LAB 11 – Wired Intercomm, with op-amp

LTspice files for most of the circuits in this lab are available online. Use them!

In this lab, the goal is to build two very simple op-amps and use them, with feedback, to perform both the microphone amplification and the speaker driving from the previous lab. The circuit below shows an ideal opamp performing this function. For an ideal op-amp: the input resistance is infinite so it doesn't load the microphone or the feedback network; the output resistance is zero, so 8 Ohms isn't a problem; there is no current limit, so +/-120mA slewing won't be a problem; and R1 and R2 set a fixed gain of +101. The only challenge with this circuit is to make sure that the input bias point of the positive terminal of the op-amp is within ~10mV of ground, otherwise the DC gain of the amp will rail the output. Note that making R2 variable gives you a volume knob. The two opamps that you will build below are decidedly NOT ideal.

Figure 1: ideal opamp intercomm circuit.

Part 1 3T Opamp

You'll start with the simplest circuit that could be called an opamp, 3 transistors and 3 resistors, forming a differential input stage and a gain stage, shown below. You need to use a positive and negative supply for this application. Make sure that you tie the “common” outputs of the power supplies to ground.

Build this opamp circuit, and test by making the following measurements:
1. Ground both inputs, and measure the DC bias points for tail, out1, and out2. Tail should be a diode drop below ground, and out1 should be a diode drop below the top rail (why and why?). Out 2 will probably be railed high (why?)

2. Apply a small low-frequency input sine wave on the right input. Is this the positive or negative input? Why? Measure the gain (roughly), and make sure that it is large.

Now put the amplifier in feedback with $R_2=10k$ and $R_1=1k$. $K=1/11$. What gain do you expect?

![Figure 3: Amplifier in feedback with $K=1/11$ and speaker load.](image)

3. Measure the low-frequency gain in feedback (no cap or speaker yet).

Now add the blocking capacitor and speaker.

4. Measure the AC gain at 1kHz in feedback with the blocking capacitor and speaker load. Use a small AC input so that the output looks sinusoidal (if you can). What is the maximum input amplitude, and corresponding output amplitude, before the output starts to slew negative (stops looking sinusoidal)?

5. With the input large enough to cause nonlinear gain, and the output is slewing negative, what is the voltage at out1? What is the current through Q3? What is the current through the speaker (assuming that it’s 8 Ohms)? Where does that current come from?

6. With the input large enough to cause nonlinear gain, and the output at its maximum, what is the current through the speaker (assuming that it’s 8 Ohms)? Where does the current come from?

7. Change the feedback to $K=1/101$ (R2=100). Does the AC gain change much? (note: this is NOT an ideal op-amp)

**Part 2 5T op-amp**

Now add an NPN and PNP transistor as an output stage.
Hook the scope up to the input, out2, out3, and out8.

8. With a small 1kHz input, what is the phase shift (roughly) between the input and out, out2, and out3?

9. Measure the AC gain at 1kHz with R2 equal 10k and 200. Vary the input amplitude and measure the AC gain for small inputs, and in each case find the input/output voltage levels at which the output stops looking sinusoidal.

10. Looking at out2, you should see a big vertical jump in voltage each time the output voltage goes through 0. How big is that jump, and why is it there?

11. Estimate the current flowing into and out of the load at the maximum sinusoidal output, and compare to the quiescent (no input) current for the whole opamp. It should be much bigger. How is that possible?

12. At maximal sinusoidal output, measure the voltage difference between the two input terminals of the opamp. Estimate what the effective input impedance is in terms of \( r_\pi \) and that voltage difference.

**Part 3 Intercom**

Now hook up the microphone to the input of the opamp. You will **either** need to carefully adjust the DC bias point of the opamp input to be very close to zero, **or** you will need to AC couple the output of the microphone to the opamp. Using a DC blocking capacitor on the input is fine, but make sure that you give the input a DC ground through a resistor (that input is the base of a BJT that you’re hooked to, and it needs a small DC bias current).

13. Can you vary the speaker volume with a different resistor R2?

14. If you put the speaker next to the microphone, can you get a feedback oscillation?

15. Take a long wire and try to get an intercom working across the lab: you drive someone else’s speaker, and have their driver drive your speaker.

**EXTRA CREDIT**

If you want to get some extra credit, build the “all active” amplifier shown in the spice deck and try it out. Alternatively, build a CMOS op-amp and characterize it.