University of Maryland Baltimore County
Department of Computer Science and Electrical Engineering

CMPE 314 Lab Project

Audio Amplifier

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I. Objective

Design, implement, and demo a simple audio amplifier circuit.

II. Introduction

This project is to design and implement an audio amplifier that can be used in an AM radio receiver. An AM radio wave is an amplitude-modulated electromagnetic wave, as illustrated in Figure 1. It has a radio frequency carrier wave (red line) whose amplitude varies (modulated) with audio signals (dash line). The AM radio carrier frequencies are in the range of 540-1600 kHz, and the audio signal frequencies are in the range of 20 Hz to 20 kHz.

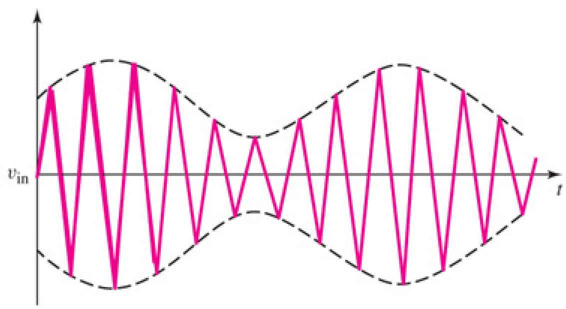

Figure 1. Amplitude-modulated wave form. The red is the carrier wave, and dash line shows the amplitude modulation.

An AM radio receiver consists of the following basic functional building blocks: a frequency-tuning antenna, a radio frequency (RF) amplifier, an audio signal detector, and an audio signal amplifier.

Figure 2. AM radio receiver basic building blocks.

- Antenna and tuner: The antenna picks up various radio wave signals. The frequency tuner has a band-pass frequency dependence and selects the correct carrier frequency (the correct radio station).
- RF amplifier: in remote areas, the received AM radio signal is usually weak. The RF amplifier serves to boost the AM radio signal strength (may consist of multiple stages).

- Audio signal detector: It serves to demodulate the AM radio signal, namely, removes the high-frequency carrier wave, and output only the low-frequency audio signals.

- Audio amplifier: Amplifies the audio signal to a sufficient level (may consist of multiple stages) to drive a speaker or earphone.

In this project, we will skip the antenna and the audio signal detector units. Instead, we will use the sinusoidal signals from a function generator to emulate weak RF input signals and audio input signals (as if obtained after the audio signal detector). To illustrate the concept of multi-stage amplifier system, we will use a sinusoidal signal at frequency of 100 kHz to represent both the RF and audio signals. In this context, we refer the whole system as an audio amplifier, so the RF amplifier stage is just the pre-amp stage, while the audio amplifier is just the last stage amplifier. The multi-stage amplifiers must be able to amplify weak input signals without distortion to drive an earphone, which we use a load resistor to emulate.

III. Design Requirements and Considerations

The full audio amplifier will consist of multi-stage common emitter and emitter follower amplifiers.

- Source signals. Use sinusoidal signals from a function generator to emulate realistic weak input RF/audio signals (weak antenna signals are less than 1 mV). Since typical function generator minimum output amplitude is around 50 mV, you need to use a voltage divider to scale down the wave amplitude to ≤ 1 mV, with an equivalent source resistance ≤ 50 Ω.

- Common emitter amplifiers: Implement a two-stage transistor amplifier with an overall $\mathbf{> 500 \times}$ amplitude gain.

- Emitter follower: Implement a transistor output amplifier that is sufficient to drive a speaker or earphone (**> 200 mV**). Use a load resistor (4 ~ 10 Ω) to emulate a an earphone.

- Use capacitors at certain interfacing locations to isolate DC biasing between each transistor amplifier, and couple AC signals from the source all the way to the load.

- A single 9 V battery will be the only power source for the whole circuit.

Read "Gain and Frequency-Response Considerations" for more theoretical guidance. Textbook Section 6.11 provides a good discussion about an audio amplifier example as well. You may search other audio amplifier examples. However, you must digest those examples and come up with your own design. You are expected to explain and analyze the operation of each building block in your circuit (so do not copy or follow more complex or advanced designs).

IV. Equipment and Parts

Components from the lab kit, breadboard, DC battery. Testing equipment: Function generator, digital multi-meter, oscilloscope.

V. Project Phases and Timelines (progress dates specified by instructor/TA)

Phase 1 --- Pre-Amp Stage (weeks 1 and 2)

1.1 Design and Analysis

- Each team is expected to come up with a design of a pre-amp stage with the small-signal voltage gain (open circuit gain without a load resistor) > 400. Draw the circuit diagram with transistors, resistors, capacitors (if you choose to use), and battery connection prior to the day of assembling. Consult with the instructor/TA for appropriate components and values to be used. Try using the components available in the lab kit.
- Perform DC analysis (calculate and plot the quiescent point values, DC loadline)
- Perform AC analysis (calculate the small-signal voltage gain, input and output resistances, plot AC loadline) for each transistor amplifier employed. Neglect the early voltage effect. You may do PSpice simulations to confirm your design (optional).
- Present the design and analysis in **preliminary report 1** for the pre-amp stage. Circuit design can be updated.

1.2 Assembling and Testing

- Assemble the designed pre-amp circuit on a breadboard. Use the left half of the board and leave sufficient space on the right-half for the last stage amplifier. You may use capacitors to interface between the source and the first amplifier, and between two or more amplifiers. Make sure that AC signals around **100 kHz** can pass through the capacitors.
- To test the circuit, use a sinusoidal signal from the function generator to emulate the weak AM radio signal from the antenna. Use frequency at **100 kHz,** and a voltage-divider to scale down the input signal amplitude to **1 mV**. Use the oscilloscope to measure and record waveforms and voltage amplitudes of the input and output signals for each transistor amplifier in the pre-amp stage. You may use a capacitor to interface between the output of the pre-amp stage and the oscilloscope (or use the ac coupling of the oscilloscope). Verify that the designed pre-amp stage works and provides sufficient overall voltage gain (open-circuit gain) around **500**.

Do not disassemble the constructed and tested pre-amp stage, as it will be integrated with the last stage amplifier for the full system.

Phase 2 --- Last Stage Amplifier (weeks 2 and 3)

2.1 Design and Analysis

- Each team is expected to come up with a design of the last stage amplifier that delivers a sufficient current to an earphone (or a load resistor). Draw the circuit diagram with transistor, resistors, capacitors (if you choose to use), and battery connection prior to the day of assembling. Consult with the instructor/TA for appropriate components and values to be used. Try using the components available in the lab kit.
- Perform DC analysis (calculate the quiescent point values).
- Perform AC analysis (calculate the equivalent input resistance, the small-signal voltage gain or current gain and the output resistance). Neglect the early voltage effect. You may do PSpice simulations to confirm your design (optional).
- Present the design and analysis in **preliminary report 2** for the last stage amplifier before the beginning of forth project lab meet time. Circuit design can be updated.

2.2 Assembling and Testing

- Assemble the designed circuit on the right-half of the circuit board. Do not remove the constructed and tested pre-amp stage. Disconnect the DC supply voltage to the pre-amp stage and leave its output open (not connected to the last stage amplifier). Make sure that the pre-amp stage and the last stage circuits share the same ground. Connect the DC supply voltage only to the last stage amplifier.
- To test the circuit, use a sinusoidal signal from the function generator to emulate the input signal to the final stage amplifier (not using the output of the pre-amp stage). Use the wave amplitude at **300 mV** and frequency at **100 kHz** (record the waveform and voltage magnitude). Use a load resistor (around **10 Ω**) to emulate the earphone. Measure the load current by measuring the voltage across the load resistor by the oscilloscope. Record the waveform and voltage magnitude. You may use capacitors to interface between the source and input side of the amplifier, and between the amplifier output and the load resistor. Verify that the designed circuit works and provides sufficient current to the load resistor (load voltage **> 200 mV**).

Phase 3 --- Full System Integration (weeks 4–5)

Connect the output of the pre-amp stage to the input of the last output stage through an interfacing capacitor. Connect the DC supply voltage to both stage circuits. Use a sinusoidal signal from the function generator to emulate the source signal. Use frequency at **100 kHz**, and a voltage divider to scale down the input signal amplitude to **1 mV** (record the waveform and voltage magnitude). Measure the voltages at the output of the pre-amp stage and at the load resistor by the oscilloscope. Record the wave forms and voltage magnitudes.

Phase 4 --- System Simulation (weeks 5–6)

4.1 Interfacing Capacitor Frequency Response (week 5, or in week 4)

The full audio amplifier system uses capacitors at certain interfacing locations to serve certain purposes. You need to complete your design by placing needed capacitors at the appropriate interfacing locations, and specify the capacitor values to be used. Remember, you need to pass AC signals at 100 kHz to the load resistor.

Calculate the corner frequency (indicating low pass or high pass) for the following capacitors:

(a) input coupling capacitor (interfacing with the antenna).
(b) capacitors used to isolate DC biasing between amplifiers in the pre-amp stage and last stage.
(c) output coupling capacitor (interfacing with the earphone load).

In these calculations, you need the values of relevant equivalent input resistance R_i and/or output resistance R_o of each amplifier, which you have obtained in Phases 1 and 2. Verify that each frequency response satisfies the design requirement. Modify your design if necessary.

4.2 PSpice Simulation (week 6)

Perform PSpice simulation of the pre-amp stage, the last stage amplifier, and the full audio amplifier system. Use the values of the components used in your circuit. Use a sinusoidal input with voltage of 1 mV, at frequency 100 kHz. Calculate the output voltage (in unit of mV) after each transistor amplifier and the voltage at the load resistor.

Lab Report

Full description of your audio amplifier system. Update the final circuit diagram, DC and AC analyses of each transistor amplifier, and corner frequencies of interfacing capacitors, all based on the actual components used in your circuit. Present the theoretical overall amplified voltage (input at 1 mV) at the load resistor (assuming AC signals pass all capacitors). Present PSpice simulation results. Compare the theoretical, PSpice simulation, and experimentally measured voltage at the load resistor, given input voltage of 1 mV.

Gain and Frequency-Response Considerations

Overall Gain:

The input signal coming from the antenna (in the case of this project, input audio signal) is approximately less than 1mV. The speaker is driven by an AC current, and typically needs a few mW power to work. We need to consider the fowling issues:

Power and current considerations:

1. Required earphone power $\boldsymbol{P_L = 1 - 5\ mW}$. (Value as an example)
2. Required earphone load current is determined from $P_L = R_L i_L^2(rms) = R_L i_L^2(peak)/2$
3. Required load voltage is determined from $v_L(peak) = R_L i_L(peak)$
4. Let source voltage $\boldsymbol{v_s(peak) \approx 1\ mV}$. **Expected system overall voltage gain is $> 300\times$.**

DC biasing consideration:

To ensure the last stage amplifier to deliver the required $i_L(peak)$ and yet without any signal distortion, one needs to design the DC biasing point appropriately. Specifically,

5. Load current $i_L(peak)$ is a portion of $i_c(peak)\ or\ i_e(peak)$ of the last stage amplifier. Use current division to determine $i_c(peak)) \approx i_e(peak)$.
6. $\boldsymbol{I_{CQ} > i_c(peak) > i_L(peak)}$.

   Note that one can approximate $I_{CQ} \approx I_{EQ}$ in the design for DC biasing.
7. You may consider using $R_L \approx 10\ \Omega$ in your design and calculation.

Example:

Say the speaker needs 5 mW power to work. Hence, if we assume the speaker resistance is around 10 Ω, from $P_L = R_L i_L^2(peak)/2$, one needs $i_L(peak) \approx 32\ mA$, or $v_L(peak) \approx 320\ mV$ at the speaker, which is the output of the last stage amplifier with load. Thus, if we assume the source signal is 1 mV, the overall gain of the amplifier system should be $320\times$ in this case. This requires I_{CQ} of the last stage: $I_{CQ} > i_c(peak) > i_L(peak) \approx 32\ mA$.

However, in the case that input signal is less than 1 mV, or speaker needs more power, or resistance of speaker is different from 10 Ω, you would need to modify the circuit to have an overall gain more than 300, say 500. This can be done by adding more amplification stages.

Important: in pre-amplification and audio-amplification stages you can use more than one transistor amplifier to satisfy the requirements. That means you can have multistage transistor circuit to make a RF amplifier or audio amplifier, and you need take care interfacing between them.

Frequency response:

In capacitor-related frequency response, the corner frequency is determined from $f_c = 1/R_{eq}C$. Consider a general capacitor filter network shown in Figure 3.

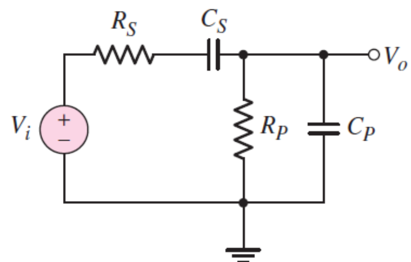

Figure 3. A general capacitor filter network.

The voltage transfer function can be found as

$$\frac{V_o(s)}{V_i(s)} = \left(\frac{R_P}{R_S + R_P}\right) \times \frac{1}{\left[1 + \left(\frac{R_P}{R_S + R_P}\right)\left(\frac{C_P}{C_S}\right) + \frac{1}{s\tau_S} + s\tau_P\right]}$$

where $\tau_S = (R_S + R_P)C_S$ and $\tau_P=(R_S||R_P)C_P$

When $C_P << C_S$, the transfer function becomes |

$$\frac{V_o(s)}{V_i(s)} \approx \left(\frac{R_P}{R_S + R_P}\right) \times \frac{1}{\left[1 + \frac{1}{s\tau_S} + s\tau_P\right]}$$

which has a band-pass response. The capacitor C_S influences the lower corner frequency $\omega_{C1}=1/\tau_S$ and the capacitor C_P influences the higher corner frequency $\omega_{C2}=1/\tau_P$. Note that the equivalent resistance seen by C_S can be found by shorting V_i and neglecting C_P (at low frequencies). Similarly the equivalent resistance seen by C_P can be found by shorting V_i and C_S (at high frequencies). **Important:** in a transistor amplifier circuit, capacitor C_S or C_P, or both, are used at relevant interface locations, and R_S is affected by the output resistance of the previous amplifier stage, and R_P is affected by the input resistance of the next amplifier stage or the load resistor. You may want to read Chapter 7 in the textbook for more information.

In this project, we work with an emulated audio signal. Thus, the low-pass filter that removes the high-frequency RF carrier wave is not employed. You only need to ensure passage of audio signals in the range of 50 Hz to 20 kHz from input to the earphone, and yet isolation of DC biasing (remove DC) between different stages. Because the DC is very very low frequency, you should design this high pass filter to remove DC while preserve the audio frequency. Hence:

$$0< f_C<f_{audio}$$