for Part 1.

For all of the open loop measurements below, you will want to set your input signal amplitude as large as possible without the output limiting. To determine the limit on input amplitude, you should consider the effective gain  $v_o/v_i$  of the inverting amplifier circuit in Figure L2.1.

- (a) Before beginning, measure the values of  $R_1$ ,  $R_2$ ,  $R_3$  and  $R_4$  with the DMM. Use these measurements to accurately compute the ratio  $v_-/v_x$ , assuming zero input bias current. Be sure to take care with these computations as the accuracy of the following measurements depends on this data. Build the circuit on your breadboard, again using the Analog Discovery 2 voltage supplies to create  $\pm 5$  V rails.
- (b) First, ground the input  $v_i$  and use a DMM set to mV scale to measure  $v_o$ . Use this value of  $v_o$  to determine the op amp offset voltage  $V_{OS}$ , again assuming zero input bias current. You can do this later if you do not want to derive the expression while taking measurements.
- (c) Set one of the Analog Discovery 2 waveform generator outputs to  $0 \Omega$  via the jumper and use a BNC cable to connect it to  $v_i$ . Set both oscilloscope channels to DC coupling via the jumpers and connect two compensated oscilloscope probes set to 1X attenuation to the channels on the BNC adapter board (it's important you set the attenuation with *both* the physical red switch on the probe itself as well as in the WaveForms software). Setting the waveform generator to the maximum amplitude that produces an undistorted output, measure  $v_o/v_x$  at frequencies of 10 Hz, 1 Hz and 0.1 Hz. Note that you may need to create a custom global measurement script in order to measure the amplitude of  $v_x$ . Calculate the open-loop gain  $A_o = v_o/v_-$  based on your measured gain and the voltage divider ratio you calculated in part (a).
- (d) Keeping your circuit and the connections to the Analog Discovery 2 intact, create a Network Analyzer tool window in WaveForms by clicking the plus button and then clicking 'Network'. If you connected Channel 2 of the oscilloscope to  $v_x$  in part (b), make sure Channel 1 is connected to  $v_x$  instead, connecting Channel 2 to  $v_o$ . You should measure the magnitude response of  $v_o/v_x$  (on Channel 2) from 0.5 Hz to 20 Hz, making sure that there is a green check mark next to "Relative to Channel 1" under "Magnitude" on the right side of the window.

Note that even with a minimum number of points, this sweep will take a long time due to the low frequencies being measured. You may want to keep the frequency above 100 Hz while you set up the Network Analyzer measurement.

**Results Sheet for Laboratory Exercises**

NAME: \_\_\_\_\_

LAB SECTION: \_\_\_\_\_

**1. Closed Loop Characteristics**(a)  $V_o =$  \_\_\_\_\_

What is the source of this voltage?

(b) 3-dB Frequency (attach annotated oscilloscope or network analyzer plot) = \_\_\_\_\_

What is the open-loop gain of the op amp at this frequency? (You should determine this from your closed-loop measurements) \_\_\_\_\_

(c) Slew Rate (attach annotated oscilloscope plot with  $\Delta V/\Delta t$  markers) \_\_\_\_\_

Was the distortion on the output totally due to slew rate limitations? How can you tell the difference between a square wave limited by slew rate and one limited by frequency response? Sketch an example of each below.

(d) 3-dB Frequency (attach annotated oscilloscope or network analyzer plot) = \_\_\_\_\_

Define the feedback factor  $\beta$  as the voltage ratio  $v_-/v_o$  of the resistive feedback network. What is the loop gain  $|\beta A(j\omega)|$  at the 3dB frequency measured above?

(e) 3-dB Frequency (attach annotated oscilloscope or network analyzer plot) = \_\_\_\_\_

What is the open-loop gain of the op amp at this frequency?

## 2. Open-Loop Characteristics

(a)  $R_1 =$  \_\_\_\_\_,  $R_2 =$  \_\_\_\_\_,  $R_3 =$  \_\_\_\_\_,  $R_4 =$  \_\_\_\_\_

$$\frac{v_-}{v_x} = \underline{\hspace{10cm}}$$

(b)  $v_o =$  \_\_\_\_\_

$$\frac{v_o}{V_{OS}} = \underline{\hspace{10cm}}$$

$$V_{OS} = \underline{\hspace{10cm}}$$

Contrast the value of  $V_{OS}$  measured in this way to  $V_{OS}$  measured from the unity-gain buffer in Part 1. What factors induce error in each measurement?

(c) Attach annotated oscilloscope plots.

$$\underline{10 \text{ Hz}}: \frac{v_o}{v_x} = \underline{\hspace{2cm}}, \quad A_o = \underline{\hspace{2cm}}$$

$$\underline{1 \text{ Hz}}: \frac{v_o}{v_x} = \underline{\hspace{2cm}}, \quad A_o = \underline{\hspace{2cm}}$$

$$\underline{0.1 \text{ Hz}}: \frac{v_o}{v_x} = \underline{\hspace{2cm}}, \quad A_o = \underline{\hspace{2cm}}$$

(d) Attach annotated network analyzer plots.

$$\text{Estimated } A_o \text{ from magnitude response} = \underline{\hspace{2cm}}$$

### 3. General Questions

(a) Using the DC open-loop gain from part 2(d) and all the 3dB frequencies measured in part 1:

(i) Create a detailed plot of the open-loop frequency response of the op amp. Be sure to indicate all the above data points on your plot. You should additionally indicate the dominant pole frequency and unity gain frequency on your plot. You may assume a single pole model of the op amp.

(ii) Based on your gain plot, create an open-loop phase plot of the LMC6482 op amp. Compare your results to a simulation of the phase plot for the open-loop op amp modeled by 'lmc6482.mod' using SPICE. How well does your plot agree with the data sheet plots? *Analytically* explain any discrepancies between your plot and the data sheet plots. (You should estimate the location of any additional poles or zeros that you postulate.)

- (b) Could you conveniently make a slew rate measurement using a sinusoidal input for the LMC6482 op amp used in this lab with the circuit given below? Why or why not?

