BME 194: Applied Circuits Lab 5: audio amp

Kevin Karplus

January 22, 2013

1 Design Goal

In this lab, you will design a low-power audio amplifier for an electret amplifier, using an op-amp chip and a single-rail 5v or 6v power supply.

We do not want to amplify any DC bias on the microphone, just the audio frequencies (say, greater than 5Hz).

We would like the output to be centered in the middle of the output range, that is, at 2.5V for a 5V power supply when there is no sound coming into the microphone.

2 Background

Based on the measurements you did in Lab 2 (electret microphone), you should be able to make a simple circuit that produces voltage fluctuations from an electret microphone by adding a pullup resistor. The voltage fluctuations can be fairly high, but the current through the microphone remains quite small. In other words, this circuit has a high source impedance, and so is not capable of delivering much power. In particular, it is not capable of driving a loudspeaker.

To get enough power to drive a loudspeaker, you'll need an amplifier that can provide substantial current and voltage. For this lab, you'll use an op amp chip (the MCP6004 quad op amp chip) to make the amplifier, which is not really capable of driving a loudspeaker very loudly (we'll do a more powerful amplifier in a later lab).

Amplifying the DC bias on the microphone can result in the op amp output saturating (getting stuck at either the highest or lowest voltage). To get rid of the DC bias, you can use a simple high-pass filter between the microphone circuit and the input to the amplifier. This can be as simple as a capacitor and resistor, acting as a voltage divider. The impedances have the same magnitude when $\left|\frac{1}{j\omega C}\right| = R$, that is, when $\omega = \frac{1}{RC}$, where $\omega = 2\pi f$. If you want frequencies greater than f to be passed with little change in amplitude, then you want $RC > \frac{1}{2\pi f}$.

When there is no sound, the input of the amplifier should be in the middle of the voltage range (2.5V for a 5v supply). Think about ways you can accomplish this. Remember that a capacitor is an open circuit for DC.

An op amp provides a very large open-loop gain (25,000 to 400,000 for the chip you are using), and so is almost always used in a feedback loop to set a reasonable gain. The output should be centered in the middle of the output range, that is, at 2.5V when the input is at 2.5V (for a 5v power supply)

It is not good to drive loudspeakers with a DC signal (that would push the cone away from the center-rest position), so you'll want to AC-couple the output as well as the input. How can you do this simply?

3 Pre-lab assignment

Read the Wikipedia articles
`http://en.wikipedia.org/wiki/Operational_amplifiers`
`http://en.wikipedia.org/wiki/Operational_amplifier_applications`

Using the measurements from Lab 2 (electret microphone), determine the resistor sizes needed to get a DC voltage across the microphone of 1V, 2V, 2.5V, 3V, and 4V.

The current into the microphone is about 175μA (depending what DC bias voltage you decide to use on the microphone). The current fluctuation due to sound is about $\pm 1\mu$A to $\pm 80\mu$A, depending on how loud the sound is. Determine what voltage swing to expect with each of the resistor sizes given $\pm 80\mu$A variation in current. What are the lowest and highest voltages expected? If these go outside the 0v and 5v power rails, then you will not be able to get the projected currents, and the microphone will clip the output.

Choose a pull-up resistor that will give you a large voltage swing, but one that should not cause clipping.

Assuming that a typical sound causes about a $\pm 2\mu$A change in current, how much gain will your amplifier need to get a $\pm$2v change in output voltage?

The MCP6004 chip can only supply $\pm$23mA (short circuit current). How much power is that with an 8Ω load, assuming a sine wave as input?

What is the RC time constant for the loudspeaker in series with the largest electrolytic capacitor in your parts kit? What cutoff frequency does that correspond to?

Make a block diagram of your circuit showing the major sections of the circuit (for example, the microphone, the pull-up resistor for the mic, DC-blocking RC input filter, the op amp, the feedback for the op amp, the DC-blocking output capacitor, and the loudspeaker).

Design your circuit using one or two op amps, and draw a schematic for the whole circuit. Put boxes around parts of the schematic to show the relationship to the block diagram. Put pin numbers on all the op amp connections, to speed wiring.

You need to have a block diagram and circuit diagram before coming to lab, though it need not be the one that you end up with after debugging your design.

Note that to test the design, you must have some expectations about what you should see on the oscilloscope or with the multimeter at each stage. It would help a lot if you wrote some of those expectations down before the lab time (like what DC voltage you expect to see at the microphone, and how large an AC signal you expect to see added to that). What about the DC voltage and AC signal after the input high-pass filter? At the output of the op amp?

4 Parts, tools, and equipment needed

Parts for this lab from kit:

- breadboard
- CUI inc CMA-4544PF-W electret microphone

- MCP6004 quad op-amp chip
- loudspeaker
- resistors
- electrolytic capacitors

- 10kΩ trimpot (optional, if gain is made adjustable)

Parts students need to provide on their own:

- None.

Tools for this lab:

- wire cutters
- wire strippers
- screwdriver (if trimpot used)

Equipment in lab:

- 5v or 6v power supply
- oscilloscope (for observing output)
- multimeter (for debugging)

5 Procedures

Wire up your circuit one block of the block diagram at a time, starting with the microphone and pull-up resistor. After each block is wired up, test it with the oscilloscope. If it does not behave as you expect, change the design (either of the part already wired or of the next block it connects to).

When the whole amplifier is working, measure the voltage gain of the amplifier by measuring the AC input voltage and AC output voltage of the amplifier. Do these measurements with and without the loudspeaker connected.

6 Demo and writeup

Demonstrate to one of the instructors or group tutor a working amplifier. Show the input and output of the amplifier as two traces on a dual-trace oscilloscope.

Demonstrate the amplifier working by speaking into the microphone. (You may also be able to get some feedback squeal, but don't irritate people too much by doing it a lot.)

7 Design Hints

You need to arrange your feedback circuit to make the output be centered between the power rails. There are at least two ways to do this. One is to create a "virtual ground" at 2.5v by using a voltage divider as the input to an op amp configured as a unity-gain buffer (that is, with its negative input tied directly to its output). The output of the op amp would be a 2.5v voltage source capable of delivering up to about $\pm 25mA$.

Another way is to use a voltage divider in place of a resistor to ground every time that a resistor to ground would be used in an op-amp design with both positive and negative power supplies. Remeber that the Thévenin equivalent of a voltage source V and a voltage divider with two equal resistors R is a voltage source of half the voltage $V/2$ and half the source resistance $R/2$.

Because the impedance of the loudspeaker is so low (8Ω), you'll want to use the largest electrolytic capacitor in your parts kit as the DC-blocking capacitor for the output high-pass filter to get a reasonably high RC time constant. You don't want to add resistance to the loudspeaker to increase the RC time constant, since that would result in very little power to the speaker, and this amplifier is already fairly feeble. The lowest frequencies the amplifier can deliver are (probably) determined mainly by this output filter.