Lab 5: Audio Amplifier

GOAL

To implement a two-stage audio amplifier (BJT common emitter + BJT emitter follower).

OBJECTIVES

To build, test, simulate, and understand an emitter follower to drive an audio speaker.

Fig. 0: (Left) Small signal BJT (Center) Power BJT (Right) Audio speaker.

GENERAL GUIDELINES

1) Each student must build, test, and demo all circuits.
2) During the lab session, students may need to share test stations.
3) Students are allowed (even encouraged) to help each other. Hedrick and/or the lab teaching assistant will be around to help as well.
4) Ask questions! The more questions you ask, the more you learn (assuming Hedrick can provide adequate answers ☺).
5) Build your circuits with neat wiring and the correct wire colors.
6) Please keep your lab kit and work area organized.

PARTS AND MATERIALS

- Lab kit (breadboard, wire stripper, wire)
- Circuit from Lab 3 (if you need to re-build, that's fine).
- Scope, scope probes, multimeter, function generator, coaxial cable (with alligator clips), benchtop power supply
- Transistors: 2N3904 (1)
  TIP 31 (1)
- Resistors:

16 ohm	(brown/blue/black)	(1)
68 ohm	(blue/gray/black)	(1)
12 kohm	(brown/red/orange)	(1)
33 kohm	(orange/orange/orange)	(1)
100 kohm	(brown/black/yellow)	(1)

- Capacitors: 10 uF (1), 470 uF (1)
- Audio speaker + cable

PART 1: COMMON EMITTER (STAGE 1 OF AUDIO AMPLIFIER)

- **Step 1a**: Rebuild the lab 4 circuit and ensure that it still works correctly,
  - **Do NOT cram your circuit into a tiny area!**
  - Use neat and color-coded wiring!
    - RED wire = +9V
    - BLACK wire = ground
    - YELLOW wire = everything else
  - The 2N3904 pin diagram is on the course website.
  - Careful with the orientation of Cin and Cout!
  - The input comes from the function generator (NOT the microphone).
    - V_S is a sine wave (20 mV_{PP}, 1 kHz).
    - Set the function generator to "High Z" (see Lab3 pdf, if necessary).
    - Use a coaxial cable to connect the "SYNC" output to the scope's "EXT TRIG" port.
  - Configure the scope to measure V_OUT:
    - CH1 (measure V_OUT): Probe = 1X, BW Limit = ON
    - Trigger: Source = EXT, Level = 1V
    - Adjust the horizontal and vertical scales to see about two cycles of V_OUT.
    - V_{OUT} should be roughly 1.9 V_{PP} (can be higher or lower by 0.1V).

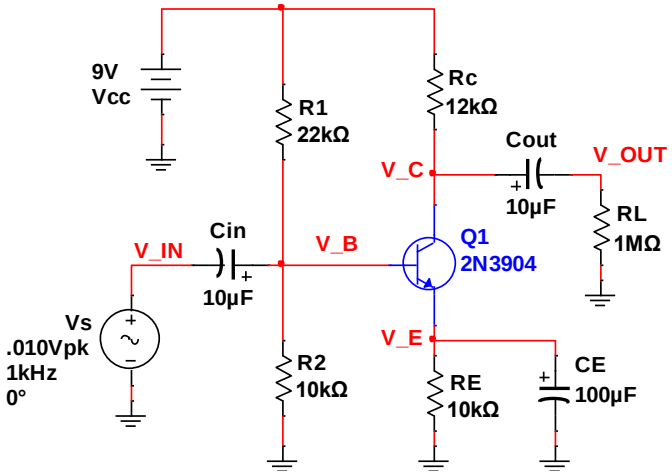

Fig. 1: Common emitter circuit from Lab 3. The input comes from the function generator (NOT the microphone).

DO NOT DISASSEMBLE THIS CIRCUIT!

(End of Part 1)

PART 2: DARLINGTON FOLLOWER (STAGE 2 OF AUDIO AMPLIFIER)

The extra high β of a Darlington pair means the low speaker impedance (16 ohm) looks like a much larger impedance to the source (over 10 kohm!).

For this lab, we are using a "firm" divider, rather than a "stiff" divider, to bias the Darlington follower. A firm divider is defined by $R1//R2 < 0.1\ (\beta+1)R_E$. A firm divider is nice because it raises the input impedance Z_{IN} by a factor of 10. This is highly useful for a variety of applications.

- **Step 2a**: On a different part of your breadboard, build the circuit (emitter follower) shown in Fig. 2.

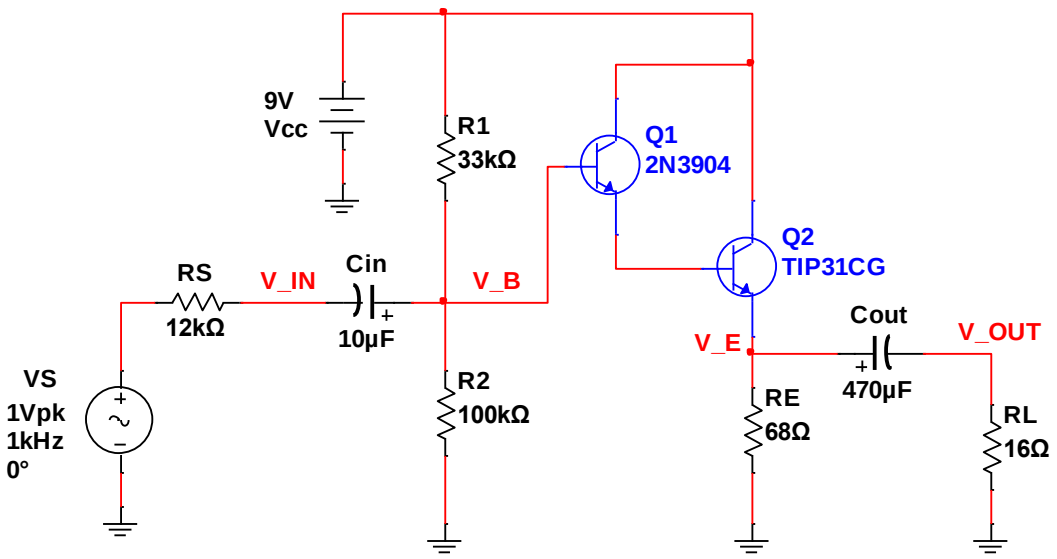

Fig. 2: Darlington follower using a 2N3904 with a TIP31 transistor. The input comes from the function generator ($2V_{PP}$ sine wave), while the load is a 16 ohm resistor. Do NOT use the speaker as the load (not yet).

  - Do NOT cram your circuit into a tiny area! Consult Hedrick's breadboard, if necessary.
  - V_S is a $2V_{PP}$ sine wave at 1 kHz.
  - The R_S = 12 kohm resistor mimics the output impedance of the Lab3 common emitter circuit.
  - Pay attention to the orientation of the electrolytic capacitors.
  - The pin diagram for the 2N3904 and TIP31 transistors are on the course website.
  - The load is a 16 ohm resistor (NOT the speaker – at least for now).

- **Step 2b**: Make some DC voltage measurements.
  - Use the multimeter to measure the DC values of V_B and V_E. Enter these values into Table 1. They should be similar to your PreLab results!

Table I: DC operating point

V_{BB}	V_{EQ}

- **Step 2c**: Measure the voltage gain.
  - Next, use the scope to measure the peak-to-peak values of V_{IN} and V_{OUT}. Enter these values into Table 2.
  - Compute the voltage gain. It should be similar to your PreLab "Transient analysis" results!
  - **Save scope traces of both V_{IN} and V_{OUT} and combine them into a single MATLAB plot for your report**.

Table II: Voltage Gain with RL = 16 ohm

$V_{IN,PP}$	$V_{OUT,PP}$	Gain

- **Step 2d**: Measure the input impedance Z_{IN} of your emitter follower.
  - The key concepts are the following:
    - We know Z_S and Z_{IN} form a voltage divider where:

      $$\mathbf{V_{IN} = V_S \times Z_{IN} / (Z_{IN} + Z_S)} \quad \textbf{(Eqn. 1)}$$

    - If we know the values for V_S, V_{IN}, and Z_S, then we can solve Eqn. 1 for Z_{IN}.
  - So how do we determine the values for V_{IN}, V_S, and Z_S?
    - You already have all the data you need!
    - From Fig. 2, we know $V_S = 2V_{PP}$ (function generator output) and $Z_S = 12$ kohm.
    - We know V_IN (see your Table 2).
    - Using your known values for V_S, Z_S and V_{IN}, use Eqn. 1 and some algebra to calculate Z_{IN}. Your Z_{IN} should be roughly 25 kohm (may be 5 kohm higher or lower).
    - **Record your Z_{IN} for your lab demo and report**.

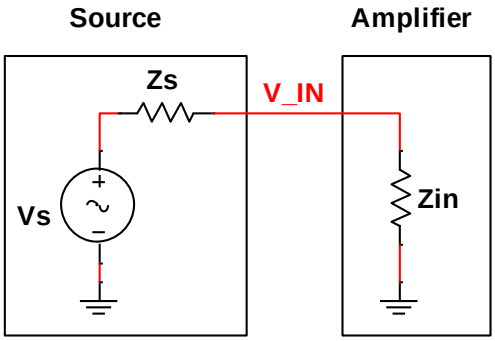

Fig. 3: General description of input impedance Zin.

- **Step 2e**: Measure the output impedance Z_{OUT} of your emitter follower.
  - The key concepts are the following:
    - We know Z_{OUT} and R_L form a voltage divider where:

      $$\mathbf{V_{OUT} = V_O \times R_L / (Z_{OUT} + R_L)} \quad \textbf{(Eqn. 2)}$$

    - If we know the values for V_O, V_{OUT}, and R_L, then we can solve Eqn. 2 for Z_{OUT}.
  - So how do we determine the values for V_O, V_{OUT}, and R_L?
    - You already have V_{OUT} and R_L (from Table 2).
    - V_O is the open circuit output voltage of the amplifier.
      - Looking at Fig. 4, $R_L = \infty$ means $V_{OUT} = V_O$.
      - How to make $R_L = \infty$? Just remove the 16 ohm load resistor from the breadboard.
      - Use the **scope** to measure the peak-to-peak value of V_{OUT}. Your measurement is therefore V_O!
    - Using your known values for V_O, V_{OUT}, and R_L, solve Eqn. 2 for Z_{OUT}. Your Z_{OUT} should be roughly 1.5 ohm (may be 0.5 ohm higher or lower).
    - **Record your Z_{OUT} for your lab demo and report**.

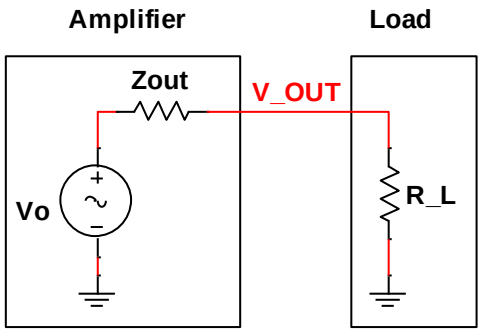

Fig. 4: General description of output impedance Zout.

(End of Part 2)

PART 3: MULTISTAGE AMPLIFIER

OK, now we need to connect your two stages (common emitter and emitter follower) together to make an audio amplifier!

- **Step 3a**: Assemble the multistage amplifier following the steps below (see Fig. 5):
  - Emitter follower:
    - Move the function generator V_S to the common emitter input and set the amplitude to 20 mV_{PP}.
    - Remove the R_S = 12 kohm resistor from the input.
  - Common emitter:
    - Remove the 1 Mohm load and 10 uF output coupling capacitor
    - Use a sort-of-long yellow wire to connect V_C to the emitter follower's input.
  - Your final two-stage amplifier should look like Fig. 5

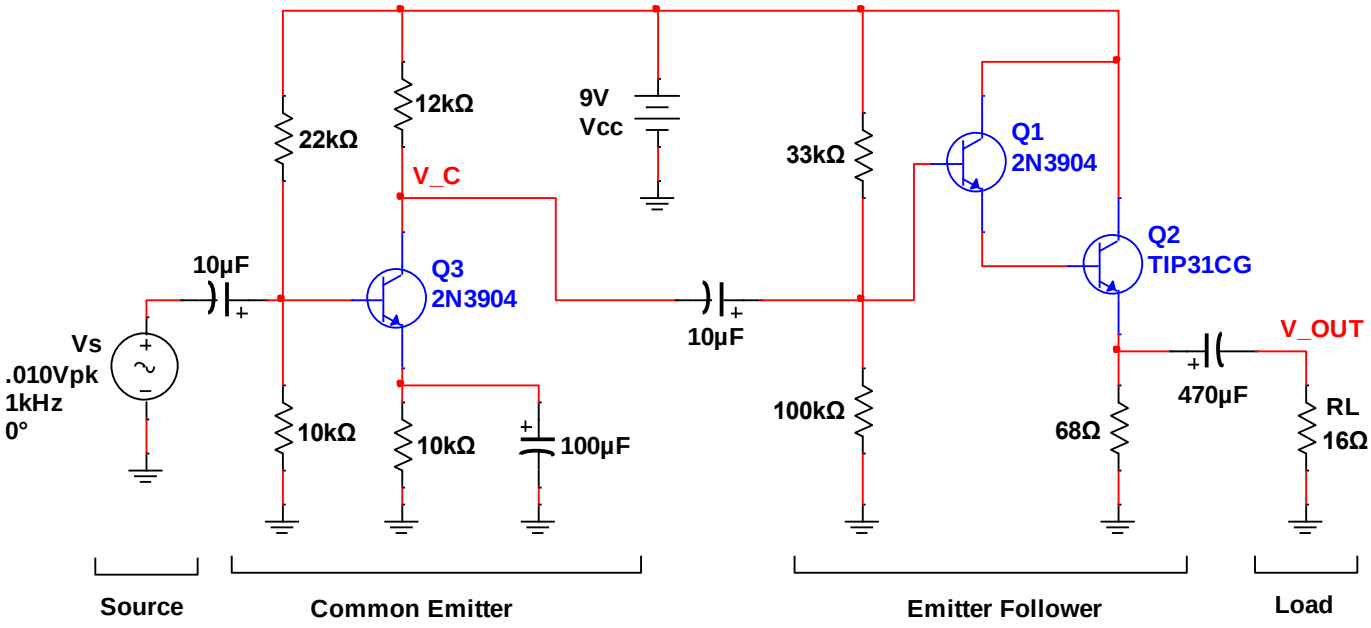

Fig. 5: Schematic of the multistage amplifier. The source Vs is the function generator while the load RL is a 16 ohm resistor.

- **Step 3b**: Measure the overall gain of your circuit:
  - Measure the peak-to-peak value of V_OUT and complete Table 3.
    - You know V_S = 20 mV_{PP}, so compute the overall gain. It should be around -55 (may vary from -50 to -60).
  - Based on your overall gain (Table 3) and follower gain (Table 2), compute your common emitter gain. It should be roughly -60.
  - Answer the following question: The common emitter gain is around -90 when its load is 1 Mohm. Why is the common emitter gain only -60 (roughly) in the multistage amplifier?

Table III: Overall voltage gain

$V_{OUT,PP}$	V_{OUT}/V_S

(End of Part 3)

PART 4: AUDIO AMPLIFIER

OK, now we can finally listen to some sounds!

- Step 4a: Make the following modifications to your breadboard:
    - Amplifier input:
        - Remove the function generator from the amplifier input.
        - Connect the audio cable to your breadboard.
            - The "red" wire goes to your amplifier input.
            - The "copper" wire goes to GND.
        - Insert the audio cable jack into your phone, or laptop, or the desktop computer.
        - Choose your music, or podcast, or whatever.
        - Set the volume VERY LOW.
    - Amplifier output:
        - Remove the 16 ohm load resistor.
        - Connect the audio speaker.
            - You will need two wires to connect the speaker's two-pin socket to the breadboard.
        - If all goes well, you should hear stuff coming out of the speaker! ☺

(End of Lab 5)