LAB 6.5

NPN Common-Emitter Amplifier

(See Section 6.8.2, p. 455 of Sedra/Smith)

OBJECTIVES:

To study an NPN-based common-emitter (CE) amplifier by:

- Completing the DC and small-signal analysis based on its theoretical behavior.
- Simulating it to compare the results with the paper analysis.
- Implementing it in an experimental setting, taking measurements, and comparing its performance with theoretical and simulated results.
- Measuring its output resistance.
- Qualitatively seeing the impact of transistor-to-transistor variations.

MATERIALS:

- Laboratory setup, including breadboard
- 1 NPN-type bipolar transistor (e.g., NTE2321)
- 3 "large" (e.g., 47-μF) capacitors
- Several resistors of varying sizes
- Wires

PART 1: DESIGN AND SIMULATION

Consider the circuit shown in Figure L6.5:

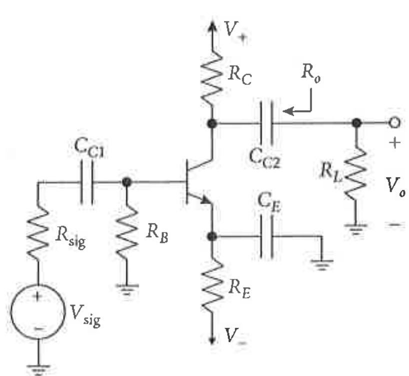

FIGURE L6.5: Common-emitter amplifier circuit, with coupling capacitors, and resistor R_B for DC-biasing purposes. Based on Fig. 6.65 p. 455 S&S.

Design the amplifier to achieve a small-signal gain of at least $A_v = -200$ V/V. Use supplies of $V_+ = -V_- = 15$ V, $R_{sig} = 50\ \Omega$, $R_L = 10\ k\Omega$, and $R_B = 10\ k\Omega$, and design the circuit to have $I_C = 1$ mA. Although there will be variations from transistor to transistor, you may assume a value of β of 100 in your calculations. Obtain the datasheet for the NPN transistor that will be used. In your lab book, perform the following:

DC Operating Point Analysis

- Sketch a DC model of the circuit in your lab book, replacing the three "large-valued" coupling capacitors C_{C1}, C_{C2}, and C_E, by open circuits (for simplicity you may also omit v_{sig}, R_{sig}, and R_L).
- What are the values of I_B and I_E? What is the value of V_B?
- Determine a value of R_E that produces a base-emitter voltage drop of 0.7 V. What is V_E?
- Is the value of R_E available in your kit? Can you achieve this value by combining several resistors? Comment.
- *Note*: At this stage we know neither V_{CE} nor R_C.

AC Analysis

- Sketch a small-signal model of the circuit in your lab book, replacing the transistor with its small-signal model (V_A is large, so you may ignore r_o), replacing the capacitors with short circuits (what happens to R_E?), and replacing V_+ with an AC ground. What happens to V_-? Label the base of the transistor as v_i, i.e., the small-signal voltage at the input. What are the values of g_m and r_π?
- What is the ratio of v_i/v_{sig}? Can you approximate it?
- Derive an expression for $A_v = v_o/v_i$. What is the value of R_C that produces a small-signal voltage gain of *at least* $A_v = -200$ V/V? Is the value you calculate for R_C available in your kit? Can you achieve this value by combining several resistors? Comment.
- What is the DC voltage at the collector? Does this satisfy the assumption that the transistor should be operating in the active region? Explain.
- What is the output resistance, R_o?

Simulation

- Simulate the performance of your circuit. Use capacitor values $C_{C1} = C_{C2} = C_E = 47\ \mu$F and the values of R_E and R_C based on your preceding calculations. Use a 10-mV$_{pk-pk}$, 1-kHz sinusoid with no DC component applied at v_{sig}.
- From your simulation, report the DC values of V_{BE}, V_{CE}, I_B, I_C, and I_E. How closely do they match your calculations?
- From your simulation, report A_v. How closely does it match your calculations?

PART 2: PROTOTYPING

- Assemble the circuit onto your breadboard using the specified component values and those just calculated. Note that R_{sig} represents the output resistance of the function generator, and therefore you should *not* include it in your circuit.

PART 3: MEASUREMENTS

- *DC bias point measurement*: Using a digital multimeter, measure the DC voltages of your circuit at the base (V_B), emitter (V_E), and collector (V_C) of your transistor.
- *AC measurement*: Using a function generator, apply a 10-mV$_{pk-pk}$, 1-kHz sinusoid with no DC component to your circuit. (*Note*: Some function generators only allow inputs as small as 50 mV$_{pk-pk}$. If this is the case, use that value instead, but you may expect some distortion in the output waveform.)
- Using an oscilloscope, generate plots of v_o and v_i vs. t.
- *Output resistance* R_o: Replace R_L with a 1-MΩ resistor and repeat the AC measurement. What is the amplitude of the output waveform? Adjust R_L until you find a value such that the amplitude of the output waveform is approximately 50% of what it was for the 1-MΩ resistor. This new value of R_L is the output resistance R_o. How does it compare to the value you calculated earlier in Step 2? *Hint*: It cannot be greater than the value of R_C.
- *Further exploration*: What happens to the shape of the output signal as you increase the amplitude of the input signal, e.g., to 1 V$_{pk-pk}$? At what input amplitude do you begin to see significant distortion?
- Using a digital multimeter, measure all resistors to three significant digits.

PART 4: POST-MEASUREMENT EXERCISE

- Calculate the values of V_{BE} and V_{CE} that you obtained in the lab. How do they compare to your pre-lab calculations? Explain any discrepancies.
- Based on the measured values of V_B, V_C, and V_E and your measured resistor values, what are the real values of all currents based on your lab measurements? How do they compare to your pre-lab calculations? Based on the measured values of currents, what is the actual value of β for your transistor?
- What is the measured value of A_v? How does it compare to your pre-lab calculations? Explain any discrepancies.
- *Hint*: The single biggest source of variations from your pre-lab simulation results will be due to variations in β.

PART 5 [OPTIONAL]: EXTRA EXPLORATION

- Instead of tying R_B to ground, try tying it to the collector terminal of the transistor. Repeat the DC bias point measurement and the small-signal gain measurement. What has changed? Do R_C and R_E need to be altered to meet design specifications?