

Lab 4 – Microphone Preamplifier

GOAL

The overall goal of this lab is to demonstrate a microphone preamplifier based on a BJT common emitter.

OBJECTIVES

To build, test, and understand the following circuits:

- 1) Biased common emitter
- 2) Electret microphone



Fig. 1: (Left) Electret microphone (Right) Bipolar junction transistor.

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. Buma and/or the lab teaching assistant will be around to help as well. Use neat wiring for your circuits! A messy circuit will cost you 10 pts from your lab demo grade.
- 4) Ask questions! The more questions you ask, the more you learn (assuming Buma can provide adequate answers ☺).
- 5) Build your circuits with neat wiring! Messy circuits will result in a 10 pt deduction from your lab demo grade.
- 6) Please keep your lab kit and work area organized.

PARTS AND MATERIALS

- Lab kit (breadboard, wire stripper, wire)
- Function generator, multimeter, oscilloscope, benchtop power supply
- BJT transistor: 2N3904 (1)
- Resistors: 4.7 kohm (yellow/purple/red) (1)
- 10 kohm (brown/black/orange) (3)
- 12 kohm (brown/red/orange) (1)
- 22 kohm (red/red/orange) (1)
- 1 Mohm (brown/black/green) (1)
- Capacitors: 10 uF (2)
- 100 uF (1)
- Electret microphone (1)

PART 1: BASIC COMMON EMITTER

- **Step 1a:** Build the common emitter amplifier in Fig. 2.
 - Use neat and color-coded wiring!
 - RED wire = (+) voltage supply (9V)
 - BLACK wire = ground
 - YELLOW wire = everything else
 - +9V and GND come from the benchtop supply.
 - The pin diagram for the 2N3904 transistor is on the course website.
 - Be careful with the orientation of C_{in} and C_{out} !
 - The sine wave comes from the Agilent function generator.

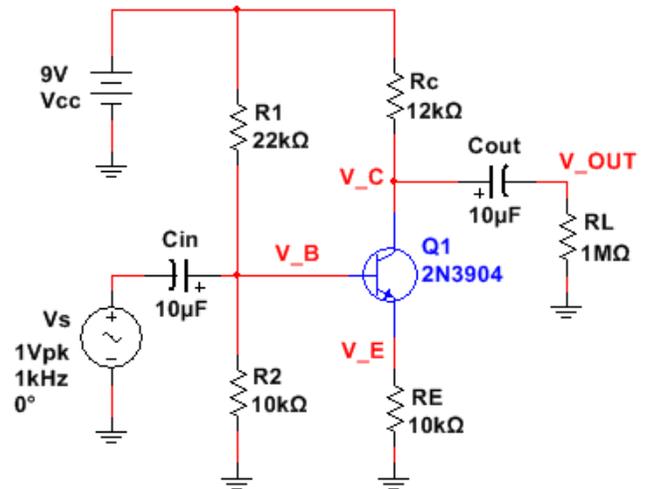


Fig. 2: Common emitter amplifier.

- **Step 1b:** Check the transistor bias by measuring the DC operating point.
 - **Make the necessary multimeter measurements to fill in Table 1 below.**
 - ❖ Hopefully your V_B , V_E , and V_C are in reasonable agreement with your prelab!
 - ❖ V_{BE} is the difference between V_B and V_E . Is your measured value close to 0.7V?
 - ❖ Likewise, V_{CE} is the difference between V_C and V_E . Is your transistor in active mode?

Table I: DC Operating Point Analysis

V_B	V_E	V_C

- **Step 1c:** To measure gain, we need to input a test sine wave and use the scope to make measurements.
 - Input a test sine wave ($2 V_{PP}$, 1 kHz) to the circuit using the function generator.
 - Set the Agilent waveform generator to “High Z” output.
 - Press “Utility”, then press “Output”, then press “High Z”, and finally press “Done”.
 - Set the amplitude to $2 V_{PP}$ and frequency to 1 kHz.
 - Connect the output of waveform generator to the circuit input using the coaxial cable with alligator clips.
 - Press the “Output” button on the waveform generator to turn on the output.
 - NOTE: “High Z” means the load is expected to be high impedance (as opposed to 50 ohm, which is pretty low). Otherwise, the generator will output TWICE the voltage that you want (very annoying for this course).

- Configure the scope.
 - Attach TWO scope probes to the transistor (CH1 = base, CH2 = collector).
 - Make sure each probe is set to 1X.
 - Press the “Default” button on the scope and press “Force Trigger” if necessary.
 - To properly capture the voltage waveforms, we need to configure the scope trigger:
 - Change the scope’s “Trigger Source” to be “EXT” instead of “CH 1”.
 - Use a coaxial cable to connect the function generator’s SYNC output to the “EXT” input of the scope.
 - Adjust the trigger level to be +1V.
 - Why do this?
 - ❖ In this lab, some of your scope signals will be very weak.
 - ❖ It is a bad idea to trigger the scope with a weak signal, because the lack of a reliable rising edge will cause the scope trace to be very unstable. ☹
 - ❖ Fortunately, the function generator produces a SYNC output (a TTL signal) with the same frequency as the output sine wave.
 - ❖ This SYNC output provides a nice rising edge to trigger the scope in a reliable fashion.
 - **Adjust the vertical and horizontal settings of the scope to produce waveforms that resemble your PreLab 3 (Task 3) results. Use the default DC coupling for both channels!**
 - ❖ You should notice that the V_B and V_C waveforms have opposite polarity.
- **Make the necessary voltage measurements to complete Table 2 below.**
 - You should get a voltage gain of roughly $A = -1.15$ (may vary from -1.05 to -1.25).

Table II: Scope measurements for common emitter amplifier

V_B (peak-to-peak)	V_C (peak-to-peak)	Gain

❖ Record scope snapshots of both waveforms (e.g. using MATLAB) for your lab report.

You will need to capture each trace separately. Below is sample Matlab code you may use.

```
[ch1,time]=swave(1);
[ch2, time] = swave(2);
subplot(2,1,1)
plot(time , ch1)
grid
title('Common Emitter Amplifier with no emitter bypass capacitor vb');
ylabel('Amplitude (V)')
xlabel('Time (ms)')
subplot(2,1,2);
plot(time, ch2)
grid
title('Common Emitter Amplifier with no emitter bypass capacitor vc')
ylabel('Amplitude (V)')
xlabel('Time (ms)')
(End of Part 1)
```

PART 2: EFFECTS ON VOLTAGE GAIN

We can crank up the amplifier gain by using a neat trick involving a bypass capacitor! This capacitor shorts out R_E for AC signals, leading to a much higher gain.

- Step 2a: Add a 100 uF capacitor in parallel with the $R_E = 10$ kohm resistor (see Fig. 3).

- Be careful with capacitor orientation!
- **Reduce the function generator sine wave amplitude to 20 mV_{PP}.**
 - NOTE: The input signal must now be tiny to avoid an excessively large output due to the large voltage gain!

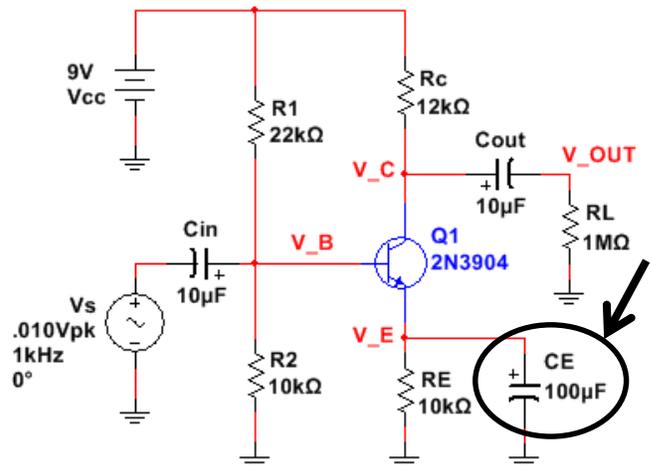


Fig. 3: voltage gain can be significantly increased by adding a 100 uF emitter bypass capacitor.

- Step 2b: Measure the voltage gain.

- Use the scope to measure V_B and V_C .
 - Use **AC coupling** for CH1 and CH2. This makes it easier to see both waveforms.
 - Remember to adjust the vertical scale for each channel to see two beautiful sine waves of opposite polarity!
 - Remember that the sine wave for V_C is nearly 100 times bigger than V_B !
- Make the necessary scope measurements to fill in Table 3 below.
 - You should get a voltage gain of roughly $A = -90$ (may vary from -85 up to -100).

Table III: Scope measurements with emitter bypass capacitor

V_B (peak-to-peak)	V_C (peak-to-peak)	Gain

• Step 2c: Measure the input impedance Z_{IN} of your amplifier.

- The key concepts are the following:

- We know Z_S and Z_{IN} form a voltage divider where:

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

- 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 ?

- We know $V_S = 20 \text{ mV}_{PP}$ (function generator output).
- We'll intentionally make $Z_S = 4.7 \text{ kohm}$ by inserting a 4.7 kohm test resistor between the function generator and the amplifier's input coupling capacitor C_{IN} .
 - Why use $Z_S = 4.7 \text{ kohm}$? From the prelab, we expect Z_{IN} to be near 5 kohm . The accuracy of our experimental procedure is better if Z_S is similar in value to Z_{IN} .
- Use the **scope** to measure V_{IN} . NOTE: This is simply the peak-to-peak value of V_{IN} .
 - **The waveform will be pretty noisy, so use the "BW limit" to show a cleaner trace.**
 - **Since the waveform has some noise, use the CURSORS to manually measure V_{IN} !**
- Using your known values for V_S and Z_S and your measured V_{IN} , use Eqn. 1 and some algebra to calculate Z_{IN} . Your Z_{IN} should be roughly 4.5 kohm (may be 1 kohm higher or lower).
- **Record your Z_{IN} for your lab demo and report.**
- **Remove the 4.7 kohm test resistor from the amplifier input.**

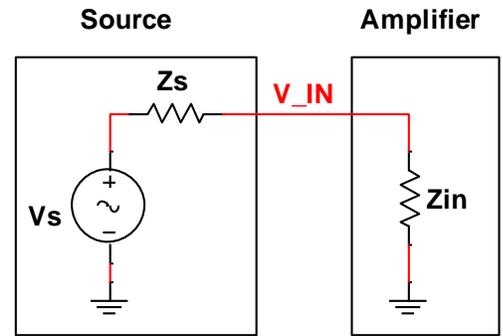


Fig. 4: General description of input impedance Z_{in} .

• Step 2d: Measure the output impedance Z_{OUT} of your amplifier.

- The key concepts are the following:

- We know Z_{OUT} and R_L form a voltage divider where:

$$V_L = V_O \times R_L / (Z_{OUT} + R_L) \quad (\text{Eqn. 2})$$

- If we know the values for V_O , V_L , and R_L , then we can solve Eqn. 2 for Z_{OUT} .

- So how do we determine the values for V_O , V_L , and R_L ?

- V_O is the open circuit output voltage of the amplifier.
 - Looking at Fig. 5, $R_L = \infty$ means $V_L = V_O$.
 - How to make $R_L = \infty$? Just remove the 1 Mohm load resistor from the breadboard. This creates an open circuit. Use the **scope** to measure V_L . Your measured value is therefore V_O . NOTE: V_L is just the peak-to-peak value of V_C .
- Now that we have determined V_O , we deliberately make $R_L = 10 \text{ kohm}$ by inserting a 10 kohm test resistor for R_L .

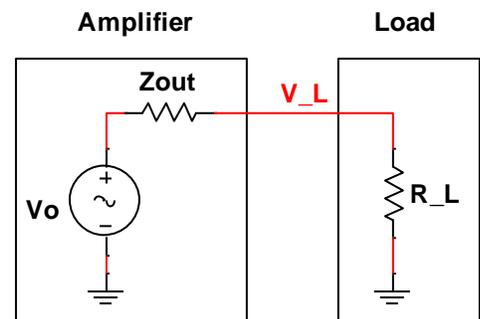


Fig. 5: General description of output impedance Z_{out} .

- Use the **scope** to measure V_L . It should be roughly 50% smaller than your previous measurement.
- Using your known values for V_O , $R_L = 10\text{ kohm}$, and measured value of V_L , you can solve Eqn. 2 for Z_{OUT} . You should get Z_{OUT} near 12 kohm .
- **Record your Z_{OUT} for your lab demo and report.**
- **Replace the $R_L = 10\text{ kohm}$ test resistor with the original $R_L = 1\text{ Mohm}$ resistor.**

PART 3: MICROPHONE PREAMPLIFIER

OK, now we can do some really fun stuff! Our signal source will be an electret microphone, as shown in Fig. 6.

- The small capsule contains a thin electret foil that acts like a permanently charged capacitor.
- Sound waves compress and expand this foil, producing a teeny tiny AC voltage.
- The capsule also contains a JFET (junction field effect transistor) that amplifies the teeny tiny electret signal.
- The capsule needs a 10 kohm resistor and a $+9\text{V}$ power supply to power the internal JFET amplifier.

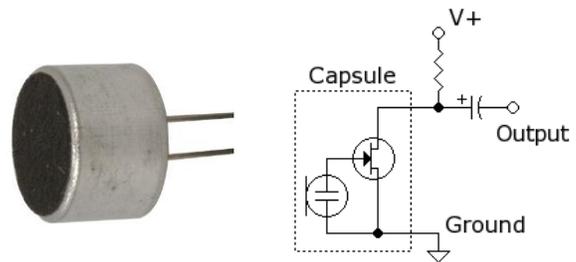


Fig. 6: (Left) Electret microphone capsule. (Right) Circuit schematic showing typical installation.

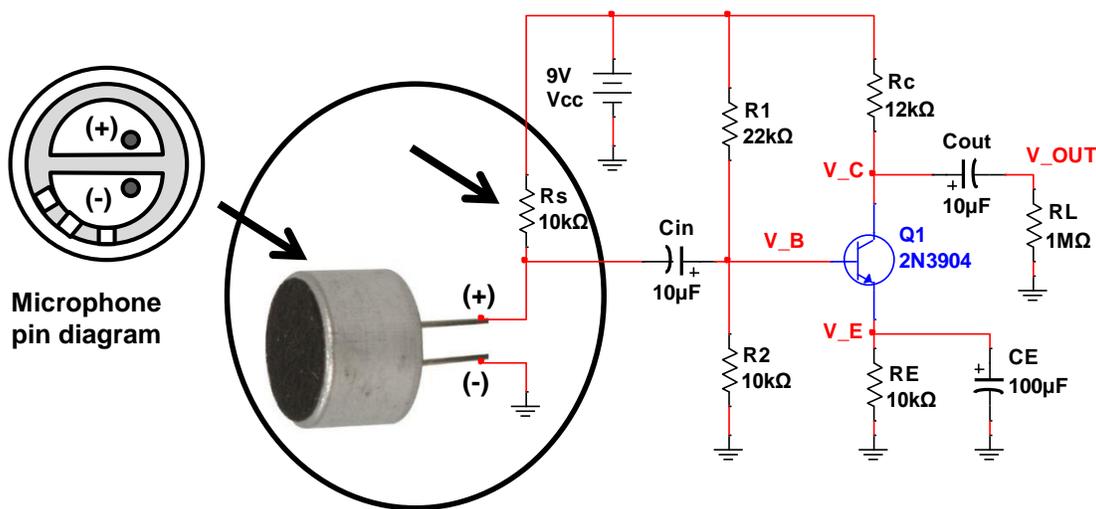


Fig. 7: Add the microphone to your AWESOME common emitter amplifier.

- **Step 3a: Add the electret microphone to your common emitter amplifier, as shown in Fig. 7.**
 - Disconnect the function generator from your circuit (remove the alligator clips as well).
 - The microphone needs a $+9\text{V}$ supply and a 10 kohm resistor, as shown in Fig. 7.
 - The (-) pin of the microphone has the “three-spoke” pattern on the back of the capsule (see left side of Fig. 7).
- **Step 3b: Test your microphone preamplifier.**
 - Attach the CH1 scope probe to the base and the CH2 scope probe to the collector of the transistor.

- You will need to adjust the scope settings:
 - Set the horizontal scale to 2 ms/div.
 - Make sure both CH1 and CH2 are set to “AC coupling”.
 - For CH1, initially use something like Scale = 50 mV/div and Offset = -50 mV.
 - For CH2, initially use Scale = 2V/div and Offset = +2V.
 - Change the trigger settings to:
 - Source = CH2 (instead of EXT), Sweep = Normal, Trig level = 1V
- Clap your hands above the microphone.
 - You should see two waveforms appear on the scope. An example is shown in Fig. 8.
 - You should notice that the collector waveform is much larger AND inverted with respect to the base waveform.
 - If you prefer, you can repeat the experiment by saying something (e.g. “two”), whistling, or snapping your fingers – you may need to adjust the horizontal scale and try a few times to get a nice waveform.
 - **Save both waveforms for your lab report.**

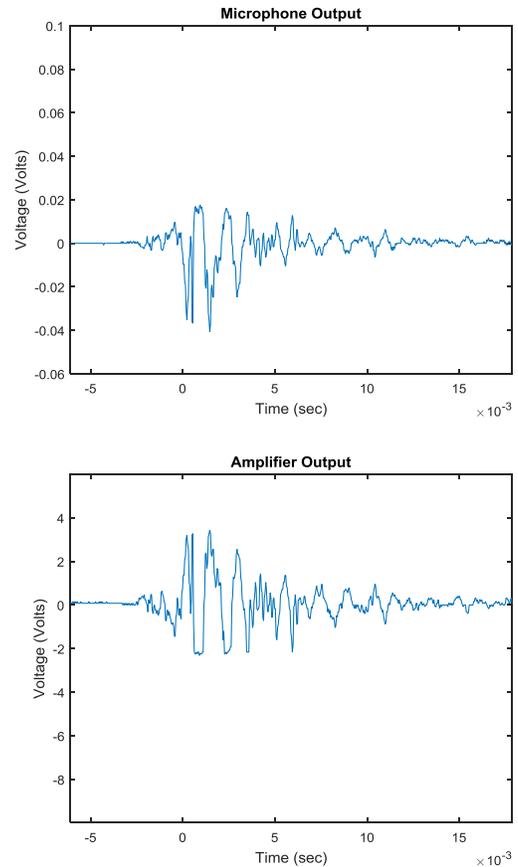


Fig. 8: Scope waveforms from the transistor base (top) and collector (bottom) due to Buma's clapping. In addition to the amplitude difference, notice that the two waveforms have opposite polarity!

(End of Lab 4)