ECEN3250 Lab 8
Audio Power Amplifier

ECE Department
University of Colorado, Boulder
Prelab assignment

Read textbook sections 5.1, 5.2, 5.3, 5.4, and 14.3
An audio power amplifier takes audio signal $v_i(t)$ from a source (e.g. CD player) and produces an output voltage $v_o(t) = A v_i(t)$ to drive a loudspeaker.

The output power can be found as

$$P_{out} = \frac{V_{o,rms}^2}{R_L} = R_L I_{o,rms}^2$$

where $V_{o,rms}$ is the rms value of the output voltage and $I_{o,rms}$ is the rms output current. Since the speaker’s impedance is relatively low ($R_L = 8 \Omega$ is typical), the amplifier must have a low output impedance, and must be capable of driving the speaker with significant output current. For example, assuming $R_L = 8 \Omega$, the rms output current of a 100 W audio amplifier is about 3.5 A.

In this lab, the objective is to design an audio power amplifier according to the following specifications:

- $|A| = 10$, $R_L = 100 \ \Omega$
- $P_{out,max} = 125 \ \text{mW}$
- $V_{o,rms} = 3.54 \ \text{V}$
- Sinewave $V_{o,peak} = 5 \ \text{V}$, $V_{opp} = 10 \ \text{V}$
Step 1: Simple op-amp amplifier

The starting point for the power amplifier is the simple op-amp based amplifier shown here. The gain is ideally $-10$.

- Construct the op-amp amplifier. Do not forget the decoupling capacitors for the dc supply voltages.
- Using a 1 KHz sinewave from the lab waveform generator, verify the gain.
- Adjust the input signal amplitude to 1Vpp so that the output peak-to-peak voltage is 10 Vpp (output peak-to-peak amplitude should be 10 V)
- In the report, include the circuit diagram, and a labeled sketch of the $v_{in}(t)$ and $v_o(t)$ waveforms
Step 2: Op-amp amplifier with load

- Adjust the input sinewave signal to 1Vpp amplitude at 1 KHz
- Load the output of the op-amp with $R_L=100\Omega$
- In the report, include the circuit diagram, and a labeled sketch of the $v_{in}(t)$ and $v_{o}(t)$ waveforms.

You should observe that the output waveform is severely distorted. Explain why in the report. Hint: the op-amp maximum output current is limited to about 25mA. See the attached plots from the op-amp data sheets.
Step 3: Op-amp amplifier with BJT buffer

- An npn (2N3904) and a pnp (2N3904) can be connected as shown here to form a “class-B” buffer where the output current is supplied by one of the BJTs, while the op-amp sources or sinks a significantly smaller current ($\beta$ times smaller than the output current). Note that the positive output current (for $v_o(t) > 0$) is supplied by the npn; the negative current (for $v_o(t) < 0$) is sunk by the pnp.
- Construct and test the buffered op-amp amplifier using the 1Vpp, 1KHz sinewave input.
- You should observe that the output waveform is significantly different compared to the waveform observed in Step 2. However, the output waveform is still visibly distorted. In the report, sketch and explain the waveforms $v_{in}(t)$, $v_b(t)$ and $v_o(t)$. Hint: read textbook Section 14.3 (4th ed. Section 9.3).
- Experiment with changing the amplitude of the input signal and describe your observations in the report.
Step 4: Improved buffered amplifier

- An improved version of the buffered amplifier is shown here. The feedback resistor R2 is connected after the BJT buffer. The op-amp output $v_b(t)$ tends to correct the nonlinearity introduced by the BJT buffer and the output should be much closer to the ideal sinewave than in the amplifier of Step 3.
- Construct the improved buffered op-amp amplifier and test using the 1Vpp, 1KHz sinewave input.
- In the report, sketch, label and explain the waveforms $v_{in}(t)$, $v_b(t)$ and $v_o(t)$. 
Step 4: Improved buffered amplifier

- Prepare a PSpice simulation file corresponding to the improved buffered amplifier in Step 4. Use the transistor models from the 3250.lib library. Consult the on-line PSpice reference manual about how to include the BJTs in the simulation file. In the report show the simulation results for the waveforms $v_{in}(t)$, $v_b(t)$ and $v_o(t)$. Compare to the experimental waveforms and comment on the results.
- Compute and report the output power $P_{out}$, the power $P_{nnp}$ dissipated by the npn (2N3904), the power $P_{pnp}$ dissipated by the pnp (2N3906), the power $P_{CC}$ taken from VCC, the power $P_{EE}$ taken from –VEE, and the power efficiency of the amplifier, $\eta = P_{out} / (P_{CC} + P_{EE})$.
- Experiment with changing the amplitude and frequency of the input signal and describe your observations in the report.
Extra credit experiment

- Construct and test a buffered op-amp amplifier using the LF356 op-amp followed by a MOS buffer consisting of an NMOS (ZVN2106) and a PMOS (ZVP2106) instead of the BJTs
- Repeat Step 4 experiment and report tasks for the MOS buffered amplifier
- Compare the performance of this MOS buffered amplifier to the performance of the BJT buffered amplifier of Step 4 in terms of the output signal distortion, efficiency and bandwidth
- This extra-credit assignment is worth up to 3 extra-credit points