Introduction

In this lab you will build a 6-transistor operational amplifier (differential-input, single-ended-output), similar to the LM741, and then characterize its performance. You will build a current mirror and use it to bias two stages, build a differential pair, and an output buffer. The goal of this lab is to get a functional opamp built so you can characterize it similarly to how the LM741 was characterized in Lab 1. Because the opamp is built using discrete devices, its performance will not come close to that of the LM741. If you are interested in learning more about how to design high-performance integrated opamps, take EECS 413 next Fall!

![Operational Amplifier Schematic]

Figure 1. Operational Amplifier Schematic. Q1-3 form a current mirror for biasing, Q4-5 form a differential pair, and Q6 is an emitter follower. Transistors Q1-5 are from a single CA3083, transistor Q6 is a 2N3904.

Prelab Component

Refer to the schematic in Figure 1.

P6.1 You will use the resistors $R_{BIAS}$ and $R_{E1-3}$ to set the bias currents in the two stages. For good bias stability, use a voltage drop across all $R_{EX}$ resistors of 5V. The reference bias current $I_{C1}$ in $Q_1$ should be 500μA, current $I_{C2}$ in $Q_2$ should be 2mA (4x the reference current), and current $I_{C3}$ in $Q_3$ should be 1mA (2x the reference current). Choose values for the resistors $R_{E1}$, $R_{E2}$, and $R_{E3}$ based on these assumptions for bias currents and desired voltage drop. Now choose a value for $R_{BIAS}$ that sets the reference current in $Q_1$. Use only resistors from the table of available values online. Choose values closest
to calculated values to meet the bias specifications; do not combine multiple resistors to create more precise values.

In-Lab Component

L6.1 Build the opamp shown in Figure 1. Use $R_c = 5.6k\Omega$, and the values for other components found in P6.1. Use the CA3083 for the 5 transistors $Q_{1-5}$. This chip, found in your lab kit, contains 5 NPN transistors that have similar device parameters ($\beta$, $I_S$, etc.). A datasheet with pinout can be found at the website below. Transistor $Q_6$ should be implemented using a 2N3904. Do not forget to add decoupling capacitors on both your +12 and -12 power supplies (watch polarity of caps on -12V supply). Also, do not forget the capacitor at the output of the differential pair. This is used to stabilize the opamp, for more information read section J&B 17.12.

http://www.eecs.umich.edu/courses/eecs311/f08/labs/ca3083.pdf

L6.2 Configure the circuit in unity-gain feedback as shown in Figure 1 by wiring the output of your circuit to the inverting terminal, and the input from the signal generator to the non-inverting terminal. Initially connect the non-inverting input terminal to ground and measure the DC output voltage using the multimeter. This is the offset voltage of the amplifier, record this on your check-off sheet.

L6.3 With the opamp still in unity-gain feedback, apply a 50mVppk sine wave and measure the 3dB cutoff frequency of the amplifier and record this in you check-off sheet.

L6.4 With the opamp still in unity-gain feedback, apply a 1kHz square wave with an amplitude of 1Vppk. Measure the slew rate of the amplifier on the falling edge of Vout.

L6.5 OPTIONAL: Measure the gain in your amplifier using the same technique used in Lab 1 with the HP4155. Refer to Exercise L1.1 in Lab 1 for instructions on setting up the HP4155.

http://www.eecs.umich.edu/courses/eecs311/f08/labs/lab1.pdf

Figure 2. Opamp in unity-gain feedback.
Have the GSI check you off once your circuit is complete and characterized. Be prepared to answer questions about your circuit or the results.

**Results Summary**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LM741 Datasheet</th>
<th>Measured</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Offset Voltage</td>
<td>2 mV</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Unity-Gain Bandwidth</td>
<td>1.2 MHz</td>
<td></td>
<td>MHz</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>0.5 V/\mu s</td>
<td></td>
<td>V/\mu s</td>
</tr>
<tr>
<td>Gain (optional)</td>
<td>200 kV/V</td>
<td></td>
<td>V/V</td>
</tr>
</tbody>
</table>

Table 1. Results summary table.

**Exercise** ................................................................. Date Completed

Demonstrated working amplifier........................................................... _____