ECE222 Spring 2014

Term Project

Design and Implement a Headphone Amplifier

Report Due May 12, 2014 by 4pm

In this project, you will apply the circuit design techniques and methods you learned in this course to a real-world engineering task: to design and build a hi-fi headphone amplifier for portable audio players such as your cell phones or mp3 players. The goal is to demonstrate your understanding of amplifier design as well as to introduce you to the hands-on engineering of building practical electronic devices.

A headphone amplifier is typically needed to drive those hi-fi headphones with higher input impedance (32-600 Ω) and/or with lower sensitivity than your typical earbuds (16-32 Ω, >100 dB/mW). For example, the popular Sennheiser HD650 has an impedance of 300 Ω and a sensitivity of 98 dB/mW, while the iPhone5s EarPods are 23 Ω and 109 dB/mW. The difference in sensitivity means that hi-fi headphones typically require much higher output power to drive than earbuds to achieve the same loudness.

The higher impedance of hi-fi headphones means that the output power delivered is much smaller when driven by the output signal with the same voltage amplitude. The latter is determined by the output stage design of the amplifier, and ultimately limited by the power supply voltage. A typical portable audio device such as a cell phone and mp3 player are not designed to drive such high impedance with large output power, and hence needs a headphone amplifier.

There are several common designs for headphone amplifiers, ranging from a single op-amp circuit, e.g., the legendary CMOY design, to designs using all discrete transistors. In this project, I encourage you to explore all these options in the initial phase. Unless you are really adventurous, though, we will use the two-stage architecture in this project as shown below:

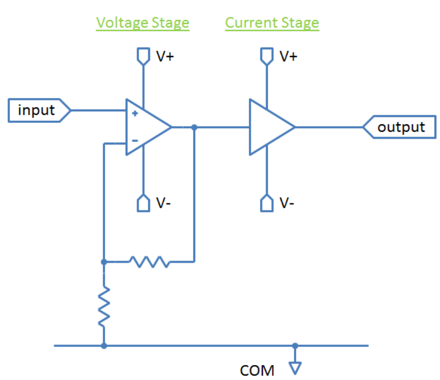

Fig.1 Two-stage design of the headphone amplifer in this project (for illustration purpose only, not an exact circuit).

The first stage is an op-amp voltage gain stage that can achieve a reasonable voltage gain and large input impedance. It also determines the frequency response of the amplifier and handles volume control and possibly equalization and other filtering. The second stage drives the load (headhone) and is capable of delivering large currents to a wide range of impedances. It determines the nonlinear characteristics (distortion) of the amplifier. Note that the feedback can be global (across both stages) or local (separate for the voltage and current stages.

Design Tasks and Specifications:

- **Tasks:**
  1) Read the literature and understand the characteristics of headphones, headphone amplifiers, and audio op-amps.
  2) Evaluate the following headphone amplifier architectures: a) single op-amp designs such as CMOY; b) single-stage voltage buffer designs; and c) two-stage all op-amp designs.
  3) Design the first stage in HSPICE. Then implement it on the prototype board and evaluate the performance. You only need a single channel for this task and hence can use a single-channel op-amp. You need to select an op-amp from the few we have in stock first to try the circuit, and then try different op-amps in simulation to see which one works the best for the specifications. In this task, use the sinusoidal and square-wave signals from the function generator as your input signal. Use a resistor as its load which corresponds to the input impedance of the second stage, or simply a 10kΩ resistor before you have done the design of the second stage.
  4) Design the second stage. Then implement it on the prototype board and evaluate the performance. You still only need a single channel for this task and hence can use a single-channel op-amp. In this task, use the sinusoidal and square-wave signals from the function generator as your input signal, and use a resistor as its load which corresponds to the input impedance of a headphone. Because of the large power dissipated on the load, this power resistor can be made using several resistors connected in parallel and/or series.
  5) Connect the first and second stages together first in simulation and then on the prototype board. You still only need a single channel for this task and hence can use single-channel op-amps. Evaluate the performance. Make changes to the designs to optimize the performance.
  6) Implement the dual-channel prototype on the board. You can use two of the single-channel op-amps you used in Task (3)-(5) or use the corresponding dual-channel version of that op-amp. The board layout probably needs to be redone.
  7) Evaluate the acoustic performance using real music input and a real headphone. Make changes to optimize the performance.

8) (Bonus) Change the second stage to a design using discrete transistors to achieve higher output power and lower cost. Select the transistors from the library on Blackboard.

9) (Bonus) Design and implement a regulated AC power supply for the headphone amplifier on a separate board and use it to power the headphone amplifier. Note that the op-amps are designed to handle a large range of supply voltages. You might need to adjust the dc bias circuitry to keep the op-amp in proper operation.

- **Specifications:**
  - Output load impedance: 32-300 Ω, and optimized for nominal impedance of your headphone
  - Maximum output power (continuous): >100 mW/ch (on battery) or >200mW/ch (on AC power) on 32 Ω load
  - Output impedance: <5Ω
  - Input signal amplitude: 0.3V (nominal Vrms)
  - Input impedance: >10kΩ
  - 3-dB full-power bandwidth: 20Hz-15kHz (min), 18Hz-20kHz (max)
  - Total harmonic distortion + noise (THD+N): <0.1% with 100mW on nominal load at 1kHz
  - Power supply voltage: ±7-±9V (2x 9V batteries) or ±12V (external AC power supply + on-board regulation)
  - Power consumption: <100mA (on battery) or <150mA (on AC power) at max output power

Logistics:

- **Laboratories:**

  We will design the circuit using HSPICE at CSB 527 as in the three labs we did so far. Building the amplifiers will be done at the ECE electronics laboratory in Gavitt 306. Component and laboratory supplies will be available from the ECE electronics shop in Hopeman and later ordered by Professor Wu as needed. For op-amps, we will use the ones in stock for initial evaluation. Once your design is done, we will order the op-amp in for your design. This will be essentially a dry-run of your senior design project.

- **Simulation:**
  - HSPICE: you know this one already.
  - Device models: We have listed several op-amps and transistors on Blackboard, which are some good choices for this project. Try to find the SPICE model for

your op-amp and transistor from the manufacturer's website if you decide to use your own devices.

Presentation and Report:

Draw the schematic of all circuits with clear component names and values. Explain your design. Report the simulation results. Attach printouts of the SPICE files and simulation results including spectrum and waveforms with clear explanations. Show a diagram of the amplifier on the prototype board and a picture of the finished prototype. Show the measured waveforms. Discuss any discrepancy between simulation and implementation.

The project will be graded based on several factors: 1) design completeness and validity; 2) design innovations; 3) design practicality; 4) implementation completeness and validity; 5) performance achieved; 6) meeting or beating the specifications, and 7) testing procedures.