Lab 5: Audio Power Amplifiers with Feedback Linearization

Introduction

The Power Amplifier (PA) is one of the most important circuits in modern electronics. Critical aspects of PA operation are its output power, efficiency and linearity. In audio systems in particular, the linearity of the PA must be very high because our ears are very sensitive to sound distortion.

Class A PAs are linear but have poor efficiency. In contrast, class B PAs can have very high efficiency but they operate under strong nonlinearities. The linearity of a class B PA can be significantly improved by employing a negative feedback around the power amplifier as shown in Figure 1. The opamp acts as an error amplifier which samples a fraction of the output voltage (V_o) and amplifies the difference between it and the input voltage (V_i).

In this lab, you will simulate and test the Audio Power Amplifier with feedback shown in Figure 1. This system consists of a differential pair, similar to the one in Lab 4, as well as a CMOS PA (also called "output stage"). You will build first a Class-A and then a Class-B output stage as shown in Figure 2. Then, you will build the differential pair, as shown in Figure 3. Finally, you will build the feedback loop around the differential pair and Class-B PA. For the differential pair, you will use transistors ALD1101 and ALD1102 as in Lab 4, while for the CMOS PA, you will use power transistors IRF510 and IRF9510. The power transistors have large $V_{breakdown}$ and are able to sustain large currents and voltages ($> 10A, <10$V) at their terminals. An 8-Ω speaker is connected to the output to convert voltage to sound.

Preparation

1. Run a 50-ms transient simulation for the Class-A output stage in Figure 2 (a) with 1-kHz 1-V_{pp} input. Show the input voltage and output voltage waveform. Set the maximum time step of the transient simulation to 1 μs. Plot the output spectrum using the FFT function of the simulator. Find the power consumption of the amplifier when the input signal amplitude is 10mVpp and when it is 1Vpp.

2. Repeat step 1 for the Class-B output stage in Figure 2 (b). Use the value for R_1, R_2, R_3, and R_4 determined in lab 3 such that both the p-MOSFET and the n-MOSFET are biased at threshold (little or no current flowing through them).

3. Determine the gain of the amplifier in Figure 1. What happens to the volume that the speaker would produce when the 1-kΩ feedback resistor value is varied?

4. The schematics in Figures 2 (a) and (b) use two supplies, 5V and -5V. This arrangement centers the output at 0V and allows us to DC couple the output stage directly to the speaker.

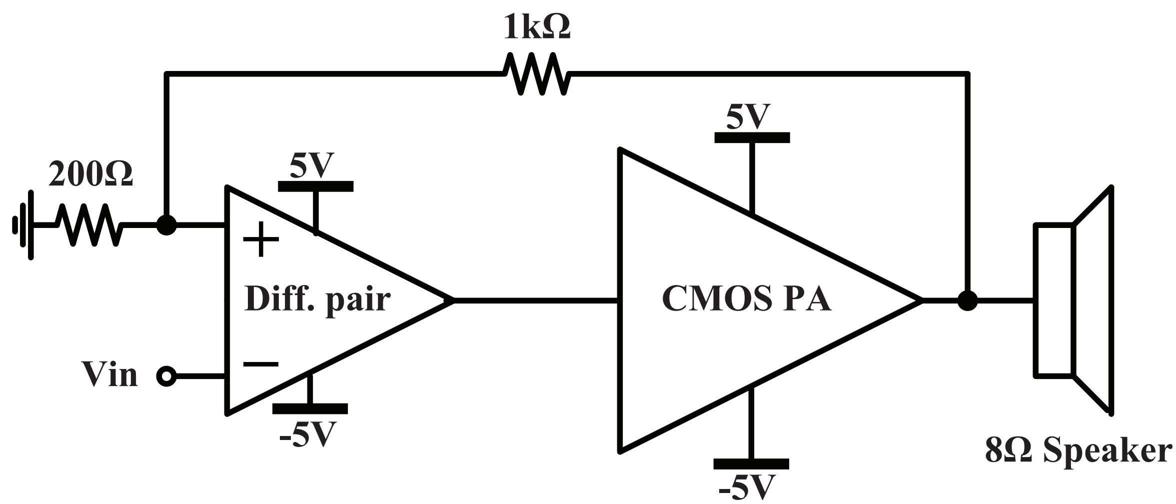

Figure 1: Audio power amplifier with feedback loop

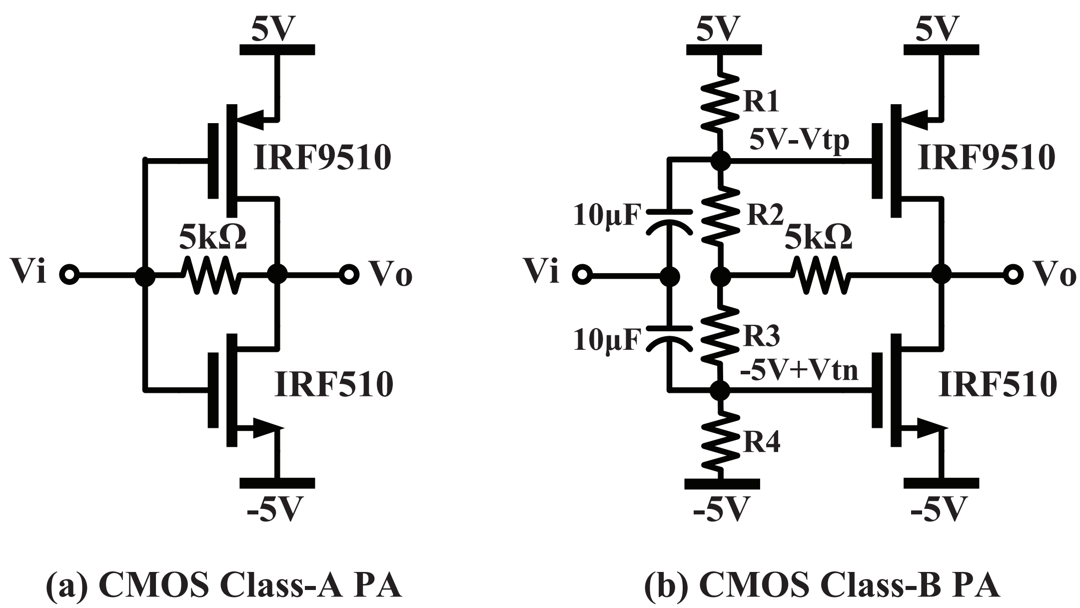

Figure 2: CMOS output stages: a) Class A, b) Class B

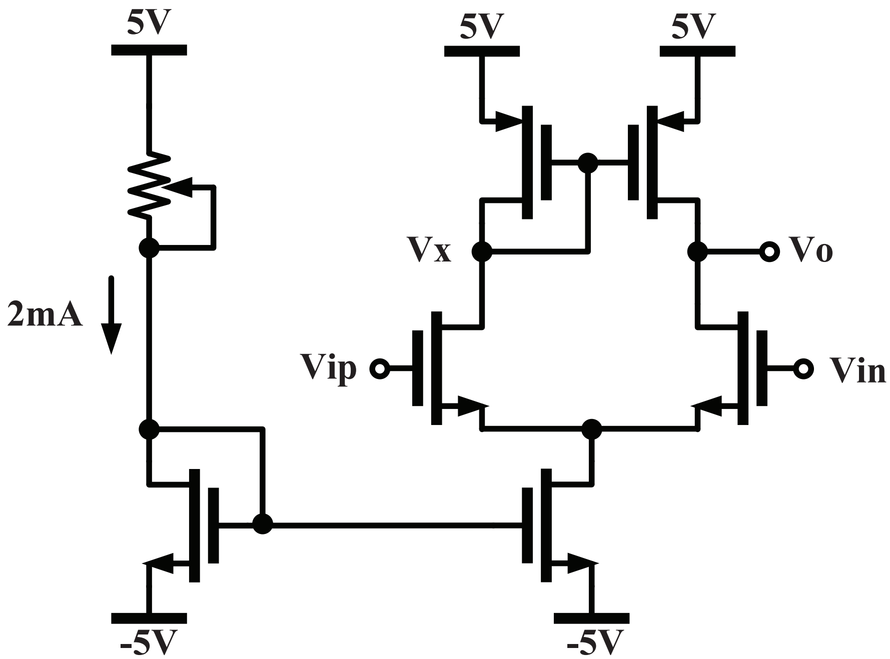

Figure 3: Differential Pair

There are cases where only a single supply is available and the speaker has to be AC coupled through a series capacitor (C_s) since the output is no longer at 0V. Determine the value for C_s for a cutoff frequency of 50 Hz or less (Hint: $f_{3dB} = 1/2\pi R_L C_s$ where R_L represents the load resistance).

Lab

The audio power amplifier simulated in the preparation is experimentally tested in lab. The minimum parts list for this lab is shown in Table 1.

The 8-Ω resistor will be used as a dummy load instead of the speaker to avoid unpleasant sound during circuit debugging.

1. Set up the power supply to limit the output current to 400mA. **This step is very important for your safety** because improper biasing of the power transistors (IRF510 and IRF9510) can cause them to sink amperes of current. In such a condition, **the power transistors get extremely hot and they may even burn and/or pop.** Set the maximum power supply current as follows:

   (a) Disconnect everything from the output port of the power supply except the connection between the '-' and GND terminals.

Table 1: Minimum parts list

Part	Description	Quantity
ALD1101	NMOS transistor pair	2
ALD1102	PMOS transistor pair	1
IRF510	NMOS power transistor	2
IRF9510	PMOS power transistor	2
-	8-Ω speaker	1
-	8-Ω resistor (1 W or more)	1
-	10-kΩ multi-turn potentiometer	1

(b) Turn the current limit to an arbitrary high value.

(c) Set the output voltage to 5 V.

(d) Turn the current limit to zero.

(e) Connect an 8-Ω resistor across the '+' and '-' terminals.

(f) Slowly crank up the current limit until the ammeter reading of the power supply reaches 400mA.

(g) Turn off the power supply and remove the short.

(h) Repeat (a)-(g) on the other output of the power supply but this time short the '+' and GND in (a).

(i) Turn on the power supply. Do not touch the current limit and Voltage knobs from this point onward.

If the current limiter trips during your experiment, do not crank up the current limit but fix your circuit. **If you are not sure about this step, ask your TA for assistance before turning on the power supply.**

2. Implement the Class-A output stage and an 8Ω load resistor. Do NOT connect the power supplies before your circuit has been fully assembled as a precaution to getting your hands burned from touching circuit components. Apply a 1kHz 1-V_{pp} sinusoid and observe the output. Determine the power consumption when the input voltage is 10mVpp and 1 Vpp. Keep the circuit as compact as possible to reduce parasitics. Show the measurements to your TA.

3. Replace the 8Ω load resistor with the speaker. Connect your Class A output stage and apply a sound waveform (from your cellphone or I-pod) at the input. Observe the sound quality.

4. Repeat step 2 and 3 with Class B PA.

5. Build the linearized power amplifier with feedback in Figure 1 with the class B output stage and set the voltage gain to 4 (by adjusting the 1-kΩ resistor). Replace the 8Ω load resistor with the speaker. Connect your Class A output stage and apply a sound waveform (from your cellphone or iPod) at the input. Observe the sound quality.